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Complex Realities, Simple Beauties: Interactions between the Development of Physics Ideas and Western Civilization, from Ancient Times to the Late Nineteenth Century

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COMPLEX REALITIES, SIMPLE BEAUTIES

Interactions between the Development of Physics Ideas and Western Civilization, from Ancient Times to the Late Nineteenth Century

"Of all the hatreds, none is greater than that of ignorance against knowledge."

Galileo Galilei

by Neil Chodorow
[redacted]
(ed. Spring 2000)

THESIS APPROVAL SHEET

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Masters Thesis Appendix: Exerpts from Physics in History text, 2000 version, to be used for revised student (text?) version.

Submitted by Neil Chodorow to Dr. Morris Beers
April 29, 2000

The enclosed list includes all topics covered in the current text, as presently edited for student use. This editing was the result of two concerns: 1) the appropriateness of some language and subjects for students, especially re. religious issues in Western history, and 2) the excessive length of text as it existed for adults (the trade version). Editing was difficult because I see the text as a tapestry in which all details and interconnections create a whole greater than the text's parts.

Nevertheless, I recognize the need for this editing, especially in relation to the potential need to add illustrations for a student version if it were published. As such, I have already cut out certain potentially objectionable material (e.g. comments about the Vatican's belated apology in "the Galileo Affair") and removed some material that seemed only distantly connected to the main story. What is left, as presented in this list, still represents 187 pages of text. Consequently, I have put question marks (??) after any item that might still be excised.

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Chapter 4 (pp 38-58): Greek science
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-Samarkand re Ulugh Beg and astronomy
*Destruction of Samarkand (??)
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  - *Papal succession and synods
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  - *monks, monasteries and Orders

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- -monastary schools: limited curricula, train new monks
- -cathedral schools re increased openness to outside ideas

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- -crowning of Charlemagne, Feudalism, role in Church
- -Otto I and HRE, decline of arts, knowledge, economy
- -emerging political units within empire
  - *region-by-region survey of Italy, Iberia, France, Normandy, England, Germany

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- -England re Magna Carta and Parliament, sharing of power
- -Italy re city states and sub-regions
- -Germany re principalities and Hanseatic League
- -Iberia re re-conquest, independent Portugal, and rise of Castillians
- -Holland and its cities

Changes in Church and education

- -street schools then universities re nonChristian ideas

Economy re feudal control and rise of merchant class, Mercantilism, and guilds

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- -cause and accelerator of above changes

New European awareness

- -T-O maps and Moslem geography knowledge
- -rediscovery of Ptolemy, Medici-led meeting in Florence
- -birth of Renaissance: impact re vernaculars, etc.
- -Age of Exploration: Portugese, Columbus, birth of empire

Rise of England re Spanish Armada

Comparison of Europe to Arabs, India, and China

- -Why Europe was home of modern science: isolation, economic need, aggression
- -voyages of Zheng He and their cessation, a lesson in cultural choice re use of technologies

New Knowledge in Europe

- -paper and printing, Gutenberg, movable type, vernaculars and dissemination of new ideas

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- -M Luther and the birth of Protestantism

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-Scotus, Bradwardine
-Oresme, re. geometry models of motion and caution asserting his ideas
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-Copernicus re sun-centered Universe
*banning by Luther and Calvin (??), Vatican silence, and limits on new theory set by Copernicus
-Bruno re science and religion in conflict (??).
-Stevin and Brahe lay the foundations for revolution
-Kepler re elliptical orbits and mystical justification
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-change in Aristotilean mechanics
-use of telescope re rejection of Ptolemaic astronomy
-conflict with Church re court cases, banning of his work (??) and punishment (??)
-redefinition of scientific method
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-abstract thought (math) in science, deductive logic, and subjectivity or observation
-Cartesian coordinates, eddies
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-freed next generation of scientists from religious beliefs, even their own
-Galileo and Descarte the "fathers" of future science

Chapter 9 (pp 127-146): European history, 1642-1873

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-England re civil war, Glorious Revolution of 1688, Locke, Divine Right to Constitutional Monarchy re contract between government and individual, rise of England as world power
-France re Divine Right and Louis XIV, expansionism, defeat, decentralized power, debt, and corruption under Louis XV and XVI
*Age of Enlightenment, shaped by science and new view of nature, inclusiveness and egalitarianism
-American Revolution re causes and written contract based on Locke. A nation of citizens
-French Revolution re Old Order vs. New Order, Reign of

Terror, war with neighbors, collapse, Napoleon, defeat, increase in English power, and rise of nationalism
-Revolutions of 1830 and 1848 re following era of conservatism and balance of power

Economic changes
-First Age of Empire re importance of Americas.
*limited territory ruled in Africa, luxury goods and horrors of slave trade
*limited territory ruled in Asia, goal is controlling trade in larger area, Gunboat Diplomacy
-Changes within Europe
*population explosion leads to increased trade and economic activity
*First Industrial Revolution: birth of factories, England leads re textiles, coal, iron, invention of steam engine
*Second Industrial Revolution: transportation key, increased distant trade, global connectedness; electricity, oil, steel and chemicals source of new wealth; other Western nations catching up to GBrit.
-Social changes due to new economy (some ??)
*growth of cities, decline of urban quality of life, change in values re family, gender, children, etc.
*social reform movement starts in Western countries, new laws, public education, rise of middle class, need for more products and services
-Second Age of Empire
*rise of racism, British Empire, more territory ruled in Africa and Asia, gap between West and non-West grows, first independence re some colonies

Chapter 10 (pp 147-167): European science, 1642-1873

Need to unify Galileo and Kepler models sets the stage

Newton re Halley's prodding
-*The Principia* re calculus and Laws of Gravity, limitation to these laws, need for an ether, calculus re Leibnitz, rise of nationalism, Royal Societies and National Observatories, science becomes popular
-light re Roemer and speed of light, then N's *Opticks* re light as beams of corpuscles, refraction and reflection as proof, Huygens re light as waves, need for ether, rejection by Newton and other scientists

Proving Newton right
-Astronomy re Halley, the scientific article, Cavendish re gravity constant, matching Newtonian predictions to observed orbits of planets, William Herschel, the finding of Uranus and looking for Neptune, nebulae, binary stars, the background stellar shift
-Physics and Chemistry, re Coulomb on electrical potential, Ohm, Carnot and Clausius on heat, unifying of all forms of energy, Dalton on atoms, chemical reactions, batteries

Changing the model
-Faraday re electro-magnetism, birth of field theory,

space as active player
-Kelvin re suggestions to Faraday, Fresnel on light, role of radiation
-Maxwell re four equations for electro-magnetism, indirect predictions, Hertz on radio waves

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-both Newtonian and Field theories are true for different circumstances in Universe, search for deeper and more unified theories continues

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*peace, prosperity, inventiveness, mandarins and education system, conservatism, reliance on occult beliefs, astrology, ancestor worship
*Foreign conquerors, decline before arrival of Europeans or colonial trade
*Western ambivalence toward East
*China's inability to use Western technologies re character writing, literacy rate, etc.

European virtues re modern science
-blend of science and math tools, political structure, fractured authority, cultural values re change, individual freedom, rare in world history
-doing science sustained and grew above values, etc.

Physics and Western culture
-interdependence, physicists shaped by cultural needs, astronomy re exploration, physics of energy re Ind'l Revolutions, still going on re atoms and energy
-must study both to understand either
-increasing isolation of science within our culture, unfounded and dangerous
-physics source of modern philosophy and context for arts

Endnote re layers of our past in present beliefs and culture
-West is less modern than we think, Third World more
-we still misunderstand modern science, big lag
-small group beginning to understand 20th Century physics and applying it to other arenas
-Plea to embrace modern science and modernity re our survival and ability to compete in future

to Susie, Nick, Josh,

and the students of Cobbles Elementary School

....for teaching me.....

PREFACE

In 1989, I decided to write a book for my soon-to-be-teenage children Nick and Josh on modern physics and its philosophical implications. Once I began, I realized how difficult it would be to explain modern physics ideas without first introducing some earlier ones. As a result, I decided to write an Introduction on Europe's Scientific Revolution and its connection to the birth of modern physics in the late-19th and early-20th Centuries.

During the next two years, my research continued and the job of writing began. Soon it became clear that I would also have to put Europe's Scientific Revolution into a larger context. This forced me to push back the starting point of my story to ancient Greece, and then to Babylonia, Egypt, and finally (if briefly) the earliest human attempts to explain nature through Animism. More importantly, as I began looking at my subject from this more chronologically and cross-culturally inclusive perspective, my focus shifted from an account of the history of physics ideas to one that would emphasize the interactions between those ideas and the cultures in which they developed.

By 1992, my "Introduction" had become a separate book. So I began planning a concluding chapter that I hoped would foster a positive attitude toward modern science by emphasizing: 1) its cultural and geographical roots and role within the Afro-Eurasia context, 2) its connections to other creative and intellectual pursuits in our culture, such as those in the arts and humanities, and 3) its importance in shaping the modern world, beyond the technical or material products of our culture usually (and often negatively) associated with science. After preparing an adult version of this work from 1995 to 1999, I returned to a final editing of this student text in 2000.

Thus, as I believe often happens, the book in your hands is the result of altered intentions. While I of course take full responsibility for any mistakes this book may contain and its historical interpretations, I would like to thank all those who helped shape this text. In particular, I owe a great debt to my wife Susie, who has tolerated this obsession for over a decade; those who helped me find materials at Cornell University, especially Margaret Nichols at the Kroch Library; and those who read my text and suggested ways to improve it, especially Dr. Morris Beers at SUNY Brockport. All of their help was invaluable.

Neil Chodorow
[redacted].
August, 1996

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INTRODUCTION

What is "nature?" Often, when we think of nature we think of sunsets, sunrises, stars, comets, clouds, landscapes, the many animals and plants that exist in the world, the moon, and the Earth itself. In fact, we usually define nature as containing all the things in the Universe that are not human-made. Perhaps for this reason, most people believe nature is "good." We also assume that the only way humans can experience or learn about nature is through our five senses: sight, sound, smell, taste, and touch.

To scientists, this understanding is too narrow. And it is clouded by cultural bias. Instead, they believe nature should be seen as a morally neutral arena that encompasses "natural" and "human-made" products, human beings, ***and*** a range of processes and entities we cannot experience directly, because they are too small or large; too short- or long-lived; odorless, silent, invisible, or tasteless, at least in relation to our ability to perceive them with our senses. Thus, even within the realm of nature represented by the scientific concept of "matter," we need ***indirect*** ways to know that many parts of nature exist at all.

More fundamentally, some aspects of nature are not material at all. Space, time, and forms of energy such as momentum, heat, electricity, magnetism, light, and the strong and weak forces involved in sub-atomic nuclear interactions, are all real, as are a variety of interactions between energy and matter. In fact, the effects of all these forces and relationships can be measured and described by humans. Moreover, when we include these phenomena in our definition of nature, we are using ideas from modern science, and especially from the science we call ***physics: the study of how nature is organized and how it works.***

The evolution of these ideas as a body of knowledge has been extremely important as an end in itself. But the ideas created by physicists have also generated technologies that have completely reshaped our society, as well as the balance of power among different peoples and countries. These ideas are also used by chemists, biologists, meteorologists, geologists, and social scientists (historians, psychologists, sociologists, economists, anthropologists, and political scientists). In fact, ***all*** scientists and increasingly most human beings depend on the understanding of nature we get from physics.

Most importantly, all modern scientists base their work on two beliefs that came from physics: 1) the processes of nature can be described by humans, utilizing the intellectual tools of mathematics, observation, and experimentation, and 2) nature is made up of parts or processes that are connected to each other in chains of "cause and effect."

All this may seem obvious and a little silly. Of course it helps to observe nature if you want to understand it. And everyone knows one thing can cause another. Or, that all natural phenomena are tied together in causal relationships. Surely everyone has always known these things, with or without physics.

Amazingly, this is not so. This way of thinking is fairly new in human history. Before the late 1500's, people had other ways of describing nature and its processes, which also means people applied different *ways* of thinking when they attempted to find solutions to their problems.

Since people have not always thought as "we" do about nature or its fundamental laws, it would be interesting to ask the following questions:

1) What did pre-modern humans think about nature?

2) Which of their ideas contributed most to the development of our ideas?

3) How did scientists build on earlier ideas to improve their understanding of nature?

4) How did scientists check to see if their ideas were correct?

5) How did the societies in which scientists lived shape their work?

And, 6) how did science affect the societies in which scientists lived.

The answers to these questions make up a wonderful story of people in different places and times striving to understand nature. This book attempts to tell this story, starting with prehistoric food-gatherers and ending in 1873, when one of the first modern physics ideas was discovered.

In other words, this book will focus on the *causes* of modern physics. But before beginning our story, we must establish a few ground-rules:

1) Those cultures and ideas that contributed most to the development of modern physics will be emphasized. This does not mean other cultures or ideas were less important or "wrong" about nature. The purpose of this book is *not* to evaluate the merits of different civilizations or their scientific insights, but to show how different ideas and cultures contributed to *our* culture's view of nature.

2) There will be almost no mathematics in this book. Ideas about nature will be described in words. There will, however, be descriptions of scientific ideas. After all, it is impossible to write a history of a thing without describing the thing itself.

And, 3) to understand the ideas about nature described in this book, we must understand the cultures that created them. And vice versa. Therefore, each chapter or pair of chapters will start with a history of a particular time, place, or culture (a society) before turning to a discussion of that society's ideas about nature, in the hope these descriptions of scientific and anthro-historical processes will illuminate each other.

That said, let us begin.

CHAPTER ONE

IN THE BEGINNING: ANIMISM

Bones, camp-sites, and tools dug up in many places around the world suggest the first human-like animals appeared about 3 million years ago. However, these first humans were not exactly like modern ones. In fact, there have been several different species of humans. Along the way, new species of humans have replaced earlier ones. Humans exactly like us (***Homo sapiens***, or "wise humans") apparently developed around 70,000 years ago in East Africa and first arrived at the Eastern end of the Mediterranean Sea and in Southeastern Europe between 50,000 and 40,000 BC, where they competed with the earlier Neanderthals.

By 20,000 BC, or perhaps earlier, Homo sapiens were the only humans left on Earth. By 10,000 BC, they spread to all the larger pieces of land in the world, except Greenland, Antarctica, and the most northerly parts of North America, Europe, and western Asia. This made Homo sapiens the first essentially world-wide species of humans.

Food Gatherers and Producers

For the great majority of human history, until 9,000 BC, humans fished and hunted wild animals and picked wild plants to get the food they needed. This "food gathering" way of life required humans to live in small groups, in order to move around more easily and to find enough food to meet the needs of the group. In a larger sense, of course, people had no choice but to live in ways the local climate, land, and wild animals and plants could support. Consequently, most nomadic groups "set up camp" in one place for part of the year, and then moved to another place for a different part of the year, making these moves several times a year. However, they usually used the same camp-sites year after year within an essentially permanent territory.

For the vast majority of time Homo sapiens have been on Earth, all humans lived as nomadic food gatherers. In that sense, the story told in this book has occurred in only the last, brief, fraction of the time humans have been on Earth.

Around 9,000 BC, humans began farming and domesticating animals to provide the food they needed. This "food producing" technology first appeared in Israel, Palestine, Lebanon, Syria, and Jordan (altogether, the Levant), southern Turkey, northern Iraq and western Iran, areas that form an arc around Iraq, and which are parts of a larger area that includes all the land from Egypt through Iran that we call ***the Fertile Crescent***.

Food producing forced people to "settle down" in places that could provide the right climate, soil, and other essential resources a less mobile group needed. Consequently, the first food producers built the world's first permanent villages. Then, as farming and animal husbandry methods improved, the population in areas in which food producing was used grew larger. This was the world's first population explosion, at least within certain local areas. The invention of food production, however, did not mark an abrupt passage from one cultural era to another, even in the area in which it was invented. Instead, as a "safety net" for years when farming might be bad, many tribes alternated between nomadic and village life-styles or contained individuals who continued to live each way. Meanwhile, people in other parts of the world, even within the Fertile Crescent, continued to live as food gatherers long after food producing was invented.

Nevertheless, farming and animal husbandry were among the most important discoveries of human history. First, they changed the kind of communities people could live in, and the problems people faced and tried to solve. In fact, village life made it necessary for humans to make *change* itself a goal, if only to improve the techniques and tools needed to provide an increasing food supply and the human-made products used by a growing population. Second, by ***6,000 BC*** (and perhaps earlier), food production innovations and increasing contact among villages changed some Fertile Crescent settlements in Israel and southern Turkey into the world's first market towns, places where people traded agricultural and other products from across a large region inhabited by several tribes and a relatively large population.

Given this new more efficient way-of-life, it was not long before increasing population pressures, conflicts among tribal groups within western Asia, and a dramatic decrease in the region's annual rainfall during this period made it necessary for humans to find and use all the available farmland in the Fertile Crescent. However, while annual floods in the major river-valleys in this region dumped rich silt on this land and gave them the richest soil in the region, those floods also threatened to wash away any crops, making it impossible to farm.

To use these "premium" sites, people would first have to find ways to control the river floods, or at least manage their effects on agricultural production. Consequently, the first people who migrated into river-valleys in northwestern Iran, southern Turkey, and Syria around 6,000 BC quickly learned to dig canals from the river across their fields, so the "extra" flood waters could flow down these canals, keeping the fields dry. Then, by closing gates along these canals, they learned how to trap some of the "excess" water in a network of holding ponds, to be released later to water existing fields when there was not enough rain, or to water new fields further from the river.

In time, building canals, canal gates, and holding ponds, and learning how to clean and maintain these structures so they would stay free of silt allowed the people who lived in some of the Fertile Crescent's river valleys to increase the yield of their fields and the amount of land they had under cultivation. We call this use of canals to support farming "irrigation."

The First Cities: A New Way of Life

As with agriculture, the discovery of irrigation did not immediately change the way people lived. However, just before 5,000 BC, two groups began migrating into the valleys along the Tigris and Euphrates Rivers in Iraq, an area usually called by its Greek name, ***Mesopotamia*** ("the land between two rivers").

One of these groups, the ***Semites***, contained people from Syria, Jordan, northern Iraq and the Arabian Peninsula, while the other, the ***Sumerians***, migrated from western Iran into southern Mesopotamia. As the Sumerians moved up the Tigris and Euphrates, they came to dominate southern and central Mesopotamia, leaving northern Mesopotamia to the Semites. Once these groups were settled in their new homelands, the Sumerians who lived along the middle part of the Euphrates River developed new irrigation techniques that created a farm economy that could reliably produce enough food in bad years and more food than was needed in years in which the temperature, rain, sunshine, and the floods were "just right."

Between 5,000 and 4,500 BC, the ability to more reliably grow an adequate food supply made it possible for many more people to live in central Mesopotamia's Sumerian villages. But these techniques also made it necessary for them to do so. First, it took a lot of people to build and maintain canals, and to support the life-style that was emerging from the economy of these villages. And second, the increasing complexity of village life and the need to feed a growing population forced Sumerians to develop a wide range of new skills and knowledge, and to give certain individuals the job of creating and safeguarding that knowledge. As a result, ***Sumerian priests became the world's first permanent intellectual and spiritual elite***.

By 4,500 BC, the Sumerian communities in which this elite lived became towns in which there were an increasing number of specialists in manufacturing, trade, and building design and construction. But, since these specialists spent little of their time gathering or producing food, they were forced to trade their work or products for the food, other products and services they and their families needed. Thus, specialization made barter-based trade an important activity in Sumerian villages.

There were also other important changes caused by the development of Sumerian towns. First, since Sumerian traders needed better ways to transport goods and materials, they invented ***the wheel***, which was used on carts pulled by people and draft animals. (NOTE: Nomads in central Asia appear to have been the first to tame horses and use them for riding or carrying supplies. Sumerians apparently learned of this innovation from their more "backward" neighbors to the North.) And second, Sumerian town-dwellers needed to build better and larger public structures to meet the needs of the entire town. These included temples, palaces, food storage buildings, and walls. Thus, as their largest towns became cities, Sumerians became the first people in the world to purposely design and build buildings for two distinct purposes: public and private (family) use.

By 4,500 BC, the increasing complexity of their life-style caused the Sumerians to invent ***writing***. At first, writing was only used for numbers, to keep track of trading and other business matters. But by 4,000 BC, Sumerians began writing words. As a result, for the very first time in human history, Sumerians could write down their ideas on anything that interested them, including farming, trading, building design and construction, religion, nature, government, law, or their own history. As importantly, writing also made it easier to pass on knowledge from one generation to the next, and to more effectively use that knowledge or add to it.

The first Sumerian community to take full advantage of all these changes, and therefore become the world's first city, may have been ***Al'Ubaid***, which was built on the lower Euphrates River between 5,000 and 4,500 BC. (NOTE: The Sumerians later considered Erich their oldest city. But the evidence we have so far suggests Al-Ubaid was older.)

Recent archeological work on ruins of Mesopotamian cities and others in neighboring Iran has given us some understanding of the people who lived in these cities and their beliefs. So, we could start our account of human ideas about nature with those of the Mesopotamian city-dwellers, or with the first use of writing by other ancient civilizations. But, since humans existed for almost 3 million years and Homo sapiens for at least 65,000 years before the first cities, it would be better to start at an earlier time, long before the invention of writing.

How can we do this? Luckily, there are three ways we can make an "educated guess" about earlier people's ideas about nature. First, we can study ideas about nature of contemporary (20th Century) nomads. Second, we can study the ideas of the earliest urbanized cultures whose writing we can read (the Sumerians, Egyptians, and Chinese), in order to construct a mental picture of the ideas that may have led to their ideas. And third, we can study the ideas seemingly expressed in the cave art, tools, and other artifacts we have found from the time before the invention of writing. We will use all these techniques to begin our story. However, we must remember that city-dwellers were the first to write down their ideas. So, any description of earlier people's ideas is just educated guess-work...

Early Humans and Nature

Perhaps the best way to think about early humans' ideas about nature is to picture a community of people living 20,000 years ago, let's say on the plains of East Africa.

The 200 people or less in our group would be the only humans a member of the group would ever know well or feel safe with. (NOTE: Over hundreds of years, groups did have contact with each other. But for any one person, this mixing was very limited.) Adult members of our group, including those actively caring for children, would spend much of their time and energy hunting animals and picking edible plants in the areas surrounding their camp. If they exhausted these resources and group members were still hungry, the group would move on, looking for more animals or plants. Sometimes they would get enough to eat, and sometimes not. So, the more group members learned about the land, weather, seasons, plants, and animals, in fact about all of nature in their territory, the better chance they would have of getting enough to eat and of solving their other problems, such as finding materials for clothing, housing, weapons, and tools.

As importantly, the territory in which our group lived, including its land, climate, animals, and plants, would be the only part of the world our group's members would ever know about or experience. Thus, this territory would be the only world they could think about or describe. As a result, many groups described their territory as if it were all of nature, and as if the center of their territory were the center of the entire Universe.

What can we guess about the specific knowledge early humans' might have gained about nature? First, they must have noticed that day is followed by night, then day, then night. Early humans must have also noticed the connection between the day/night cycle and the path of the sun, and other cycles like the changing shape and path of the moon that could be used to construct ***calendars*** to mark the passage of time.

In more general terms, it must have been obvious there are many ***natural cycles*** that repeat themselves month after month, season after season, or year after year. Becoming aware of these patterns would help food gatherers make all the decisions needed for survival. Moreover, our group's collective wisdom in making predictions based on natural cycles may have meant the difference between life and death for a person or the entire group. However, ***observing nature*** would also make it clear some cycles are not always repeated perfectly. One year the rains might not come when expected, or there might be too much, too little, or no rain at all. Meanwhile, other "things" in nature would appear to follow no pattern at all. Thus, members of our group could not predict earthquakes, comets, eclipses of the sun or moon, the sudden appearance of diseases of people or animals, or many other natural events in their lives. These things would seem to happen (or not happen) for no reason at all.

Consequently, all early humans must have understood that ***nature is sometimes predictable and sometimes not***. We can easily imagine it must have been the unpredictable part people would experience as frightening and dangerous. In fact, early humans probably felt a need to create explanations that would allow them to believe nature was not "really" unpredictable. (NOTE: It is possible to argue this remains the primary, and primitive, motive behind the doing of science, even today.)

To once again take rain as an example, it would be more comforting to believe rain could choose whether to follow its usual pattern or become unpredictable. After all, this would mean the group might find a way, perhaps by performing ceremonies to make rain "want" to rain when it was needed. In fact, carrying out such ceremonies might seem to give the group, or at least special members of the group like priests, control over nature. We call this view of the connection between human ritual behavior and nature "sympathetic magic."

The concept of sympathetic magic implied everything in nature that affected human life (and, this would be everything group members noticed and other things they imagined) has its own personality, with some freedom to act well or badly, like a human. In time, people gave these human-like spirits such complete personal histories and personalities, and endowed them with so much power, they came to be thought of as ***gods***. After all, these god-spirits could control all the events that could make human life and survival easy or difficult.

We call this belief in sympathetic magic and spirit-gods ***Animism***. When Animism was first developed as a view of nature, it gave people the feeling they understood why nature acted the way it did and that they could affect it by performing ceremonies like prayers or dances. In fact, if humans were respectful and friendly toward nature and its gods, those gods would be friendly to humans. If not, the gods would make the world a very dangerous and vengeful place.

Ancient nomadic peoples must have also experienced many aspects of nature directly with their own senses. For example, they must have noticed rocks are hard, but some are better for pounding sticks into the ground, while others are easily chipped to make arrow heads. In fact, learning how to best use rocks, or which rocks are best for which jobs, must have made it important for humans to notice simple, physical, things about a rock (like its heaviness or hardness). So, while early humans believed in the existence of a spirit-god of rocks, they also saw rocks as physical objects, the properties of which could be learned about and understood. Thus, Animistic nomads saw the Universe as both ***an arena of mysterious spiritual "happenings" and a physical place humans could experience, learn about, and describe.***

Summary

The roots of our ways of thinking lie in Animism, a system of thought which, given the life nomadic food gatherers and early food producers lived, was a very intelligent and rich way to describe the world. Since Animism gave people a reason to pay better attention to nature, it also represents the beginning of humans using observations and their intellects to understand the parts of the world that interested them. Without these habits-of-mind, later peoples would not have been able to make new, and more accurate, pictures of nature.

Clearly, early nomadic food producers lived very differently than we do. However, it is wrong to think they lived simple or static lives. They discovered how to make and use speech, fire, tools, art, and pottery. They faced many problems, some of which they solved by understanding the world in which they lived. Eventually, they figured out how to farm, tame animals, use irrigation, and build villages. Thus, although it took a long time for discoveries or inventions to spread from one group to others, the way food gatherers lived slowly changed and improved. In fact, the major discoveries made during this early period in human history were as complex and difficult to make as any that have been made by humans since 5,000 BC. We must always remember this, especially as we embark on the task of understanding some of the more "sophisticated" ideas about nature that have emerged in various civilizations in the last 7,000 years.

CHAPTER TWO
BABYLONIA AND EGYPT: NATURE AS IMAGE AND MODEL

Between 5,000 and 2,000 BC, civilizations appeared in Asia, northeast Africa and southeastern Europe. The most important were in Mesopotamia; Egypt; along the Huang Ho (Yellow River) in China; Crete, the mainland and islands of Greece, and the west coast of Turkey (the Aegean cultures); and the Harappan (Indus River) culture in Pakistan. Of these, Mesopotamia and Egypt played the earliest roles in the development of modern science, although later phases of or new civilizations in Greece, India, China and western Asia eventually had major effects on our science. Thus, we can focus on Mesopotamia and Egypt here, leaving the others to later chapters.

A Brief History of Mesopotamian Civilization

As we have seen, the world's first cities were built in southern Mesopotamia between 5,000 and 4,500 BC. By 3,500 BC, there were many cities in southern Mesopotamia. Each had its own government, traded with other Mesopotamian cities, and developed trade networks that included townspeople, nomads, and farmers across the Fertile Crescent. To defend themselves, Mesopotamian cities extended their military and political control to their nearby country-sides, thereby becoming ***city-states***, the world's first "countries." All Sumerian city-states shared similar ideas and ways of doing things. So, while each was a separate political unit, all were part of a single ***civilization***.

The first Mesopotamian civilization is called the ***Ubaid culture,*** after the city of Al'Ubaid. Each Ubaid city had a large population, traded with other cities, raised armies in time of war, and built irrigation canals, palaces, temples, walls, and other public structures. To support this Ubaid life, some individuals specialized as merchants, craftsmen, traders, planners and builders of public structures, and priests.

As Ubaid civilization spread to surrounding villages and towns, more Sumerian communities became cities. One of these was ***Ur***, a little bit south of Al'Ubaid on the Euphrates River. By ***3,000 BC***, Ur had become the largest and most powerful city in Mesopotamia, with styles and ideas that were different enough from Ubaid ones for us to say Ur had its own culture. We call this culture the ***Uruk civilization***.

Like the Ubaid culture before it, Uruk civilization spread to many cities along the Tigris and Euphrates, including one called Sumer. It is possible the first histories (now lost, if they ever existed) were written when Sumer was the most powerful city in Mesopotamia. This would explain why all southern Mesopotamians came to be called Sumerians and the territory in which they lived Sumeria. In reality, however, no Uruk city ever ruled all of Sumeria, although all shared a single culture. Aside from building walls around their cities, palaces for their kings, and temples to their gods, some of which were on top of flat-topped pyramids, Uruk city-dwellers learned how to manufacture and trade many things. But most importantly, all Uruk cities used the same language and perfected a ***shared written language*** with separate pictures (characters) for each word. (NOTE: Uruk writing slowly changed into a more abstract form in which arrowhead-shaped marks were combined to form characters. There was a separate character for each word. We call this Sumerian form "cuneiform writing.")

The existence of a single Sumerian culture greatly affected Uruk religious practices. Unlike in Ubaid culture, the gods of all Uruk cities were organized into a single "family," the head of which was taken to be the main god of the most powerful Uruk city. Thus, the Uruk god who was designated as most powerful changed whenever the fortunes of Uruk cities changed, making the relationships among Sumeria's gods as complex as the human relationships within Sumeria itself. Belief in a single family of gods also helped bind all Sumerians to their urbanized society, its leaders, and the larger Sumerian civilization. Thus began ***organized religion***.

In the Sumerian religion, the priests were go-betweens for humans with Sumeria's pantheon of all-powerful Animistic gods, whose personalities reflected the Sumerian belief that the world was a dangerous place in which the floods that made life possible could also destroy it. Accordingly, Sumerians believed if they followed the instructions of their priests, and prayed to their gods and won their favor, the gods would not do anything "too bad" to their king, priests, city, traders, army, or fields, hardly a hopeful view of the world or humanity's place in it. Since priests created the ceremonies and prayers required by the gods, and provided solutions to the many problems that faced Sumerian builders and farmers, they were expected to develop most of the specialized knowledge needed to make Uruk society work.

Consequently, Sumeria's urban priests were probably the first people in the world who devoted a great deal of time to what we would call mathematics, engineering, and science. They also created one of first calendars based on these studies, and ran the world's first schools, which trained new priests. As befit these important responsibilities, priests were given special privileges and had their "earthly" needs taken care of by offerings to the gods made at the temples they ran and staffed. In fact, priests became so important, the head priests of Uruk cities' main temples became Sumeria's first kings.

Uruk ***priest-kings*** derived their right to rule from the belief that all land in Sumeria belonged to the gods. Thus, as representatives of the gods, priest-kings could rule the land and all those who dwelt on it. However, as the Uruk civilization grew more complex, other members of Sumerian society became wealthy, leading to a greater social differentiation in Sumeria than in any earlier or contemporary (to them) tribal society.

This made Sumeria's urbanized culture less egalitarian than any earlier culture. But this new class structure proved crucial to the further development of Mesopotamian civilization. The wealthy class's "taste" for grand architecture and luxury goods led to the extension of Sumeria's trade networks to territories further away from Mesopotamia, the building of larger and more impressive public structures, and an increasing sophistication in the arts. In fact, these developments gave Sumerian civilization much of its character, and allowed its products and ideas to reach the rest of western Asia and much of northeast Africa and southeast Europe, where Mesopotamian influences stimulated the development of other civilizations.

The Beginning of Empire

As Sumerian ideas spread up the Tigris and Euphrates and reached northern Mesopotamia, the home of the Semites, some Semitic cities became as large and powerful as Sumerian ones. One of these was called ***Akkad***. Finally, in 2,200 BC, ***King Sargon*** of Akkad raised an army and conquered all of Sumeria and many other Semitic city-states. Unlike earlier conquerors, who found it impossible to hold onto or effectively rule large territories, Sargon divided his ***empire*** into ***provinces*** and named governors to rule them. Some of these governors were Akkadian generals Sargon wanted to reward, while others were local kings who had been conquered. But in all cases, these regional "kings" were held responsible to the emperor, thereby creating ***a second level of government*** between Sargon and the people he ruled. To maintain order in his empire, Sargon also kept his army together, thereby creating the world's ***first standing army***.

These innovations were based on Sargon's understanding of the value of ***structure*** in maintaining a society, rather than depending on personal relationships or the presence of a uniquely powerful or worthy Emperor. In any case, the structures Sargon created allowed Akkad to rule its empire for 150 years. However, in 2,050 BC, the Sumerians rebelled, the Akkadian Empire collapsed, and Mesopotamia once again returned to its old pattern of being divided into city-states. Then, in 2,000 BC, a tribe from Iran called the Elamites joined with a non-Semitic northern Mesopotamian tribe called the Amorites to conquer the Sumerians and Semites. However, once this conquest was complete, the Elamite-Amorite alliance collapsed, leaving the ***Amorites*** to establish several new cities in northern Mesopotamia, including one that came to be called ***Babylon***.

In time, the Amorites were absorbed into the Semitic population and disappeared as a separate people. By then, Babylon had become the largest city in Mesopotamia (and perhaps the world) and had begun conquering Mesopotamia. In fact, by 1,400 BC, the First Babylonian Empire included all of Mesopotamia and lands to the north and west of it, a much larger area than had been ruled by the Akkadians. However, the Babylonians were not the only ones who were learning from the Akkadian example. At the same time, another people, the ***Assyrians***, were establishing their own empire to the north of Babylon's.

The Babylonian and Assyrian empires used many Akkadian and Sumerian ideas. Like the Akkadians, Babylon maintained a standing army, divided its empire into provinces ruled by kings who answered to Babylon's emperor-king, and understood it would be easier to rule the Sumerians (who felt superior to all Semites or any other "new" civilization), if they showed great respect for Sumerian accomplishments. Thus, the Babylonians: 1) included Sumerian gods in their own family of gods, 2) re-wrote Sumerian laws and made them their own, 3) used Sumerian ideas about mathematics, astronomy, calendar-making, farming, and irrigation, and 4) adopted Sumerian writing.

As a result, many important Sumerian ideas were saved by the Babylonians, who later passed them on to other civilizations, including the Assyrians. However, Babylonians also added to this "inheritance," most importantly by: 1) extending Mesopotamian influence to a larger area, thereby stimulating the development of several new civilizations in western Asia, 2) developing a more complete and complex code of law, and 3) changing Sumerian writing to make it easier to use. Thus, while in Sumerian writing, each pictograph represented a whole word, in Babylonian writing each symbol represented a syllable, a group of sounds that make up a coherent part of a word in its spoken form. (NOTE: If we used Babylonian ideas about writing, we would write an English spoken word like "gar-den" with two syllable-letters.)

Since each syllable-symbol could be used in many words, Babylonian writing had fewer characters than Sumerian writing. And, since ***each character*** represented ***a sound***, it could be made ***simpler and more abstract***. In fact, Babylonia's symbols became so abstract they became stepping stones to the world's first alphabet, which was invented by the Phoenicians in Lebanon around 1,000 BC. Civilizations that later used alphabet-based writing found it possible to represent all their spoken sounds with fewer than 30 letters. Today, all European languages are alphabet-based, as are most languages in Southern Asia. However, several East Asian languages retain their character-based structures. (NOTE: The invention of the alphabet has long been attributed to Phoenicia. But recent archeological finds in southern Egypt suggest a group of Semitic laborers there may have used an alphabet as much as 1,000 years before the Phoenicians did.)

Between 1,600 and 600 BC, several non-Mesopotamian tribes conquered Babylon. In ***900 BC***, one of these, the ***Chaldeans***, built a new Babylonian Empire, while the Assyrians re-established their empire to the north. Finally, in 792 BC, Assyria conquered the Chaldeans, built a new capitol called ***Ninevah*** in northern Mesopotamia, and began conquering other civilizations in Iran, Mesopotamia, the Levant, southern Turkey, and Egypt, where it established a dynasty of pharaohs who ruled for 100 years. Assyria's greatest king and most successful empire-builder, ***Ashurbanipal***, who ruled from 668 to 626 BC, loved ideas and knowledge. So he built a ***library*** in Ninevah that housed over 25,000 clay tablets, including most of the surviving written records of the knowledge that had been accumulated in Mesopotamia since 4,000 BC. Thus, like Babylonia, Assyria preserved and passed Mesopotamian ideas on to later civilizations.

When Ashurbanipal died, there were rebellions against Assyrian rule. Then, after several alliances formed and collapsed in the turmoil that followed, a tribe from Iran called the Medes destroyed Ninevah and conquered most of the Fertile Crescent for themselves. But the Babylonians rose up one last time, and established a new empire which, under King Nebuchadnezzar, built great palaces and temples and ruled from Egypt to Iran. Finally, in ***539 BC***, a new power from Iran called the ***Achaemenids***, whom we call ***the ancient Persians***, conquered Mesopotamia and broke the tradition of all earlier western Asian conquerors of centering their empires in Mesopotamia. Instead, the Persians continued to center their empire in the place of their origin, Iran.

Between 5,000 and 539 BC, Mesopotamia was one of the most important centers of culture for the entire world. It was also conquered many times by many peoples. In fact, so many tribes moved into and out of Mesopotamia during this period and established empires there, it is often difficult for historians to tell the "outsiders" from the "locals." This confusion is made even worse by the fact that each conquering tribe was partially assimilated into Mesopotamian society. In fact, this cultural pattern has made it possible for some historians to speak of a continuous and single Mesopotamian civilization over this entire period of roughly 4,500 years.

This was also true of science and math. For example, while the best descriptions of Mesopotamian accomplishments in these fields come from the Chaldean period of Babylonia's history, the Chaldeans freely admitted their ideas were based on those of earlier Sumerian and Semitic priest-scientists. In fact, we now know that some observations of the stars, sun, moon, planets, and "special heavenly events" like comets and eclipses cited by

Chaldean astronomers date from as early as 3,500 BC, 2,600 years before the Chaldeans arrived in Mesopotamia.

Once the Persians conquered Mesopotamia, however, the age of a separate cultural, mathematical, and scientific tradition based in Mesopotamia came to an end. Thus, while Mesopotamia had cities for many years after 539 BC, and then in later periods of its history, those cities belonged to civilizations that started or remained centered in other places: Iran, Greece, Rome, and the Arabian Peninsula. Nevertheless, all civilizations that later developed in western Asia and Europe, including our own, owe a great debt to the Mesopotamians, who invented many of the ideas that made city life and civilization possible.

A Brief History of Egyptian Civilization

The development of civilization in Egypt followed a very different pattern. Farming began in Africa about 6,500 BC in small desert oases and valleys in Egypt, Libya, Algeria, and the Sudan. About 5,000 BC, however, the climate in North Africa became much drier, which: 1) made it difficult to farm in the oases where African farming had been invented, and 2) reduced the run-off of water from East Africa's highlands into the Nile, which reduced the severity of the Nile's floods, making it easier to farm along its riverbanks. As a result, the northeast African farmers and nomads who were seeking an adequate supply of water began to migrate into the Nile River basin.

After 5,000 BC, ***the Nile basin*** became the main center of North African farming. However, the first peoples who moved into the Nile basin found a very different environment than the one that greeted Mesopotamian river-basin settlers. Above all, the Nile valley was one long, nearly continuous, piece of land on which farmers could grow crops without using irrigation, as long as they were satisfied with one crop a year. In fact, this practice provided enough food for the Nile's population until about 3,100 BC. So it was not until almost 2,000 years after farming began along the Nile that irrigation was used to grow two and then three crops a year to feed Egypt's growing population.

To understand Egyptian history, we must first understand that the Nile River, the great "mother" of life along its banks, is fed by the Blue Nile and White Nile, two rivers that begin in the mountains of East Africa over 1,000 miles south of Egypt. These rivers flow northward until they join in Sudan. From there, the Nile flows northward through Egypt, until it empties into the Mediterranean Sea. **The Egyptians divided this land along the Nile** into four areas: 1) most of Sudan was called Kush, 2) to the north of Kush, in northern Sudan and southern Egypt, was Nubia, 3) north of Nubia, in the middle of Egypt, was Upper Egypt, and

4) north of Upper Egypt was Lower Egypt, including the northern Egypt and the Nile's delta. So, since the Nile flows northward, Upper Egypt was ***south*** of Lower Egypt.

Large-scale Nile-basin farming first flourished in Nubia between 5,000 and 3,200 BC. It was during this "Nubian period" that the first Egyptian hieroglyphic writing and yearly calendar were invented. However, the Nubians built no cities. Instead, they lived in small communities along the Nile, a pattern that lasted throughout most of ancient Egypt's history. Thus, while by 2,400 BC Upper Egyptian "cities" contained some of the largest and most spectacular monuments, structures, and public buildings ever made by humans, including palaces, temples to Egypt's gods, sphinxes, pyramids, and statues of the pharaohs, Egypt had no large cities until 1,200 BC, long after it had absorbed major influences from other civilizations.

Most historians believe Egypt's lack of urbanization was caused by three factors. First, farming remained a more important source of wealth for Egypt than it did for other civilizations. In fact, the technologies involved in Egyptian farming and irrigation were most efficient in smaller communities. Second, while Egypt conquered land beyond the Nile basin, and in one period ruled an empire that extended from southern Turkey to Libya, the Nile basin remained the source of Egypt's great culture. And third, Egypt's location as the most westerly of the great civilizations of its day, as well as its desert "buffer zone," kept Egypt from becoming as dependent on trade or as vulnerable to military attack as other early civilizations. Thus, it was never necessary for large numbers of Egyptians to live in urban communities to do business or for security. As a result of its geography, Egypt also did not suffer the repeated "culture shocks" and conflicts other ancient civilizations suffered, which gave Egypt a remarkable degree of cultural unity and stability.

By 4,000 BC, Nile towns were ruled as city-states, like miniature Mesopotamian ones. Then, in 3,100 BC, at about the time of the rise of Uruk culture, Upper Egypt and Nubia were unified into one kingdom, while Lower Egypt became a separate one. Unlike in Mesopotamia, however, the Egyptian theory of kingship was based on the idea kings were gods who temporarily ruled as human beings before returning to their godly forms after death. In fact, this belief in divine kingship was well established by 2,700 BC, when Upper and Lower Egypt were unified into a single kingdom. As a result, for the next 2,700 years, through periods now designated as the Old, Middle, and New Kingdoms, Egypt's god-king, or ***pharaoh***, wore two crowns.

Many of the symbols and cultural forms we associate with classical Egypt were well established by the end of the Old

Kingdom. It was during this period, for example, that the Great Pyramids and Sphinx in the Valley of the Kings were built as symbols of Egypt's prestige and power, and of its belief in the pharaoh's connection to ***a divine order*** that infused the entire Universe, including Egypt's political, religious, and social systems. Ironically, the stability of these beliefs allowed Egypt to legitimize the dynasties that were established by Babylonian, Assyrian, and Persian conquerors, and to weather the periods during the Middle Kingdom when more than one person claimed to be pharaoh or Egypt split into several kingdoms. In fact, Egyptians never stopped believing in a unified Egyptian kingdom or the right of a divine pharaoh to rule that kingdom, a belief that facilitated the establishment of ***any*** new dynasty that honored the traditions of Egyptian culture and government. (NOTE: As we will see in Chapter 11, this seeming incongruity between Egypt's turbulent political history and its ideological stability has an interesting parallel in Chinese history.)

When looking back at ancient Egypt, we must remember its culture lasted a very long time, and that its long history was divided into several periods, some of which involved foreign rule, while others were marked by great internal cultural renewal. This is perhaps best illustrated by the period of great conservatism and nationalistic pride that began in 1,570 BC, when a native Egyptian founded the New Kingdom and began the world's first massive archeological effort by attempting to restore the pyramids and sphinx in the Valley of the Kings, which, at that point, had been abandonned for almost 900 years.

Although these efforts probably did more harm than good to the monuments themselves, they were immensely successful in ensuring the new pharaoh and his descendants could claim the "old culture" as part of their own heritage. Perhaps inadvertantly, these efforts also ensured that Egypt's ancient beliefs were kept alive in later versions of the classical Egyptian culture. (NOTE: It is worth noting in this context that 1,570 BC is as close to today as it was to 5,000 BC, when large-scale farming began in Nubia and urbanization began in Mesopotamia. Thus, amazingly, the beginning of Egypt's New Kingdom in 1,570 BC is the chronological midpoint in the Western history.)

In 330 BC, Egypt was conquered by the Greco-Macedonian armies of ***Alexander the Great***. After Alexander's death, one of his generals, Ptolemaios I, established a new Greek kingdom in Lower Egypt. While all later "Ptolemaic" kings and queens took the title of pharaoh, the Greeks were never fully assimilated into Egyptian culture. Instead, the newly-built capitol of Egypt, Alexandria, became a major center of the new international Greek culture. (NOTE: See Chapter 3 for more on Alexandria.) So, while the outward form of classical Egyptian government continued, Egypt's ancient cultural integrity began to erode, a process that was completed in 30 BC when Roman conquered Egypt.

Nevertheless, the Greeks and Romans had a deep interest in all ancient civilizations. So, both allowed Egyptians to follow their own religious beliefs, while the Romans once again tried to restore the sphinx and the pyramids. As a result, Egypt's ancient heritage did not completely disappear until Christianity became dominant in Egypt after AD 400.

As with Mesopotamia, Egypt influenced all civilizations that later developed in North Africa, western Asia, Europe, and all the places to which European civilization ultimately spread. In fact, before continuing with our story, it is worth emphasizing again that ***the roots of our civilization were formed in Egypt and Mesopotamia long before the rise of Greece and Rome, the first truly European civilizations.*** (NOTE: After the Fall of Rome, Egypt's ancient monuments and heritage were not re-discovered or studied again until Napoleon's conquest of Egypt in the 1800's sparked a pan-European interest in Egyptian artifacts and ideas.)

The Egyptian ideas described in the next section are from 2,000 to 1,400 BC, during the late Middle and early New Kingdoms, the last "golden age" of Egyptian science and math. Before turning to these ideas, however, we should note that the picture of Mesopotamian and Egyptian history given here implies these two civilizations developed separately. It might therefore seem logical to assume they had totally separate ideas about nature and mathematics. But this is not true. All ancient civilizations in Afro-Eurasia had some contact with each other through trade, migration of peoples, or warfare. Thus, ***the very existence of civilization allowed ideas and people to mix over a large area and population.*** In fact, the world view of the people who lived in these civilizations could never again be as localized or isolated as it had been before 5,000 BC, or among those who continued to live in isolated areas. The energy that came from this sharing of influences and ideas was perhaps the greatest present the first civilizations gave to future world culture.

The Science of Mesopotamia and Egypt

Every aspect of life in Mesopotamia and Egypt required new skills and knowledge. So let's begin by listing some of the ***practical problems*** that led Mesopotamians and Egyptians to create new ideas about nature.

Despite their differences, Egypt and Mesopotamia both had growing populations. So each needed to improve its farming methods to produce an ever-increasing supply of food. Farmers needed to measure their fields accurately; select the best land for growing crops; plan the planting, growing, and harvesting of each year's crops; measure and store their crops so they would know how much of it could be sold or eaten and how much to save for planting next year's crop; select the best seeds for re-planting; and know when to plant them the following year. From the beginning in Mesopotamia and later in Egypt, farmers also needed to design, build, maintain and clean irrigation systems.

These tasks required knowledge about animals (zoology); plants (botany); soil (geology and agronomy); surface water drainage and flood patterns (hydrology); weather (meteorology); surveying (geometry); and the stars, planets, sun, and moon (astronomy). In time, Mesopotamians and Egyptians learned their problems were easier to solve if they created new ideas about numbers and arithmetic, as well as other mathematical concepts that were formalized by later civilizations as geometry, algebra, and trigonometry. Thus, ***mathematics became an important tool in maintaining "civilized" life.***

As Mesopotamians and Egyptians built palaces, monuments, temples, walls, storage barns, and pyramids, they needed to learn how to design and build these structures (architecture) and how best to use materials such as stone and wood, which also made it necessary to learn where to find the best stone, how to get it out of the ground, cut it, move it to a building site, and how to fit the pieces together to make the most useful and long-lasting buildings. Each of these steps required specific inventions and discoveries in transportation, geology, mining, surveying, engineering, geometry, and construction.

People also needed to learn about the human body (anatomy) to better deal with diseases and injuries (medicine) ***and*** to plan the sewage systems needed when a large number of people live in a small area. And lastly, they needed new tools and weapons, which required new knowledge about metals (metalurgy) and a range of other materials, as well as manufacturing methods for turning raw materials into finished products. In fact, some archeologists credit the emergence of civilizations in Mesopotamia, Egypt, Iran, Pakistan, Crete and China---and of other civilizations not mentioned here---to the discovery of how to make and use ***bronze***, and the later renewed energy of these civilizations and the birth of entirely new ones after 1,500 BC to new technologies tied to the use of ***iron***.

Trading with other cities by sea, sometimes over 1,000 miles away, required knowledge about navigation, boat design and construction, weather and wind patterns, and "reading" the stars; while trading by land required knowledge about road-building, the use of pack animals, and vehicle construction. Moreover, trade by either means required knowledge about the location of coasts, cities, mountain ranges, and rivers (geography), as well as how to represent those features on maps (cartography).

Running governments, collecting taxes, raising and maintaining armies, and organizing religion all required other kinds of new knowledge and mathematical skills. In fact, performing magic that would impress the average person, if not the gods, depended on priests having ***secret knowledge*** about the properties of natural substances (chemistry), while the timing of religious ceremonies became as important a reason as farming for studying ***astronomy*** and making accurate ***calendars***.

As far as we know, the first calendars in all civilizations were based on the cycles of the moon, perhaps because changes in its shape are easy to see with "the naked eye." In fact, all early calendar-makers seem to have noticed that the moon becomes full about every 29½ days, a unit called a lunar month, and that annual events, such as the beginning of Spring, repeat themselves after approximately 12 lunar months. Thus, the first definition of ***a year*** was the time needed for a full cycle of the seasons, as ***measured by 12 lunar months***.

The invention of the lunar calendar was an important and remarkable achievement. However, early lunar calendars had a major flaw. Since a year is really equal to the time it takes the Earth to go around the Sun, which is approximately 365¼ days, and a lunar year of 12 months only has 354 days (12 x 29½ = 354), a lunar year is roughly 11¼ days too short. Thus, it was difficult to use a lunar calendar to ***predict*** the onset of the flood season, or to decide when to plant or harvest crops. In fact, if a farmer planted on the same date on next year's calendar as he did on this year's, he would do so roughly 11 days "too early."

There were two ways lunar calendar-makers could solve this problem. First, they could add a regular month every few years. Or second, they could add an extra short month each year. Both ways of "fixing" lunar calendars were used at different times by different cultures. Sumerian and Egyptian priests apparently preferred adding a short thirteenth month each year, and then designating it as a special religious "season," an idea that lives on in spirit in modern religious practices, like Islam's Ramadan or Christianity's Lent.

Once this adjustment was made, Egyptians became very good at matching their calendar to the seasons. Thus, sometime around 4,000 BC during Egypt's Nubian period, they arrived at a lunar calendar with a short thirteenth month and a year-length of 365 days. Sumerians, and later Babylonians, made similar adjustments, although their calendars apparently never achieved the consistent accuracy of the Egyptians'. (NOTE: Adding an extra month may seem like an arbitrary way to fix a calendar. But it is not much different from the adjustments we make to our calendar. Every four years, we add a Leap Year Day, although we skip this practice every year divisible by 100, except those that are also divisible by 400. There are also times we adjust our calendar by a single second. Without all this "fine-tuning," our calendar would drift too, if more slowly than ancient lunar ones.)

Sumerian Cosmology: The Birth of Science

Mesopotamian ***cosmology*** was based on ***two separate ways of thinking about nature***. The Sumerian religion described the Universe as a giant room in which the sky (with its heavenly bodies) is the ceiling, the Earth is the floor, the Earth-floor is surrounded by a water-filled moat, to the outside of the moat are giant mountains that hold up the sky, and at the center of the Earth-floor are mountains whose melting snows form the headwaters of the Tigris and Euphrates Rivers, thereby acting as the source of all life in the world.

Clearly this picture of the Universe had little to do with observing the Earth or the heavenly bodies. However, Mesopotamians also developed a second picture of the Universe that reflected their ***astronomy*** observations.

The origin of Sumeria's astronomy-based picture remains one of the great mysteries of science history. However, we know that long before the rise of Babylon in 1800 BC, astronomy had already become an important activity in Mesopotamian society, probably because it helped priests: 1) solve practical problems like making better calendars and providing merchants and travellers with better navigational tools, 2) satisfy their ***intellectual curiosity*** about the heavenly bodies and how best to describe or measure their movements, and 3) justify an Animistic belief system called ***astrology*** that was based on the assumption that the alignment of heavenly bodies at key moments in a person's life affect that person's personality and luck. In fact, the Babylonians believed the military, political, and civic well-being of their city, kingdom, or empire depended on astrological signs and patterns that ***caused*** good or bad fortune.

Sumerian and Semitic priests created complex astrological charts (***horoscopes***) that predicted the outcome of royal decisions and actions, which made astronomical and astrological knowledge powerful tools in the maintenance of Babylon's social, religious, and political systems. Moreover, since priests were the only people who had the astronomical knowledge needed to make horoscopes, astrology also legitimized the power and position of priests within Babylonian society. (NOTE: Babylonians were the first to develop a system of astrological "knowledge," at least in the West. But they were not the last. As we will see in Chapter 11, all civilizations, including our own, have retained some belief in astrology. In particular, for over 3,000 years, the Chinese shared the Babylonian belief that horoscopes could be used to predict the success or failure of all political and military decisions, as well as private ones.)

In a concept related to astrology, Mesopotamian priests pictured the clusters of stars they observed as representing mythological characters, some of whom were designated as the

figures of the Zodiac. However, since these figures involved shapes such as circles, triangles, and quadrilaterals that arose in relation to more earth-bound concerns, even this Animistic imagery helped Babylonian priests come to understand that the ***mathematics*** developed for astronomy—or astrology could also be applied to practical problems on Earth. And vice versa.

A brief aside about Mesopotamian mathematics is in order here. The Sumerian number system was based on 60. This may explain why their astrologers divided the sky into six "houses," each of which could be divided into 60 parts, giving (in modern terms) a total of 360 "degrees" for the entire sweep of the sky. Seeking greater precision in their observations, Chaldean astronomers next divided each degree in the sky into 60 parts, forming a fine imaginary grid of 21,600 (360 x 60) radial units, like the modern concept of angular minutes on a circle. On the other hand, having invented the wheel, early Sumerians may simply have come to see the year as a wheel (or, circle) of time. In that case, 360 may have been their first crude estimate of the number of days that make up that wheel. In any case, modern ways of measuring time and describing the geometry of a circle are clearly based on Mesopotamian ideas, although it is interesting to note in this context that the Chinese, who used a base-10 number system, arrived at a similar astrological division of the sky into 6 and then 12 houses and the division of a circle into 360 units, facts that implicitly support the "wheel of time" explanation for the Mesopotamian creation of similar ideas.

Whatever its origins, the Babylonian superimposition of an imaginary grid on a circular sky gave their measurements of the positions of heavenly bodies and their descriptions of objects, lines, or points in the sky much greater accuracy. Babylonians used similar concepts to design their wheeled implements and vehicles, and to invent the ***cardinal points*** of the compass (north, south, east and west) that they added to their maps. Moreover, it is impossible for us to know whether these ***truly seminal concepts of imaginary grids and the presence of geometric relationships in the "everyday" world*** were first invented in relation to the calendar, heavens, geography, or the wheel. Nor, in the end, does it matter. For, these mathematical concepts proved useful in relation to all the problems that arose in the course of Babylonia's practical pursuits.

In any case, the above-mentioned mathematical tools made it possible for Mesopotamian priests to make accurate measurements of the motions of the heavenly bodies across the sky in a day, month, season, or year. By 900 BC, these observations had been recorded and saved for at least 2,500 years, which allowed

Chaldean astronomers to produce impressive descriptions of the cycles involved in the motions of the planets and stars, and remarkable predictions of "unusual" heavenly events, such as the re-appearance of comets or the exact times of lunar and solar eclipses. (NOTE: As we will see in Chapter 11, China later surpassed Babylonian and all Western accomplishments in this regard. But China's impressive record of observations and predictions is less ancient than Mesopotamia's or Egypt's.)

Perhaps most importantly, in one of the great intellectual achievements of world history, the Babylonians' noticed that their vast catalogue of astronomical observations suggested there were different ***kinds of orbits*** exhibited by different types of heavenly objects. Moreover, this insight led Babylonian priests to sub-divide the heavenly objects they studied into ***categories***. First, there were "unusual" objects or events like comets, shooting stars, novas (suddenly brighter stars), and eclipses. And second, there were "ordinary" objects, which could be divided into four sub-categories: 1) stars, which move in clusters across the sky, 2) the sun, 3) the moon, and 4) planets, which wobble individually across the sky.

Just making these distinctions on the basis of "naked-eye" observations was a remarkable accomplishment. But the Babylonians also tried to explain ***why*** the heavenly bodies would fall into these categories by creating a picture of ***how the four sub-categories of ordinary heavenly objects might be arranged.*** According to this picture, the Earth is at the center of the sky, with the planets circling the Earth in an inner sphere, the moon in a second and larger sphere, the sun in a third sphere at a still greater distance, and the stars in a fourth sphere.

Babylonian priests next used this ***Model of the Spheres*** to calculate each sphere's diameter, based on a belief that the ratios of the spheres' diameters should reflect easy-to-use multiplication factors in their base-60 number system. (NOTE: Since 1, 2, 3, 4, 5, 6, 10, 12, 15, 30, and 60 are all factors of 60, the ratios 1 to 60, 2 to 60, 3 to 60, 5 to 60 and so on are all easy to use. In fact, the ease of working with so many fractional ratios is one of the advantages of a base-60 number system.) Babylonian astronomers also argued that all unusual heavenly bodies must be trapped in the inner sphere, a necessary consequence of their belief that the spheres were solid, truly physical, objects, like hollow glass balls. Therefore, to cite one example used by later Greek astronomers who were influenced by this Babylonian notion, since meteors fall to the Earth, they must originate within the inner sphere.

There was, of course, no way for the Babylonians to prove or disprove the Model of the Spheres. It was just one picture of how the heavens ***might*** be organized given how the heavenly objects were observed moving across the sky. But this does not matter.

The Model of the Spheres, along with the observations that supported it, was the first explanation of nature that made no reference to gods or spirits and was based on mathematical reasoning and a belief that natural objects and processes could be described as entirely physical realities.

Babylonian astronomy shares many elements with science. Above all, science is a ***way*** to construct a description of nature that: 1) is usually based on observational data of nature or experimental evidence, 2) develops a way to improve the accuracy of that data, 3) organizes that data into some kind of order (categories), 4) relates one category to another, and, 5) makes a model that tries to explain the meaning of a set of observations and categories, often with mathematics as its language.

The Model of the Spheres meets all these qualifications. Thus, it does not matter that it was "wrong," or that Babylonian observations and measurements were not as accurate as their priests thought they were. Nor that Babylonians believed in the Model of the Spheres while continuing to see celestial objects as Animistic gods in a separate, purely religious, cosmology. Nor finally, that the Babylonians used astronomy to support a belief in astrology. What matters is that the Model of the Spheres was the beginning of an entirely new way of describing the Universe that was based on ***scientific methods and ideas***.

The Egyptian Way

Like Mesopotamians, Egyptians developed new mathematics to describe circles, other geometric figures, and angles. In fact, the Greeks tell us Egyptians were the greatest geometers ("land measurers") of the ancient world. From the excellence of their calendar, we know Egyptians must have observed the heavens, although we do not have a good record of their observations, making it difficult for us to know if they were as numerous or accurate as Babylonian ones. More importantly, Egyptian priests remained convinced astronomy and mathematics should only be used to solve practical problems. As a result, the only Egyptian cosmology was an Animistic one similar to the Mesopotamian one. According to the Egyptian version, the sky was held up by pillars and the back of a god, and Egypt and the Nile (not Mesopotamia) were in the center of a universal Earth-floor. In other words, Egyptian cosmology upheld the Egyptian belief that, while it was possible to observe the heavenly bodies, the "god-objects" in the sky controlled their own positions, movements, and destinies.

While astronomy was important to both Mesopotamians and Egyptians, their priests also studied other aspects of nature.

Egyptians, for example, excelled in agronomy, medicine, surgery, and calendar making, while Babylonians excelled in the writing of numbers and arithmetic. In fact, a comparison of the two civilizations' accomplishments in irrigation, military matters, weapons, tools, building design and construction, farming methods, pottery, mining, government, or legal thought shows that each had strengths and weaknesses.

This illustrates an important point. We must not judge one civilization superior to another simply because it developed "better" ideas in one field of study, even if that field is the subject of our own interest (in this case physical science). In any case, it is worth repeating again that despite the impressive range of knowledge accumulated by Egyptian and Mesopotamian priest-scientists, most of their knowledge was created to solve practical problems. So, neither civilization developed scientific explanations that united observations from several fields of study. In fact, Babylonian astronomy was the one great exception: a body of knowledge that included a natural and abstract theory designed to explain observations of nature.

Summary of Science in Egypt and Mesopotamia

The ancient civilizations in Mesopotamia and Egypt lasted a very long time. This gave both a remarkable opportunity to build on earlier ideas and observations from their own civilizations, and to borrow ideas from other civilizations. But ***time alone does not produce knowledge. It takes a desire to create, save, and pass knowledge down to future generations. And, a desire to use knowledge.*** In the ancient world, these urges were perhaps best illustrated by the library at Ninevah, although there must have been similar collections of papyrus scrolls in the temples in Egypt, if not all in one library. (NOTE: Each clay tablet in Mesopotamia or papyrus roll in Egypt was a separate "book." The book as we know it was not invented until many centuries later.)

Some of the writings in ancient libraries dealt with nature. However, knowledge about nature was never completely separated from religion, because the "scientists" in these civilizations remained priests who had a vested interest in ensuring scientific knowledge supported (or appeared to support) their Animistic religious beliefs. Thus, the gods maintained their hold on nature, while the priests maintained their hold on the gods and knowledge itself.

The high point of Egyptian science was reached between 2,000 and 1,400 BC, while the first period of great Babylonian science occurred between 1,800 and 1,500 BC, as each reached its maturity as a Bronze Age culture. Then, the scientific spirit in these cultures declined. However, by 900 BC, the Fertile Crescent had entered the Iron Age, leading to a re-birth of Babylonian science under the Chaldeans and the birth of several new civilizations around the eastern half of the Mediterranean that later carried on Egypt's and Mesopotamia's scientific traditions.

In the end, the priest-scientists of Mesopotamia and Egypt not only observed nature more intensely, with better mathematics, and over a longer period of time than anyone had before them, ***they also created problem-solving and analytical habits-of-mind that affected all later civilizations*** in "the West," and more recently around the world. Thus, whenever we celebrate our own science and mathematics, we must remember that, at their roots, we owe many of our intellectual traditions to these two great non-European civilizations.

CHAPTER THREE

THE GREEKS AND THE FERTILE LAKE

The Aegean Civilizations

The first Greek civilization arose about 3,500 BC on Crete, an island south of Greece in the Mediterranean Sea. We call this the ***Minoan*** civilization after its most famous king, Minos. Minoan ideas soon spread to Greece's mainland, its surrounding islands, and the coast of Turkey. The culture in mainland Greece is called the ***Mycenaean*** civilization after one of its largest cities. The culture in the surrounding islands is called the ***Cycladic*** civilization. And the culture in western Turkey is called the ***Trojan*** civilization, after the city of Troy, a name that lives on in stories of the war fought between Troy and an alliance of Mycenaean and Cycladic city-states. However, historians often lump all four together and call them the ***Aegean civilization***.

The Aegean civilization flourished from 3,500 to 1,150 BC. Among all early Bronze Age civilizations, it was the only one that did not use irrigation or rely on farming for its economic strength. Instead, it depended on the sea and on trade across the Aegean. As importantly, while the Minoans were ruled as a single kingdom, the others remained collections of city-states that, as in Mesopotamia, often fought each other for territory, political gain, and control over trade.

Around 1,500 BC, the Mycenaean civilization underwent a period of expansion and colony-building in lands that rimmed the Eastern Mediterranean coastline. Then, around 1,300 BC in Greece, the Cyclades, and western Turkey; and around 1,150 BC in Crete; the Aegean civilization collapsed. We do not know why this happened. But natural disasters like fires, undersea earthquakes, and floods; cultural exhaustion; or invasions by "less civilized" peoples are among the possibilities cited by historians. In any case, the period after this collapse is called the ***Greek Dark Ages*** because Greece lost most of the knowledge it had accumulated in the previous 2,000 years and became an illiterate, food producing, village-based society. Nevertheless, some Aegean stories, like that of the Trojan War, became part of an oral tradition that was passed down from generation to generation until a new civilization appeared in Greece.

The Hellenes

Just before 900 BC, a people arrived in Greece from Turkey, European lands north of Greece, or both, and built a new Iron Age civilization, called the ***Hellenic culture***. Like the Mycenaeans, the Hellenes were great traders, sailors, and colonizers. So, between 900 and 338 BC, they built cities in mainland Greece, and many colonies in the Greek islands, Turkey, Italy, Sicily, North Africa, and the northern and eastern shores of the Black Sea.

Hellenic Greek traders and colony-builders spent much of their time competing with Phoenicians. Remarkably, however, this competition brought both civilizations great wealth and power, and pushed both to make important intellectual and technological breakthroughs. Nevertheless, like the earlier Aegean cultures, the Hellenes never were ruled as a single empire. Instead, they remained a loose network of largely independent city-states.

The cities in mainland Greece and its surrounding islands were the main centers of Hellenic culture. So it is not surprising that the largest mainland city, ***Athens***, produced some of Hellenic Greece's most important individuals and ideas, especially in the years between 600 and 350 BC. But people in other parts of the Greek world also made important contributions. Cities in western Turkey, which the Hellenes called ***Ionia***, gave the Greeks the world's first true ***history writing and the first flowering of Greek science***, while colonies in Sicily and southern Italy later played important roles in the development of Hellenic science and mathematics. In fact, as Greek settlers mixed with "locals" in colonial areas, many half-Greek or entirely non-Greek individuals who lived in or near Greek colonies made important contributions to their adopted Hellenic culture. Thus, the glory of Hellenic Greece did not belong to Greece alone. In fact, many historians believe Ionia's remarkable contributions to Hellenic and world culture were the direct result of it being a "melting pot" in which ideas and peoples from many cultures mixed.

During the Hellenic period, whenever Greece and Persia were at war, Ionia became a dangerous place to live. However, in times of peace, Ionian Greeks benefitted from their direct contacts with Phoenician, Egyptian, and Mesopotamian scholars, some of whom moved to Ionia to escape Persian conquests of their own homelands. In other words, Ionia became a valuable "window on the world" for all Hellenes.

The Macedonians

By 400 BC, an area north of Greece in the Balkans, called ***Macedonia***, adopted many Hellenic styles and become a Greek-style kingdom. Then, in ***338 BC***, Macedonia's King Philip conquered Greece before dying later that year. Phillip's successor was his seventeen year old son, Alexander, who moved quickly to expand upon his father's military success. In fact, it soon became clear Alexander's goal was nothing less than conquering the entire "known world." Amazingly, by 323 BC, when Alexander (now called ***Alexander the Great***) died of wounds he received in Afghanistan or perhaps from disease at the still-young age of thirty-three, his armies had conquered all of Greece's Mediterranean colonies, northeast Africa (including Egypt and Libya), the Levant, Turkey, Mesopotamia, Persia, and Afghanistan. Alexander's armies even reached the Indus River in Pakistan, where they discovered the banana and defeated an Indian army shortly before Alexander died.

During his brief reign, Alexander proved he was one of the greatest military strategists and leaders of world history. But he knew it would be harder to rule his large and multi-cultural empire than to conquer it. So Alexander built new cities in the territories he conquered in the hope they would become provincial capitols, permanent military posts for the Greco-Macedonian army, and out-posts of Greek culture that would make local people prefer Greek ways and ideas. Thus, remarkably for his time, Alexander reasoned people who felt "more Greek" would also feel greater allegiance to him and his empire.

But Alexander's death ruined these plans. Within months, his empire broke into three kingdoms: 1) Egypt, 2) western Asia, including Persia and Mesopotamia, and 3) Greece, including its islands and Macedonia. Alexander's policies did, however, succeed in spreading Greek ideas to a much larger area and allowing ideas from Egypt, Mesopotamia, Persia, and India to enter the Greek world. As time passed, much of this intellectual exchange took place in the cities Alexander had built, several of which became major cities in new regional empires. Thus, despite his death, Alexander did, in the end, succeed in creating a new and more cosmopolitan Greek culture, called ***the Hellenistic civilization***.

The Hellenistic World

Upon Alexander's death, one of his generals, ***Ptolemaios I***, made himself pharaoh of Egypt and the king of its surrounding North African provinces. Once he solidified his position as the new pharaoh, Ptolemaios I turned to the task of completing Alexander's Egyptian capitol. When it was finished, Ptolemaios I named ***his*** new capitol ***Alexandria***. But Ptolemaios I and his son, Ptolemaios II, wanted Egypt's Alexandria (there were over 30 other cities named Alexandria in the territories Alexander had conquered) to be more than a capitol for their kingdom. They wanted it to be a leading center of Greek culture. So they established ***a school, library, and museum in Alexandria***, and invited leading thinkers from all over the Greek world to join its faculty. (NOTE: A Greek museum was similar to a science building at a modern university, with laboratories and rooms to display materials from nature.)

Amazingly, Greek civilization did not decline after Greece was conquered by the Macedonians, or even after the break-up of Alexander's empire. Instead, Hellenistic cities and towns around the Mediterranean experienced a rebirth of economic and intellectual activity. As Ptolemaios I had hoped, Alexandria played a leading role in this renaissance and became one of the most multi-cultural and inter-racial cities in human history. In fact, traders from the rest of Egypt, Libya, Kush and areas south and west of it (perhaps including Africa's sub-Saharan heartland), the Arabian Peninsula, Syria, Persia, Greece, Italy, Israel, and Lebanon visited Alexandria regularly and did business there, while others came to live there year-round.

In an echo of Ionia's earlier role as a "frontier" melting-pot, Alexandria's economic vitality helped the school started by Ptolemaios I and II attract many teachers and students who became famous throughout the Greek world. Meanwhile, Alexandria's library became the largest the world had ever seen, further increasing Alexandria's new role as the most important center of Greek mathematics and science. In fact, in time, Alexandria came to symbolize the spirit of the entire Hellenistic culture, whose wealth and influence came from the trade its city-states and kingdoms controlled, the diversity and inclusiveness of its population, the range of ideas created by its thinkers, and its ability to raise well-trained and outfitted armies and navies to protect Hellenistic colonies and trade routes.

The Romans

In each of its stages, Greek civilization stimulated other peoples around the Mediterranean. But there was no time when the Greeks the only power in this area. The Hellenes had to defend their territories and trade networks against Assyria, Persia, and Phoenicia, while the Hellenistic Greeks had to contend with the Persians and then several Italian powers. The first of these was the Etruscans. But by 500 BC, Etruscan power waned, creating a vacuum in which other central Italian powers emerged, just as the Greek colonies in Sicily and southern Italy were reaching their height as centers of Greek thought and trade in the western Mediterranean. As the power-struggles among Italian tribes intensified, the Greeks alternately sided with one then another, in the hope this would keep all Italian tribes from becoming too powerful.

The Greek position in Italy-Sicily was further complicated by its competition with ***Carthage***, an independent North African city in modern-day Tunisia that had been founded as a joint Greek and Phoenician colony in the early Hellenic period. However, by 300 BC, Carthage had built its own colonies around the western Mediterranean, become a naval and economic threat to Greek interests, and created a second military front that made it difficult for Greek strategists and colonists in the western Mediterranean to focus their energy and resources on Italy alone.

Despite this chaotic situation, by 250 BC, one Italian tribe, ***the Latins***, defeated all their traditional Italian enemies and several tribes that had recently migrated into northern Italy, including the Celts. The Latins next built a new capitol city called ***Rome*** on the Tiber River site of a major Etruscan town. In the next 50 years, the Romans, as they came to be called, established a kingdom that ruled all of Italy, except for the southern areas controlled by Greeks, and began launching attacks against Greece's Italian colonies and the Greek navies sent to protect them, and, separately, against Carthage. While the Greeks held their own in many of the fixed battles they fought against Rome during this period, Greek resources were stretched to their limits and the tide of battle eventually turned against them.

By 200 BC, Rome defeated Carthage, gained control over Greece's Italian colonies, and began attacking more distant Greek centers. As these attacks continued, Greek trade was disrupted, the economies of Hellenistic cities declined, and Greek power crumbled. In 30 BC, Rome completed this initial phase of Imperial expansion by making Greece, Ionia, the Levant, and Egypt (where they discovered the joy of eating chicken) Roman provinces. But Rome did not stop there. In the following years, Roman armies defeated the Sassanid Empire (a renewed Persian empire that had been founded by another of Alexander's generals) and marched to the banks of the Indus River. Meanwhile, Roman armies conquered much of Western Europe, including Spain, Portugal, France, southern Germany, Austria, Switzerland, Belgium, and southern England, lands that had never before been part of ***any*** western Asian or Mediterranian empire. In fact, at its height around AD 200, Rome controlled the largest empire that Europe, Africa, or western Asia had ever seen, and one that would not be equalled again until the Mongols conquered most of Eurasia in the 1200's.

Roman ideas about military tactics, organization, and weaponry revolutionized warfare in the West, while its remarkable ideas on law-making and governmental structure allowed Rome to rule its large empire for almost 500 years. As a result, and with some justification, at least in matters of government and war, the Romans felt superior to all peoples they met and conquered. But in philosophy and science, with the exception of medicine, Romans depended on Greek ideas, even merging their own religious and mythological stories with Greek ones. In fact, the Romans respected Greek learning so much many wealthy Roman families owned well-educated Greek slaves who gave their children classical Greek educations. Meanwhile, Roman scholars produced exhaustive analyses and commentaries on Greek works, as if they were part of their own ancient heritage.

While centers of Hellenistic learning such as Alexandria initially declined after being conquered by Rome, they quickly regained their vitality. In fact, Athens remained a center of neo-Hellenic thought and Alexandria continued to be the most important center of Hellenistic science and mathematics. Moreover, many of Rome's greatest thinkers came from "the Greek provinces." In a sense, then, the intellectual and spiritual centers of the Roman Empire became Rome, Athens, Alexandria, and to some extent Israel (where the Jewish melting-pot under Roman rule gave birth to Christianity).

The Germanic Tribes and the Roman World

As Rome was conquering Western Europe, several nomadic tribes were arriving in Europe from central Asia, and then sweeping westward across northern Europe. These ***Germanic tribes***, as they were called, were illiterate "horse cultures" led by warrior-kings. In fact, their warriors were fierce and brave fighters who thought of suicidal attacks, burning towns to the ground, or killing all their inhabitants as "normal" military tactics. To the Romans, this made the Germans (including the Franks, Angles, Saxons, Lombards, Vandals, Goths, Visigoths and Ostrogoths) ***barbarians***, a term that came from the name of a North African nomadic tribe the Romans also fought, lacking in all the refinements civilization brought.

Germanic tribes launched an almost endless string of attacks on Roman frontier towns and military outposts. In a strange parallel to the earlier military encounters between the Romans and Hellenistic Greeks, Rome won most of its pitched battles against Germanic forces. But the economy of the Empire's northern provinces began to collapse. Thus, by AD 300, Germanic tribes had seriously disrupted the western European part of the Roman Empire and begun claiming parts of it as their own. In fact, by then, it was clear Rome itself might soon fall to a Germanic warrior-king. As a result, in ***332, Emperor Constantine*** moved his capitol from Rome to a small town on the border of Greece and Turkey, far away from Germanic attacks. Renamed ***Constantinople*** ("the city of Constantine"), this new capitol quickly grew into a great city. (NOTE: Constantinople was later re-named Byzantium. So, the later eastern Roman Empire came to be called the Byzantine Empire. During this period, Byzantium became one of the largest, richest, and most influential cities in the world. Still later, under the Ottoman Turks, Byzantium became Istanbul, an important center of Moslem culture. Today Istanbul is a major city in Turkey.)

The Roman Empire was saved. But Constantine was still unable to defend his western provinces against Germanic attacks. Nor did Constantine's decision ensure the unity of what was left of Rome's glory. In fact, when Constantine died in 337, his two sons split the Empire, with one ruling an Eastern Empire from Constantinople and the other ruling a skeletal (and at times theoretical) Western Empire centered in Rome.

Despite this new arrangement, Germanic attacks continued, until Rome was partly destroyed (or, ***sacked***) in ***AD 476***. In the following years, several Germanic warrior-kings called themselves "King of Rome" or "Western Roman Emperor." But in reality, there was no longer a Western Empire to rule. Thus, despite the survival of the Byzantine Empire for another 1,000 years and the feeling of many Western Europeans that they were still Roman citizens, many historians use 476 to mark the Fall of the Roman Empire in Western Europe. After all, by then, Byzantium's focus had shifted to southeastern Europe and western Asia, while its bureaucrats were beginning to use Greek instead of Latin as their official language, a clear indication of its transformation into an Southeastern European power.

Nevertheless, Byzantine emperors continued to believe they were the "rightful" rulers of the entire Roman Empire. The most successful attempt to re-establish this claim was launched ***between 527 and 565*** by ***Emperor Justinian***, whose armies drove the Ostrogoths and Lombards out of Italy and the Vandals (the root of our word "vandalism") out of North Africa. As these campaigns continued, many Europeans hoped Justinian might re-claim all the territory and glory that had been Rome's before Constantine. But Justinian never recovered northern France, southern Germany, or England. Nor could later Byzantine emperors hold the territories he won back. Thus, by 600, only a small piece of Italy remained under Byzantine control in all of Western Europe.

The Rise of Christianity

By 300, the Roman Empire was home to many religions. Some people worshipped the Greek gods, or Roman gods modelled on them, while others believed in Judaism, the ancient Egyptian religion, animistic Mesopotamian ones, other local ones in other provinces, and Christianity. Consequently, the first peoples to convert to Christianity included Jews, Greeks, Syrians, and Roman soldiers. Or, that many local Christian communities sprung up within the Roman Empire, each with its own beliefs and practices.

Religious disagreements among early Christian communities (***sects***) focused on such basic questions as the essential physical and spiritual character of Christ, His teachings, and the proper ceremonies to follow to be a good Christian. However, these disagreements did not slow the acceptance of Christianity within the Roman Empire. In fact, in ***323***, just before moving his capitol to Constantinople, ***Constantine converted to Christianity***. (NOTE: Given the many examples throughout history of rulers building new capitols when they introduced major reforms, it is possible Constantine's reason for moving his capitol was to take control away from those in Rome who would have resisted the use of Christianity as the Empire's official religion.)

Constantine's personal conversion made Christianity the official religion of the Empire, thereby ensuring its growth and importance as a major Western religion. But his decision also forced all future Roman emperors and their advisors to decide which ideas should be accepted as the official version of

Christianity. After all, the power and prestige of the Empire rested on *its* version being accepted as the only true one, at least within the Empire.

The almost continuous use of Christianity as an Imperial religion after 323 greatly increased its influence, even in areas far from Constantinople. In fact, by 500, Christianity was the dominant religion in the parts of Europe that had been Roman provinces, and a major religious force in western Asia, Egypt, and other parts of North Africa. By 600, it also became the official religion of an Ethiopian kingdom in East Africa, called Axxum. It was only later that Christianity came to be considered a purely European religion.

Christianity's hold on Western Europe and North Africa were greatly enhanced in the 500's when Justinian, a devout Christian, built monasteries, forts, towns, and churches in the territories his armies conquered. Long after Justinian's armies retreated and those territories were lost to new "barbarian" rulers, those structures remained to become important centers of Christianity.

Given the diversity of early Christianity, whenever important religious disputes arose, special meetings of the bishops from the towns with the largest numbers of Christians were called. However, the Bishops of Jerusalem, Constantinople, and Rome (each of whom claimed special status as "heirs" of the Apostles and the earliest Christian leaders) soon came to see it as their right and responsibility to lead these meetings. (NOTE: See Chapter 6 for more on the development of Christianity.)

Thus, while Christianity remained far from unified in this period, religious authority became more centralized, which increased the feeling among members of some sects that they were no longer welcome in the Roman Empire. At the same time, Church and Imperial leaders became less tolerant of non-Christian ideas and institutions, including the Greek schools in Alexandria and Athens. Thus, ***the library, school, and museum at Alexandria were attacked by a mob of Egyptian Christians*** and then later, in 640, ***by Moslem invaders***. Undoubtedly, the destruction of Alexandria's library cost the world many unique records of Hellenic and Hellenistic learning, as well as many irreplacable Greek writings on earlier intellectual accomplishments of Egypt, Mesopotamia, and other civilizations, like the Hittites and Phoenicians.

In any case, the last Hellenic school in Athens, which had been founded in 388 BC by Plato, whom we will meet shortly, was closed by Justinian in ***529***. Consequently, historians sometimes use this date to mark the end of classical Greek culture, its 1,500 years of learning, and its 1,100 years of science.

Summary

Greek civilization spanned 4,000 years, and included four stages: 1) the Aegean period from 3,500 to 1,350 BC, 2) the Greek Dark Ages from 1,350 to 900 BC, 3) the Hellenic period from 900 to 338 BC, and 4) the Hellenistic period from 338 BC to 529.

According to this way of dividing Greek history, the conquests of Alexander the Great mark the division between the Hellenic and Hellenistic periods, as well as the bringing of Greek civilization into more direct contact with other Asian and African civilizations that gave the Hellenistic culture much of its character. Meanwhile, the Romans are treated as part of the Hellenistic Greek age. While the latter may seem strange, in physical science Hellenistic Greek ideas continued to dominate the Mediterranean world throughout the Roman period, and their influence outlasted the Western Roman Empire by 50 years. In any case, as we will soon see, including Rome in the Hellenistic period, and therefore Roman history in a chapter on Greek civilization, will prove useful as we turn our attention to the subject of Greek science.

CHAPTER FOUR

GREEK NATURAL PHILOSOPHY: COMPLEX REALITIES, SIMPLE BEAUTIES

We call the wonderful stories about ancient Greek gods and heroes Greek mythology. Modern people are fascinated by these stories because they contain wonderful descriptions of human behavior, relationships, and moral dilemmas. But they were not mythology to the Greeks. These stories were part of an Animistic religion that originated in the Aegean cultures as a way to explain natural occurances and human behavior, and then were passed down by word-of-mouth to the Hellenes, who added to them and then wrote them down. As a result, it is the Hellenic version of Greek mythology that has come down to us.

When examining Greek science, it is tempting to think they replaced Animism with a scientific way of thinking. This is not true. The Greeks took their gods seriously, and many Greeks and Romans continued to believe in versions of them until the end of the Hellenistic period. Thus, like the Babylonians, the Greeks saw the world in two ways: as a natural place that could be understood and explained by observation and human thought, and as a magical and tragic place in which Animistic gods decided what happened and why it happened. However, unlike all earlier peoples, including the Babylonians, the Greeks looked for natural explanations that could be applied to many aspects of nature.

The Greeks began their quest for these rational explanations of nature by borrowing arithmetic, geometry, and concepts for measuring time and space from the Egyptians and Babylonians. Then they improved these mathematical ideas, created some of their own (especially in geometry), and developed an original style of reasoning that became one of the founding hallmarks of Western civilization. And finally, they utilized ***all*** these tools to reach entirely new and startling scientific conclusions. (NOTE: The Greeks did not use the words science and scientist. Instead, they called the study and creation of ideas philosophy. So the study of nature, by whatever means, was called natural philosophy. We, however, will use the modern words science and scientist.)

During the Hellenic and Hellenistic periods of Greek history, philosophers studied mathematics, physics, astronomy, chemistry, biology, geography, geology, metallurgy, and medicine. In fact, one measure of the vigor of the Greek scientific tradition is that a complete description of it would fill many books. So, we will limit ourselves here to an examination of the Greek ideas that contributed most to the eventual development of modern physics. Even within this limitation, however, it would be impossible to cover all Greek ideas or thinkers. There were simply too many who studied these questions, and too many ideas they considered. Moreover, the Greeks, alone at that point in world history, allowed different ideas about nature to compete with each other, which gave Greek scientists the freedom to criticize other Greek thinkers' work. This freedom also made it easier for Greek scientists to build on earlier ideas, suggest new ones, and add to their understanding of nature.

The Ionian Period

The birth of the Hellenic culture in 900 BC was marked by an explosion of activity in art, literature, and other intellectual pursuits. Much of this work was begun in Greece. But many Greek ideas were invented in Hellenized communities in Ionia. By 600 BC, the largest Greek "city" in Ionia was ***Miletos***, with a population of about 10,000 free males.

In ***624 BC***, a man named ***Thales*** was born in Miletos. We know very little about his early life, although it appears his parents were Phoenicians. We do not even have copies of his writings. So we must rely on descriptions of his ideas written by others, in some cases centuries after his death. According to these descriptions, ***Thales was Greece's first great mathematician and scientist*** as well as a philosopher, engineer, businessman, and statesman. In recognition of his remarkable talents and his great contribution to Greek civilization, later Greeks considered Thales one of the seven wise men of Greece and, most tellingly, the only one who was not a political leader.

Greek accounts state Thales learned geometry from Egyptian priests, either in Egypt or Ionia. While it is impossible for modern historians to prove or disprove this story, it appears Thales introduced geometry to the Greeks and was the first to use it as a scientific tool. In any case, after inventing several new geometry propositions that described circles, triangles, angles, and intersecting lines, Thales turned to physical science by asking why there seem to be so many different "things" in nature, like rocks, soil, water, air, living things, fire, and so on. Then he asked if everything in nature might be made out of the same ***basic element***, a universal building-block that could change form. Finally, Thales answered this question by stating there must be a basic element, and it is ***water***.

Thale's work raises one of the most puzzling and important questions in science history: why did he assume there must be a basic element? We will probably never know. But Thales seems to have believed ***it made sense for the world to be simpler than it appears***. This was a belief he and later Greek thinkers could not prove and felt no need to prove (in mathematics, this would be called an axiom). However, once this belief was embraced, it was a short but incredibly important jump to the idea that the complexity of nature might be explained by the presence and behavior of a single basic element *or* a set of basic principles (laws) of nature.

But why would the basic element be water? Thales observed that water can change into several physical states (ice, snow, liquid water, mist, and vapor), and that earthquakes result from an "event" that occurs under the surface of the Earth. Therefore, Thales argued, the Earth must be a flat disk of land floating on a larger disk of water, while earthquakes must be caused by the pressure of water pushing up on weak spots in the land.

While we have been unable to trace Thales' idea of a basic element to any earlier influences, his "map" of the Earth clearly owes much to the Babylonian picture of the Earth as a disk of land surrounded by water. But this should not surprise us. After all, Thales proposed his ideas less than 200 years after the end of the Chaldean period of Babylonian history, at a time when Mesopotamian scholars were still active. In any case, as an Ionian, Thales was probably as aware of Babylonian ideas about nature as he was of Egyptian mathematics.

It is therefore only fair to ask how Thales' ideas differed from earlier ones. First, Thales attempted to explain a wider range of facts with natural ideas. Second, while Babylon's Model of the Spheres was the first theory of nature that did not depend on gods or spirits, Thales tried to tie several ideas about nature together to form a single theory. Third, Thales based his theories on observations of such phenomena as earthquakes, exactly the kind of unpredictable natural events Animism (and the Babylonian, Egyptian, and Greek religions in particular) had been created to explain. Fourth, while we cannot be sure Thales was the first such Greek, he was ***an independent "professional" philosopher and teacher, not a priest***.

Fifth, as Babylonian astrology demonstrates, Babylonian astronomy did not alter the Mesopotamian habit of relying on animistic explanations of nature. Thales, on the other hand, marks the beginning of a separate scientific culture that competed with mythological explanations of nature within Greek society, and then throughout the history of Western civilization. And lastly, Thales used the mathematics available to him in a very precise way to describe his ideas, especially as they applied to his model of the Earth as a flat disk of land.

Of course, it is possible Thales got this last idea from the way Babylonian astronomers described their Model of the Spheres or other, now lost, mathematical analyses of the Babylonian disk-model of the Earth. But in Greek hands, this way of thinking ignited a great scientific revolution in which ***all pictures of nature included mathematical thinking***. The influence of this idea on later Western civilization alone makes Thales one of the most important people in history. (NOTE: Thales was also the first person we know of in world history who was a mathematician, scientist, engineer, and businessman. As such, through the Greeks he became the model for the Western "renaissance" hero, as later exemplified by such figures as Aristotle, Archimedes, Leonardo daVinci, Galileo, Descartes, Voltaire, Franklin, and Jefferson.)

The next important Greek scientist was ***Anaximandros***, who was born in Miletos in 610 BC. Like Thales, Anaximandros did original work in geometry. He was also the first person we know of who tried to make maps of the world based on real geographical information, as learned from travellers. But it is his work in the physical sciences that concerns us here. In that realm, Anaximandros constructed a primitive sundial to more accurately measure time, a key variable in later scientific experiments and theories, and speculated that the Universe is filled with a ***continuous medium*** that began as a soup-like mixture of liquids. However, with the passage of time, the heavier "bits" in this soup fell to the center of the Universe forming the Earth, while the lighter bits, air and fire, were thrown to the outside of the Universe, forming the spheres that hold the moon, sun, planets, and stars. Thus, these bodies are made of progressively lighter bits of the original soup. Finally, while the Earth sits still at the center of the Universe, the spheres spin. This is why we observe the heavenly bodies moving across the sky.

Clearly, Anaximandros owed much to the Babylonian Model of the Spheres. But he went further than Babylonian thinkers by offering an explanation of ***why*** the heavenly bodies move, and why the Universe is organized into separate spheres. According to Anaximandros, the heavier an object, the closer it is to the Earth. The lighter an object is, the further it (and its sphere) is from the Earth. In fact, Anaximandros based this reasoning on observations he made of nature on Earth. As Anaximandros put it, the materials of the Earth are heavy, air is light, and fire rises in the air. So, fire must be lighter than air, and air must be lighter than the materials that make up the Earth.

In other words, Anaximandros based his model on observations that "proved" its correctness. Anaximandros' ideas also implied the Universe had changed from an evenly mixed soup to the form he saw in his day. Or, to put this idea in modern terms, there are processes at work in the Universe, an idea Anaximandros extended to all animate and inanimate objects, which he said experience three (3) stages of existence: ***coming into being, existing and passing away***. Therefore, processes are part of what a scientist should study and describe, an idea crucial to later Greek and Western scientists, who often looked for descriptions of nature that focused almost entirely on such processes.

After Anaximandros, a student of his named ***Anaximenes*** returned to Thales' question about a basic element and reasoned, since nature includes wet, dry, cold, and hot things, the basic element must be something that is neither wet nor dry, cold nor hot. Thus, since air exhibits the properties of wetness, dryness, coldness, and hotness under different conditions, the basic element must be air, not water. In other words, to Anaximenes, it was more logical for air to be the basic element, reasoning that suggests Ionian thinkers already believed logic offered as important a proof of an idea about nature as observations.

More fundamentally, Anaximenes' said air is made up of small particles that can be pushed together or apart ("***condensed***" or "***rarified***"). When condensed, air particles form clouds. When more condensed, they form water. And when maximally condensed, they form solids, such as the materials that make up the Earth and all living things. However, when air is rarified, its particles form fire, which makes up the moon, sun, planets, and stars. Thus, just as Anaximandros' concept of heaviness and lightness (or, density) explained the separation of objects in space, the concepts of condensation and rarification explained why objects have different densities, as well as how air is transformed into fire, water, and earth, the four basic elements to later Greeks. In that sense, Anaximenes' ideas described a more basic process that could be used to explain Thales' and Anaximandros' ideas.

However, Anaximenes' picture of the Universe did not explain what ***forces*** cause change in the Universe. Thirty years later, ***Hericlotis***, a scientist from Ephesus, a city 30 miles north of Miletos, decided the Universe is balanced between opposite forces and is in constant tension (in modern terms, a state of dynamic equilibrium). Furthermore, since he observed fire changing wood into smoke and ashes, Hericlotis concluded ***fire*** must be the agent, or ***catalyst***, of all tension in the Universe.

Despite their differences about fire, both Anaximenes' and Hericlotis' ideas about change implied the Universe we see is different from the Universe that existed in the past or that may exist in the future. Thus, the observations we make depend on when we are doing the observing, a fact that sets limits on any description of nature that is solely based on observations. Therefore, if we want to understand nature, we must also use other "tools." By Hericlotis' time, it was apparent the key such tool for Greeks would be ***abstract thought***, including logic, mathematics, rhetoric, and the human imagination.

This is a very strange, subtle, and powerful idea. As we will see, the dilemma about change in the Universe and the usefulness of observations and abstract thought led to many arguments among later Greek philosophers. In fact, it is possible to argue these arguments have remained at the center of all debates about scientific methods and truth throughout the entire history of Western science.

These four scientists, Thales, Anaximandros, Anaximenes, and Hericlotis, were not the only early Ionian scientists. However, they made the largest contributions to the founding of a robust Greek scientific tradition based on the idea that ***one of the purposes of science is to examine, modify, and improve earlier scientific ideas***. These scientists also used mathematics in a new and more far-reaching way that made it a necessary part of any scientific description and, therefore, of every scientist's training. As Greek science developed in the following centuries, this Ionian use of mathematics made scientific ideas less vague, advances in mathematics useful to scientists, and shaped the kind of models scientists made or were willing to seriously consider.

The Greek version of the Model of the Spheres can be used to illustrate this last point. Since Greek astronomers had no way to observe the "actual" path of heavenly bodies, they used their knowledge of the geometry of circles, the observation that the heavenly objects seem to move across the sky in curving arcs, and their affinity for simple shapes and arithmetic to construct a model of those motions as circular. In other words, Greek astronomers imagined the paths of the heavenly bodies in terms of the mathematics they knew and liked.

Thus, Greek scientists saw observations that helped make a mathematical model, or that fit the mathematics used in a model, as more useful than observations that led to descriptive models. Amazingly, this ***connection among mathematics, model-making, and observation***, which we owe to Thales and a handful of other Ionian scientists who did their work between 600 and 500 BC, became one of the core beliefs of Western science.

The Spread of Ionian Science

If Greek science had remained a purely Ionian fascination, it would not have grown into such a rich mixture of ideas or had such a large effect on future scientific thought. But the dangers of living in Ionia, as well as the attractions of mainland Greece and other Greek colonies, led many Ionian scientists to emigrate, carrying Ionian science to the rest of the Hellenic world.

One of these scientists was ***Pythagoras***, who was born in 560 BC on Samos, an island 30 miles northwest of Miletos. Later Greek historians claimed Pythagoras spent 20 years in Babylonia and Egypt as a young man, and that he learned many of his ideas from Babylonians as they were being conquered by Persia, before returning to Ionia to do his own work as a mathematician and scientist. As with Thales, it is impossible for modern historians to verify these stories. But it is interesting that Pythagoras is best remembered today for the Pythagorian Theorem, a formula that describes the relationship among the sides of a right triangle, even though Babylonian mathematicians had described this theorem in less abstract terms over 1,000 years earlier. (NOTE: The Chinese also discovered a version of the Pythagorian Theorem before 600 BC, and an Indian book written about 400 BC that apparently includes much older Indian mathematical knowledge contains similar ideas.)

However, Pythagoras' fame should not rest solely on the theorem that bears his name. He should be equally famous for his ideas about previously unexamined aspects of the Universe and the way he related his ideas to mathematics. For example, Pythagoras studied trapped columns of air (pipes) and vibrating strings, and the musical notes they make, discovering that when a string or column of air in a pipe is shortened to 1/2 its original length it produces the same note it did originally, albeit one octave higher. Other shortenings, by a series of simple fractions such as 2/3 and 3/4, produce other notes that, when played with the original one, create ***chords*** that are pleasing to the ear. More importantly, the ratios involved in the Pythagorian Theorem and the musical chords he studied convinced Pythagoras there is something magical in the way nature "uses" ***beautifully simple numbers***. Thus, as Pythagoras put it, "all the world is numbers." Or, to put this in modern terms, mathematics is more than a language for describing the Universe. It is the substance of the Universe itself.

Pythagoras merged all of these ideas into a belief system he called ***Orphic Philosophy***, which worshipped numbers and secret knowledge about arithmetic. Despite this emphasis on mysticism, however, Pythagoras said there was no place for gods (even Greek ones) in the Universe. As importantly, at least in the everyday world of Greek society, Pythagoras told his followers to live a communal life that disregarded traditional family relationships and the idea that men are superior to women, truly radical social beliefs that offended many Ionians and led to death threats against Pythagoras. To escape Ionian intolerance and ensure his own safety, Pythagoras and many of his followers moved to a Greek settlement in southern Italy, where they set up an Orphic school.

Once in Italy, Pythagoras and his followers applied their rather exotic mixture of mathematical ideas to an array of scientific subjects. Thus, a follower of Pythagoras used Orphic ideas to explain how a pulley works, while Pythagoras argued the heavenly bodies in his Model of the Spheres must go around in circular orbits because the circle is the simplest geometric shape. Meanwhile, the spheres, which Pythagoras pictured as centered on a ball of fire at the center of the Universe, not the Earth, must have diameters that are simple fractions of each other, because these are beautiful numbers. Moreover, the Earth must be a sphere, because this is the simplest solid form. And lastly, each heavenly body must make a musical note. In fact, the heavenly bodies must produce beautiful chords, or "sing," all because the mathematics Pythagoras used to describe chords was the same mathematics he used to describe the dimensions of the spheres. In other words, mathematical logic ***proves*** the spheres sing. Amazingly, this idea, called the ***Music of the Spheres***, influenced Western thinkers for the next 2,000 years.

Aside from demonstrating the kind of logic, speculation, and imagination used by many later Hellenic thinkers, Orphic reasoning represented a significant departure from the balanced approach used by earlier Ionian scientists. In fact, Pythagoras' thinking greatly inhibited later Greek philosophers, some of whom stopped making observations altogether or severely limited their reliance on observations when constructing models of nature. Remarkably, however, Pythagoras' belief that the laws of nature should always include simple and beautiful mathematics has been a core assumption of Western physics, especially in the last 400 years. Thus, without recognizing its Pythagorean or Ionian roots, modern scientists assume an idea described by beautiful equations is more likely to be true than one represented by ugly ones.

After Pythagoras, two men created a new description of nature that was heavily influenced by Pythagorian logic. ***Zeno*** and Parmenides were friends who were born in Greek colonies in Italy just after 500 BC who believed the Universe is eternal, unlimited (endless), changeless, and motionless, ideas that came to be called ***Stoicism*** after the Greek word for the open marketplace ("stoa") where these ideas were debated. According to the Stoics, it did not matter if observations made it seem the Universe could change. Abstract mathematical proofs showed the Universe, when taken as a whole, does not change. Therefore, the very idea of change in the Universe is illogical.

These ideas completely contradicted the Ionian belief in the equal partnership of observation and abstract thought in creating pictures of nature, as well as the Ionian view of change in the Universe. Nevertheless, Stoicism proved to be very useful to future scientists for two reasons. First, it showed how logic and mathematics could be used (or abused) to produce a theory. And second, it pictured the Universe as ***one*** system, governed by a single set of scientific laws. Eventually, this became one of the most important assumptions of Western science.

Despite the rigid tone of Orphic and Stoic thinkers, the Ionian spirit of inquiry, debate, analysis, and observation was re-kindled by some later Hellenic scientists. For example, ***Empedocles***, who was born in a Greek colony in Sicily in 492 BC, argued light travels at a pre-set speed, taking a specific amount of time to move through space. In fact, human vision depends on light traveling from the object seen to the eye of the viewer.

In an echo of Anaximenes' earlier ideas, Empedocles also argued there are ***four basic elements: air, water, earth, and fire***, which were ***formed by the action of two forces, attraction and repulsion (love and hate), that acted on two pairs of contrasting qualities in nature: hot/cold and dry/wet***. Thus, the four basic elements were formed by a set of ***dynamic interactions between*** two ***forces*** and two ***qualities*** of the Universe. Moreover, according to Empedocles, the Universe began as a perfect mixture of the four basic elements and then changed as they were separated by repulsion, before attraction reasserted itself, causing a partial re-mixing that gave rise to the many substances of our present Universe, a remarkably modern concept of cyclical change and dynamic equilibra in nature. (NOTE: At the same time, Chinese thinkers arrived at a somewhat similar idea about dynamic balance in the Universe and its basic elements, although they settled on five candidates: water, fire, wood, metal, and earth.)

Empedocles' ideas about light were ignored by later Greek scientists, who thought it emanated from the eye toward the object viewed. But his four basic elements became the "standard" Greek explanation of the make-up of the Universe. It did not matter that it remained impossible for Greek scientists to test the existence of the four basic elements, the stages of the Universe, or its unity, the main agreed-upon Greek theories by the time of Empedocles' death. In fact, the acceptance of these ideas by later Greek scientists demonstrates that a scientist could propose a theory without really convincing observational proof, as long as he could cite ***some*** observations that seemed to support his ideas while using logic to construct a simple, elegant, and plausable explanation for a part (or all) of nature.

The last Ionian scientists we will discuss are ***Leucippos*** and his student ***Democritos***. Leucippos was from Miletos, but both taught at Abdera in mainland Greece between 450 and 404 BC, where Democritos was called "the laughing philosopher" because of his humorous teaching. On a serious level, both argued the Universe is made up of tiny bits of material called ***atoms*** and an empty ***void*** (what we call a vacuum). In fact, each substance in nature has its own unique arrangement of atoms and void. If that arrangement of atoms is packed closely together, it forms a solid version of that substance. If a little less so, it forms a soft or spongy solid. If even less so, it forms a liquid. And if very far apart, it forms a gas. But even solids contain voids between their atoms. Thus, all atoms can move and nature can change.

These ideas, called ***Greek Atomism***, went beyond all earlier Greek fundamental ideas to picture how universal entities like atoms or a void could be arranged to create all the substances in nature, including the basic elements, and all the states of each substance. Furthermore, Democritos argued these re-arrangements reflect purely mechanical and pre-determined processes that have nothing to do with gods or even human ideas about beauty or truth. In other words, Atomism was based on the revolutionary idea that: 1) empty space plays a role in the structure of the Universe, 2) structure is crucial to the make-up of the Universe, and 3) ***the Universe lacks moral or esthetic significance***, whatever humans might like to think about it or themselves.

Amazingly, Greek Atomism has many similarities to ideas modern scientists have developed in the last 150 years. But the Greeks could not make observations of the parts or at the scales of nature that could prove the existence of atoms or empty space. In any case, later Greek scientists ignored Democritos' ideas and Atomism was forgotten. Consequently, the scientists who developed the modern atomic theory beginning in the 1800's did not know that anyone had ever proposed such ideas before.

Summary of the Ionian Period

During the Ionian period of science, which lasted from 600 to 400 BC, Hellenic Greeks studied nature in a new way. Put simply, ***nature was made more natural.*** For the first time in history, individuals were also allowed to make their own models of nature and contradict each other. In fact, different models were left to "compete" with each other for acceptance by later Greek scientists. For future scientists, this Ionian spirit of ***scientific inquiry and debate*** turned out to be more important than whether any Greek model later proved to be correct or not.

In most cases, there was no way for Ionian scientists to test their models to decide which were "right" and which "wrong." Even when Ionian scientists could make meaningful observations, they had no agreed-upon method to judge the quality or relevance of those observations to the question being judged. Thus, lacking adequate methods for doing science in "the real world," ***Ionian Greeks made the human mind the laboratory of science.*** Today we can only marvel at how rich their models were and how well their minds worked as scientific tools.

Perhaps unintentionally, Ionian scientists also changed the reason for making observations. They were the first people we know of who made observations simply to make models, or to prove a model correct after it had been made. Thus, model-making became an end in itself and a practical reason for observing nature. In all this, mathematics functioned as the language of both the model and the observation. Amazingly, modern physics still uses these Ionian ideas today.

Athens During the Hellenic Period

Athens was the most important Hellenic city in mainland Greece. Often, when we think of classical Greek ideas or culture, we think of the Golden Age of Hellenic Athens and its art, literature, theater, politics, and philosophical ideas. In fact, the three most famous Greek thinkers, ***Socrates, Plato, and Aristotle***, lived and taught in Athens between 430 and 330 BC.

Rating these men solely on their attitudes toward and work in science, as we are about to do, is totally unfair, perhaps even ridiculous. For, together, they shaped Western ideas on art, politics, beauty, truth, honesty, justice, and history. However, it is very important to study their work as scientists, and their attitudes toward science, because those ideas had such a huge effect on the attitudes and work of all later Western scientists.

Socrates and Plato

Socrates was born in Athens in 470 BC. We only know about his ideas from the description of them by his greatest student, Plato, who tells us Socrates taught that the ***search for truth*** is the most ***noble*** human activity and that a person cannot find the truth about nature by observing it. Accordingly, Plato tells us, Socrates spoke against astronomers and other observational scientists for searching for the truth in the wrong way.

Socrates' reasoning led him to develop a new form of logic, called ***dialectics***, which could be used to define the truth about any topic, from the meaning of "beauty" to the character of nature. In a Socratic dialectic, two or more people take turns making statements and asking questions about the statements that have already been made, until they arrive at a deeper and more precise, complete, and truthful understanding of the topic.

Let's take a horse as an example. A Socratic discussion might start with the seemingly simple question "what is a horse?" Two or more people would then take turns making statements about specific qualities of a horse. One might say "a horse is fast," a second "a horse is large," and a third "a horse is an animal." Then each person would question the other about the truthfulness or meaning of these statements. For example, one might ask "what do you mean by 'an animal'?," "what do you mean by 'fast'?," or "does this mean all large animals are horses?" Then the participants would rephrase their earlier statements in a way that would satisfy each other's questions, sharpen the language used in previous statements, or pose new questions that would require further statements or questions.

The goal in this process is to account for ***unstated assumptions*** (axioms) that lie behind statements, raise points that have been omitted, and create a linguistic precision in the statements included in the final definition, like fitting pieces of a jigsaw puzzle together (including ones that were initially missing) into a pattern that can only emerge from the doing of the puzzle. According to Socrates, without dialectics, it is impossible to resolve differing opinions or descriptions that are buttressed by observations into a single, truthful, definition about any subject.

At a deeper level, Socratic reasoning is based on two axioms of its own. First, a search for truth must start with a specific fact, argument, or truth and move "outward" toward a general description or definition. We call this ***inductive reasoning***. And second, the logic and language (rhetoric) used in a description are crucial elements of the truthfulness of the description. As a result, while Socrates did not exclude observations as the basis for opening statements in a dialectic discussion, he valued rhetoric and logic more highly as foundations for a search for truth. As such, Socratic thinking flew in the face of Ionian assumptions and the modern scientific method, although it is another twist of history that dialectics and inductive reasoning later proved to be useful tools for mathematicians, whose work has greatly affected all theoretical scientists.

Plato was born in Athens in 427 BC, studied under Socrates, and then established his own school, ***the Academy***, in Athens in 388 BC. As a teacher and writer, Plato took Socrates' argument against observations to its extreme by stating that truth could ***only*** be found through logic and reasoning.

What does that mean? Let's take a tree as an example. What if we want to arrive at a definition of a tree? If we observe a tree, we can describe many things about it. We can describe its wood, bark, leaves, size, color, its nuts or berries, or whether it gives shade. In fact, we can make an endless number of observations. But no matter how many observations we make or how careful we are, there are things about trees we cannot observe. This is because a tree changes so much throughout its life ***and*** because no one tree is representative of all trees. Therefore, every observation of a tree is only accurate for a particular tree at a particular moment in its life-cycle.

This led Plato to ask a simple question. Do all observations of a tree, made at different times or of different trees, add up to "treeness?" To Plato, the answer was no. Surely, he said, a tree does not change with each observation. So, to know the truth about a tree, we must create a picture of an ***ideal and unchanging*** tree. In fact, ***such reasoning is science itself***. Hence, there is no change in the Universe, while observations that differ from each other or imply a process of change only create a false picture of nature, thereby taking us further from the truth.

Clearly, Plato's ideas were based on ideas developed by Pythagoras, the Stoics, and Socrates. But Plato elevated their belief in logic, rhetoric, and mathematics to a place of honor in a convincing philosophical system that completely discounted the value of observations or the idea of process (change) in nature. While later Greek scientists sometimes ignored these limitations and studied the real world directly, Plato's ideas greatly influenced many later Greek, Roman, and European thinkers. In fact, the concept of ***the Platonic ideal*** so constrained scientific thinking in Europe that 2,000 years later it became necessary to modify or discard this idea before Europeans could do any truly original scientific work or produce any useful scientific ideas.

Aristotle and the Lyceum

Aristotle was born in 384 BC and studied at the Academy under Plato. He was so intelligent and interested in ideas Plato called him "the mind" and "the reader." Even as a student, however, Aristotle disagreed with Plato on many questions and tried to develop his own ideas. Perhaps this is why Aristotle left Athens as a young man, moving to Ionia and then to Macedonia as the tutor of King Phillip's young son Alexander (later "the Great"). When Alexander became King of Macedonia and Greece, Aristotle returned to Athens to found his own school, ***the Lyceum.***

Throughout his career, Aristotle taught that truth could be found in two ways: through Socratic/Platonic (that is, dialectic and idealized) reasoning ***and*** by observing nature. This balanced approach led Aristotle to modify Plato's philosophical concepts, and then to apply his own version of logic and mathematical reasoning to a stunning range of scientific topics. By the end of his life, Aristotle made thousands of important observations and developed entirely new ways to categorize natural phenomena, especially in biology. However, it is Aristotle's less even work on physical questions and his melding of the ideas of earlier Hellenic natural philosophers that will concern us here.

Aristotle accepted Empedocles' four basic elements for the inner spheres, which contain the Earth, moon, and planets. But he argued the outer spheres, which contain the sun and stars, are made from ***a fifth element***, not unlike Anaximandros' universal medium, which Aristotle called ***ether.*** Aristotle also argued that the four basic elements can be re-arranged, giving the appearance of change. But ether cannot change. Thus, the Universe has two regions, each with its own set of laws. This Aristotelian idea of a duality in nature caused great mischief for almost 2,000 years.

Nevertheless, Aristotle's work sometimes demonstrated remarkable insight into the physical workings of nature and the balance possible when all Hellenic approaches to scientific questions are employed. This is perhaps best illustrated by his four-fold proof that the Earth is a sphere. First, Aristotle observed that all objects near the Earth's surface fall toward it (in the direction of its center). Therefore, logic suggests that when the Universe formed, the bits of heavy matter that came together to form the Earth must have come from all directions in a process that would lead to the formation of a sphere at the center of the Universe. Second, as a ship sails away from a port, it appears to sink into the sea as it goes over the horizon, even though those on board later report they never sank. Since other experiments Aristotle did on vision seemed to prove humans see in straight lines, Aristotle reasoned the "illusion of the sinking ship" shows the Earth's surface is curved. Third, as viewed from a ship on the open ocean, the horizon forms a gentle side-to-side arc, which suggests the Earth is spherical, not just a curved circle. And fourth, the sphere is the simplest, most beautiful, solid form, and therefore the most ideal shape for the Earth.

This proof combines Pythagoras' and Plato's philosophical ideas with those of Ionian science by including observations, mathematics, and concepts of natural beauty, simplicity, and "the ideal" in a single description of nature. In fact, it is possible to argue Aristotle's way of thinking on this question is a summary of all the Greek ideas we have discussed so far.

However, when Aristotle studied other physical questions, such as the forces that cause motion (***mechanics***), his thinking was not as balanced. For example, Aristotle argued that when an arrow flies through the air, it does so because of an "unnatural" force that caused it to move in the first place (the pulling and letting go of the bow's string). In fact, initially, the push provided by the string is the only force acting on the arrow. So the arrow flies in a straight line in the direction in which the original force was applied. But eventually, the unnatural force is used up, which allows the arrow to drop straight down due to the Earth's "natural" pull on all objects. Finally, the arrow comes to rest on the surface of the Earth, thereby attaining its natural place and state of having no motion at all. Or, to put Aristotilean mechanics in modern terms, ***motion is caused by unnatural forces, while stasis is caused by natural ones.***

More generally, Aristotle argued all forces that ***only*** act when they are applied to objects are unnatural and therefore temporary (changeable), while natural forces exist at all times. So they are unchanging. In other words, there are two separate laws of mechanics, an idea that parallels the distinction Aristotle drew in astronomy between the inner and outer spheres.

Summary of the Athenian Period

When Alexander the Great died, Athenians turned against the Macedonians and anyone who had helped them. So Aristotle fled to Ionia, where he soon died. Thus, just as Alexander's conquests mark the end of the Hellenic period, Aristotle's death marks the end of Hellenic science. Not surprisingly, then, Aristotle's scientific work represents the most complete description of nature in the Hellenic period. But his work on physical questions also demonstrates the weaknesses of Hellenic science.

First, the Hellenic obsession with logic, rhetoric, and defining pure truths undermined their ability to fully value observational evidence. Second, as time went by, Hellenic thinkers became hostile toward ***all*** practical concerns, physical labor, or computational mathematics, on the grounds these activities were beneath the dignity of a free man and an educated mind, which should be devoted to purely theoretical questions. In the end, this bias inhibited Hellenic scientists from doing many experiments, recording their observations accurately, or applying what they learned from science to practical problems, what we would call applied science or engineering.

And third, ***the Hellenes lacked a number system free of mystical ideas***. Thus, while no civilization used the zero (0) as a true number until much later (the Babylonians and early Chinese invented a zero as a place-holder, but it was not until about AD 600 that mathmaticians in India invented the idea that one could do real arithmetic with zero), the Greeks also failed to recognize one (1) as a regular number because they believed it represented perfect "unity." In fact, the Hellenes assumed ***all*** small numbers stood for moral or social ideals, such as maleness, femaleness, harmony, marriage, family, and discord. As a result, Greek computational techniques never achieved the fluidity of earlier Egyptian and Babylonian methods, except in geometry. (NOTE: The ancient Hebrews had different, but similarly mystical ideas about numbers. As a result, the ancient Hebrews contributed little to the advance of mathematics and science.)

In the end, these were crippling limitations. Without a value-neutral number system, accurate computations, and an agreement about the worth and meaning of observations, Hellenic scientists found it difficult to study questions like the mechanics of motion or test any of their ideas or models. Hence, while Hellenic attitudes and values encouraged scientists to create and debate different models of nature, they also blocked any one model from becoming a foundation of a long line of continuous observations, experiments, and later models that might have led to improved pictures of nature.

Platonic reasoning also implied all descriptions of nature are based on axioms that, by definition, cannot be proven. Thus, while experiments and observations can be used to support a model of nature, it is impossible to arrive at a full understanding of nature by observing it. In other words, as illustrated by Aristotle's idea of an unchanging ether in the outer spheres or of stasis (lack of motion) as the preferred natural state, the Hellenes believed, at its deepest level, that nature acts as it does simply because it is in its nature to do so, a statement that amounts to little more than a secular version of Animism's assumption that nature is an expression of the will of the gods.

Nevertheless, we must marvel at the many natural pictures of the Universe Hellenic scientists created, and at the way those pictures stimulated later Western scientists. Moreover, while the ***spirit of argument and dialogue*** that animated Hellenic thinking limited some kinds of scientific progress, it was also the Hellenes' greatest gift to future scientists. In the end, this spirit, along with some Babylonian and Egyptian ideas, provided the foundation for all modern European science, especially in the years after AD 1600.

Alexandria and Hellenistic Science

While Platonic and a few other Hellenic ideas were taught at the Academy in Athens until 529, by 250 BC (779 years earlier!) the school founded by Ptolemaios I and II in Alexandria became the leading center of Hellenistic mathematics and science. This happened for several reasons. First, Athenian thinkers spent almost all their time and energy analyzing and commenting on Platonic and Aristotelian ideas. Second, Alexandria's library housed much of the accumulated knowledge of Babylonia, Egypt, and Greece. In fact, by 150 it contained over 400,000 papyrus rolls, which made it a great tool for scientists and mathematicians who wanted to compare the evidence from more than 2,000 years of Babylonian, Egyptian, and Greek sources with their own observations and thinking. Third, Alexandria was an interesting and wealthy city that attracted people, including scientists and mathematicians, from across the Greek world and beyond. And fourth, Ptolemaios I and II supplied the kind of support schools, libraries, museums, and scientists need to survive and prosper.

As a result, Hellenistic scientists and mathematicians produced several remarkable textbooks on the accumulated wisdom of the Greeks, and new works in astronomy, mechanics, and geography, all of which were based on ***a new Alexandrian ethic that gave greater weight to experiments, observations, and practical demonstrations of abstract scientific ideas***. A brief survey of a few leading Hellenistic scientists and mathematicians should illustrate these points.

Euclid was born in 320 BC, as the Hellenistic era began, and wrote a textbook called **The Elements of Geometry**. It is the best record we have of the arithmetic and geometry Greek scientists used to construct models of nature. More amazingly, Euclid's descriptions of points, lines, plane shapes, and solid forms, as well as his method for constructing proofs of geometric propositions, dominated Western mathematics until the 1800's, when European mathematicians finally created a new kind of non-

Euclidian geometry that could be used to describe the structure of a curved Universe. As such, Euclid's text has been the most influential mathematics book ever written. (NOTE: See Chapter 11 for more on Euclid's world-wide influence.)

Just before 200 BC, ***Apollonius*** wrote an equally exhaustive text on the geometry of the ***sections*** one gets when cylinders and cones are cut at various angles to their bases. Most importantly, this book included new descriptions of three shapes, ***the eclipse, parabola, and hyperbola***, that would figure prominently in Europe's Scientific Revolution 1,800 years later.

Archimedes was born in 287 BC and lived in Sicily, although he probably spent some time in Alexandria. He was reputed to be the greatest mathematician of the Hellenistic era. As a physical scientist, Archimedes studied mechanics, solved many practical scientific problems, and invented several devices and machines. Among his many accomplishments, Archimedes is credited with calculating the volume of an irregular object by measuring the volume of water it displaces when placed in a bath. This was the famous "eureka" moment of science history, in which Archimedes combined this measurement for volume with one for the weight of a crown to calculate its density. This, in turn, allowed him to tell if the crown were made out of pure gold, the density of which was already known.)

Archimedes also designed the world's first screw pipe, a cork-screw device that could carry water uphill, solving the age-old problem of delivering water from wells and irrigation canals where gravity-feed systems do not work. Like other Hellenistic scientists, Archimedes also ***built mechanical gadgets and toys***, both to study the scientific principles on which they work ***and*** to demonstrate scientific principles that govern larger systems in the natural world. In other words, in a break with Hellenic attitudes, Archimedes and other Hellenistic scientists applied their scientific insights to engineering problems.

The four greatest astronomers of the Hellenistic period, ***Aristarchus*** (310-230 BC), ***Eratosthenes*** (276-195 BC), ***Hipparchus*** (190-120 BC), and ***Ptolemy*** (in Alexandria from AD 127-151), approached their work with a similar ethic of using abstract models and mathematics to solve practical problems, often with the aid of experiments. (NOTE: Despite his name, Ptolemy was not related to the Hellenistic kings of Egypt. But his name did cause confusion later. European paintings made 1,000 years after his death showed him wearing a crown.)

Aristarchus argued the sun is at the center of the Universe and that all planets, including the Earth, orbit it in perfect circles, a theory re-stated by Copernicus 1,800 years later.

Aristarchus also constructed an elegant geometric method based on triangulation for measuring the sizes and distances from the Earth of the moon and sun. While his measurements of these angles were later shown to be inaccurate, which rendered his estimates for these distances incorrect, Aristarchus was the first to offer a valid mathematical proof that the sun is much larger and further away from the Earth than the moon. More importantly, his ***experimental and geometric approach*** to this problem represented a real advance over previous mystical or speculative Greek attempts to define any numerical relationship in the Model of the Spheres.

A similar approach was demonstrated by Eratosthenes during his term as Alexandria's head librarian. Today, he is best known for doing an experiment that measured the Earth's circumference. First, Eratosthenes measured the length of shadows simultaneously cast into two wells at a distance from each other in Egypt. Then he used Euclidian postulates on the angles of a triangle, the lengths of its sides, and the nearly triangular shape of sections of a large circle to calculate the number of degrees represented by the distance between the wells, and therefore the fraction of the Earth's circumference represented by that distance. Aside from demonstrating the elegance of Hellenistic mathematical thinking and experimental designs, it is astounding that without leaving Egypt, Eratosthenes' experiment allowed him to conclude that the Earth's circumference is 24,650 miles, a remarkable achievement given that its true value is 24,875 miles! (NOTE: To cite one hypothetical example from Erosthenes' experiment, since there are 360° in a circle, 1° represents 1/360 of the earth's circumference. So if Eratosthenes calculated that two wells were 1° apart on the surface of the earth, multiplying the distance between those two wells by 360 would give the circumference of the Earth.)

In a related "experiment," Eratosthenes also compiled the extensive records of earlier observations in his library on the positions of the sun and stars as they "orbitted" the Earth in the past. Then he used Euclidian geometry to analyze that data. When he was done with this job, Eratosthenes concluded that the Earth spins on an axis tilted from the perpendicular in relation to the plane of the Earth's orbit around the sun. In fact, according to Eratosthenes, this tilt is about 22 1/2° from the "vertical," a figure that is within 1/12 of a degree (or, 5 minutes) of the agreed-upon modern value.

Above all, this experiment demonstrates the way Hellenistic scientists balanced mathematics, data from earlier observations, experiments, and abstract models of nature to create a scientific method remarkably similar to the one used by European scientists after the Scientific Revolution, 1,800 years later.

The Alexandrian way of thinking also encouraged Hipparchus to build an observatory on the island of Rhodes, where he studied the positions of the moon, sun, planets, and over 1,000 stars, in the hope a comparison of his measurements and the ones catalogued in Hellenistic libraries would allow him to describe how the planets' orbits had changed over time. To many astronomers, this made ***Hipparchus the first great quantitative astronomer, one whose descriptions are based on numerical measurements derived from specific observations***.

But Hipparchus went beyond these calculations. When he compared earlier scientists' observations to the data he collected as an observer, he concluded there must be a cyclical change of Eratosthenes' Earth-tilt over time, from a maximum of 22 1/2° to one side to 22 1/2° to the other. Moreover, Hipparchus said the Earth completes this 45° ***wobble*** every 12,500 years. Thus, a complete cycle from one extreme tilt back to the same position takes 25,000 years. As strange as these ideas must have seemed to others in Hipparchus' day (and to many modern readers), his ideas later proved correct, although the modern values for a full cycle in the Earth's "tilt wobble" are slightly more than 45° and 25,800 years.

In 150, almost 500 years after Euclid wrote The Elements, Ptolemy wrote an equally encyclopedic text on astronomy called **The Almagest**, which included all known Hellenistic and Hellenic observations, descriptions of mathematical procedures used in Hellenistic science, and an updated Model of the Spheres that was based on Aristotelian ideas ***and*** the observations of all earlier Greeks. However, when Ptolemy compared Aristotle's Model of the Spheres to the measurements and observations available to him in AD 150, he found it necessary to add little loops (***epicircles***) to the circular orbits of every known planet.

In a sense, Ptolemy's work rescued the Model of the Spheres by placing it on firmer, more modern, observational grounds. But he also introduced ***a degreee of complexity to planetary movements that violated the Hellenic belief in simple, elegant mathematics and models***. Moreover, this discrepancy took on great significance later, when Ptolemy's version of the Model of the Spheres became the official cosmology of later Arabic and European astronomers, many of whom spent a great deal of time and energy analyzing and debating Ptolemy's "ugly" epicircles.

Ptolemy also wrote another important textbook, **The Geographia**, which contained the latest and most complete maps and speculations about the size and shape of the Earth. In it, Pythagoras pictured the Earth as a globe. He also placed all the landmasses of the world known to the Greeks on that globe, and, to make relative sizes and distances easier to see, included horizontal and vertical lines that formed an imaginary grid on the surface of the Earth, not unlike our lines of latitude and longitude. Then, he divided the world horizontally into climate zones. And finally, he redid Eratosthenes' experiment in the hope of improving the accuracy of its measurements and therefore its estimate of the Earth's circumference, a clear indication Ptolemy and other Hellenistic scientists of his day believed, as do modern scientists, that there is value in ***verifying the ideas of others*** by reproducing the experiments on which they are based.

However, in one of the great ironies of all human history, Ptolemy's measurements were ***less*** accurate than Eratosthenes'. In fact, ***his estimate of the Earth's circumference was about 33% too small***, an error that took on great importance when Christopher Columbus used an Italian copy of a Ptolemaic map to estimate the distance to the Indies (East Asia) across "the unknown western ocean" as a little more than 3,100 miles. Thus, incredibly, it was Ptolemy's mistaken underestimation of the Earth's size that 1,340 years later convinced Columbus he could make his proposed voyage, and then confirmed his opinion that he had reached Japan when he found land in the Carribean Sea almost exactly where he expected to find islands off the East coast of Asia.

Summary of Helenistic Science

Hellenistic science drew on and updated the rich traditions of Hellenic science. But Hellenistic scientists based their ideas on a wider range of observations and experiments, and better mathematics. Hellenistic scientists also did experiments to ***verify*** their theories, and tried to demonstrate their ideas about nature by building toys and mechanical gadgets that could provide observational proofs of their ideas. Above all, this practice made science a useful tool in the creation of new technologies, thereby unifying science and technology in a way that amounted to a new purpose for scientific thought, at least within western Asia, Africa and Europe. (NOTE: This connection happened earlier in China, where it was the main use of science until the 1600's, when China first came into direct contact with European science and technology. See Chapter 11 for more on this subject.)

After 200, Hellenistic science lost its vitality. Even in Alexandria, little original work was done. Instead, later Hellenistic and Roman scholars turned their attention to editing and commenting on earlier Hellenic and Hellenistic works. Put simply, the great tradition of Greek science was coming to an end, at least within the territories now ruled by the Romans.

Summary of All Greek Science

Taken as a whole, ancient Greek philosophy and science is the foundation of the way we think, do scientific work, and make theories about nature. First, Greek scientists developed the not-so-obvious and essential belief that an ***individual*** human being could use his/her mind to make models of nature. Second, they decided mathematics must be a part of any scientific model. And finally, they separated science from religion by creating secular schools that taught natural philosophy and mathematics. However, we must remember that the ancient Greeks also continued to believe in their Animistic gods. In fact, to many Greeks it must have seemed as if scientists were trying to take the place of the gods. One, perhaps apocryphal, story should serve to illustrate this point.

Empedocles was said to have become so impressed with his own knowledge and intellect he decided he was immortal, like the gods. To prove it, he jumped into an active volcano. Not surprisingly, at least to us, he died.

Perhaps this did not really happen. Or, perhaps Empedocles slipped while observing the volcano and the story was exaggerated as it was retold. But the point is the Greeks told this story, because ***they*** believed a scientist who studied the Universe and made models of it was, in a way, usurping the role of the immortal gods by worshipping his own ability to shape nature in the image of his own ideas.

In the end, Greek science created many models of nature, no one of which was accepted by all scientists or all Greeks. But the ideas of Plato and Ptolemy, which relied most heavily on ideas from the Stoics, Empedocles, and Aristotle, came to dominate Roman and European thought, while the Hellenic ethic of debate and the Hellenistic experimental method were forgotten, at least within the Roman world. In fact, Europeans did not begin to rediscover the full range of Greek ideas and again take up the old question of where the gods' (or God's) role in the Universe ends and a scientific view begins, until after 1100.

In the next chapter, we will pick up the story of how a fuller range of Greek ideas survived until European attitudes and beliefs changed in the 1100's. But, for now, we must end by remembering that we still ask the same philosophical questions today that ancient Greeks asked, using language and concepts we largely inherited from them. Thus, as with much else in our culture, the very existence and style of our discussions about scientific and philosophical questions constantly re-affirms the continuing influence ancient Greek thought has on us.

CHAPTER FIVE

THE ARABS: EAST MEETS WEST MEETS EAST

A Brief History: East Meets West

After 200, scholars in Alexandria, Athens and Rome continued to analyze the philosophical, mathematical, and scientific ideas of earlier Hellenic and Hellenistic thinkers. So, even in this scientifically unproductive period, the accomplishments of Greek thinkers were still appreciated within the Roman Empire. However, after Christianity became the official religion of the Empire, hostility toward non-Christian ideas intensified. As a result, in the early-400's, Egyptian Coptic Christians attacked Alexandria's library, while similar hostility surfaced in Athens during Justinian's rule 140 years later, when Imperial officials tried to eliminate all pagan and sectarian Christian ideas because they disagreed with official Church doctrines.

This was an important turning point in world history. If people had completely obliterated the physical record of Greek ideas or stopped teaching them altogether, Greek knowledge might have been lost. Luckily, this did not happen. However, to understand how Greece's mathematical and scientific traditions survived, we must turn our attention to an area that was just beyond the control of official Christiandom and Constantinople.

Before the Arabs

The Persians built their first empire around 800 BC and spent the next 1,440 years competing with other civilizations for control of western Asia, southeast Europe, and northeast Africa. First the Persians fought Babylonia, Assyria, Greece, Egypt, and India's Aryans and Hindis. Then they fought Alexander the Great, Rome, Byzantium and the Arabs. At its height the Persian Empire became the largest empire in western Asian history. But between 500 and 400 BC, the Hellenes turned back Persian attempts to conquer Greece, and the Egyptians reclaimed their homeland after having been ruled by Persian pharaohs for almost 200 years. Thus, after 400 BC, Persian influence was mostly limited to western Asia. However, later Persian Empires sometimes included the Arabian Peninsula, the Levant, Turkey, Iraq, Iran, Afghanastan, and the central Asian steppes north of Iran and Afghanastan.

Alexander the Great conquered Persia in 325 BC. Upon his death, one of his generals established the Sassanid Empire, which eventually returned to Persian customs. However, despite later invasions of Persia by nomadic tribes from the north and the establishment of several new Persian empires after the collapse of Sassanid power, Persian society never lost its connection to its partially Hellenistic intellectual heritage.

By AD 300, the Persian Empire was home to people of many religions and cultures, including Zoroastrians from Persia; Christians in Syria, Palestine, and Lebanon; Mesopotamians, many of whom still followed their ancient Animistic religion; and Jews in almost every province. As a result, Persian cities were multi-cultural, multi-ethnic, and multi-religious, not unlike our own. Nevertheless, Persians were far more tolerant of other beliefs and customs than were the Imperial and Christian leaders who by that time controlled the Greco-Roman world. Consequently, when sectarian Christian and Hellenistic pagan scholars fled religious persecution in Athens and Alexandria, Persian rulers encouraged them to establish schools in their territories that would teach Greek ideas. (NOTE: In the years between Constantine and Justinian, some Alexandrian scholars fled to Constantinople carrying Greek books on math, philosophy, and science. As a result, copies of some Hellenic and Hellenistic books on math and science remained within the Byzantine world, which proved important when Western Europe's Renaissance began in the 1400's.)

Among the first scholars to flee the Greco-Roman world in the early-400's were members of two Byzantine Christian sects, ***the Nestorians and Monophysites***. At first, Nestorian scholars established a school at Edessa in southern Turkey near the Syrian border, just far enough away from the control of Constantinople to ensure they could practice their own version of Christianity and continue studying Greek scientific and philosophical ideas. At Edessa, Nestorian scholars began translating Greek books into Syriac, an Aramaic language akin to Arabic and Hebrew. We do not know why this school closed in 489. But when Nestorian scholars left Edessa, many moved to a school at ***Gondesphapur*** in Iran that was the leading academic institution in the Persian world, while others settled as far away as India and China. The Nestorian community in India was absorbed and disappeared in the late-700's. But, amazingly, China's Nestorian community survived for 1,000 years. In the years after 1279, some Yuan Dynasty officials even converted to Nestorianism.

Despite the flight of Nestorian scholars to South and East Asia, western Asia continued to nurture its multi-cultural heritage. Thus, in the 500's, a Monophysite priest named Sergius translated Aristotle into Syriac for his pupils, while in the early-600's, a Syrian Christian bishop named Severus wrote a book that praised Hindi astronomy and numbers. In fact, by the late-500's, Persian schools became the world's leading centers of Greek thought, just as Persian merchants were expanding their trade with India and China. So, Persian schools became the first to promote ***both*** Greek and Hindi ideas about math and science, and to begin the long and still obscure process of introducing Chinese ideas to the Western world.

While many historians claim ***all*** Christian, late Roman, and Byzantine authorities rejected Greek science, and that it was the

Arabs who, beginning in the late-600's, kept Greek knowledge and the spirit of scientific curiosity alive, this is not true. Rome, Byzantium, Western Christians, and Europeans in general accepted a few Greek ideas, most prominently those of Plato, Empedocles, and Ptolemy, while ignoring or forgetting others ***and*** the spirit of debate that had characterized Greek science. At the same time, some Hellenistic pagans and Eastern Christians embraced the Greek heritage of scientific and mathematical knowledge and inquiry in a way that helped them pass on those traditions to Persians, and later Arabs. So, the honor of saving Greek knowledge should be shared by Eastern Christians, Egyptian Greek and other pagan scholars, the Persians, and the Arabs. Without them all, a great deal of Greek knowledge and the last remnants of Babylonian and Egyptian knowledge might have been lost forever.

The Arabs and Moslem Civilization

Among those who traded with the Persians were ***the Arabs***, a people who lived in the deserts of the Arabian Peninsula. The Arabs were Semites, like the ancient Babylonians and Hebrews. But they never participated directly in the development of the great Fertile Crescent civilizations. Instead, from the days of Babylonia to the last of Persian empire-building, the Arabs acted as go-betweens in the trade in goods and ideas that developed among the civilizations in Egypt, western Asia, the Indus River valley, and India. Despite these contacts and their strategic location at the crossroads of Fertile Crescent trade routes, the Arabs continued to practice their own ancient Animistic religion because it fit their nomadic and clan-based tribal society.

This changed in 620, when an Arab named ***Muhammed*** started a new religion in the city of Mecca that was based on a mixture of his own ideas and older Jewish and Christian ones. However, in ***622***, the people of Mecca rejected Muhammed's teachings, and forced him and his followers to flee to another Arabian city, which later came to be named Medina. Muhammed's trip to Medina, ***the Hegira***, is considered the "official" and holy beginning of his new religion, ***Islam***.

Unlike in Mecca, the people of Medina accepted Muhammed's leadership and converted to Islam. Then, in 630, Muhammed raised an army which he led on a "holy march" back to Mecca. Upon seeing Muhammed approach, the people of Mecca surrendered and agreed to accept Islam as their new religion.

Having established a base of support in his own homeland, Muhammed next turned to the task of unifying all Arabian clans and tribes under his leadership. However, in 632 he died. Surprisingly, this did not slow the expansion of the Islamic religion. Instead, Muhammed's kinsmen and followers unified the Arabs as an Islamic (Moslem) people, and launched a campaign to spread Muhammed's teachings to other lands. In a burst of military energy that rivaled the Macedonians under Alexander the Great, the Arabs conquered Damascus (Syria) in 635, Jerusalem in 637, Egypt in 641, Persia in 642, the rest of North Africa by the late-600's, and Spain in 710. Amazingly, by 750, only 118 years after Muhammed's death, ***the Arabic Empire*** stretched from the Indus River in the East to the Atlantic Ocean in the West, and included all of western Asia, North Africa, and a belt of land southward into the Sahara Desert.

In 638, eight years after Muhammed's death, Islamic priests compiled Muhammed's teachings and sayings into a Holy Book called the ***Koran*** (Qur'an), which was ***written in Arabic***. The Koran was considered so holy Moslems were forbidden to translate it into any other language. Consequently, as the Arabs conquered other peoples, converts to Islam had to learn how to read and write Arabic to practice their religion. This also guaranteed Arabic would become a major world language and that Arabs would retain a special place in their own empire. In any case, by the 800's, the "international" use of Arabic increased the loyalty of all peoples in the Moslem world to their new rulers and encouraged them to feel they were part of a single Arabic culture.

Despite this enforced use of Arabic, Arabs were tolerant of people within their empire who did not convert to Islam, and of those who belonged to ancient "high" cultures just beyond their Empire's borders. This was especially true of Greeks, Jews, Persians, and Hindus, all of whom the Arabs greatly respected. In fact, in a policy somewhat reminiscent of the Roman attitude toward Greeks, many Persian scholars became teachers in Arabic schools or were hired or enslaved as tutors of the children of wealthy Arabs. As a result, especially after 800, many Greek texts were translated into Arabic, either from Greek originals or Syriac or Persian translations, while Persian and Arabic scholars began to do the same translational work on Hindi texts.

Nevertheless, the Arabs never forgot that their power rested on ***their*** customs dominating all aspects of life within their empire. So, while non-Moslem scholars were allowed to become teachers and government officials, they all had to use Arabic as their professional language. As a result, some Jewish scholars even wrote about their own Bible in Arabic, as did other "ethnic" scholars about their own intellectual heritages. Above all, however, the imposition of Arabic throughout the Arabic Empire guaranteed all scholars could participate in the lively trade of ideas that developed across the enormous territory controlled by the Arabs, and that "Arabic" scientists could more easily build and improve upon each other's work.

In 640, the ancient city of Damascus, Syria became the capitol of the Arabic Empire and its main center of learning. But by 750, arguments between "dynastic" lines of successors to Muhammed led to the formation of two Moslem sects, the Sunis and the Shi'ites. After this split, the Levant and North Africa became part of a Suni Arabic kingdom centered in Iraq, called ***the Abbasid ('Abbasid) Caliphate***; a Shi'ite caliphate was established in Persia; several small caliphates were formed in Afghanistan and southern Russia; and North Africa, Spain, and Portugal were divided into several Suni Moslem kingdoms. (NOTE: After 750, Arabic kings were considered leaders of their Islamic sects and Muhammed's representatives on Earth. So they were given the dual religious and political title of Caliph. As a result, many Arabic and other Moslem kingdoms were called Caliphates.)

The Abbasid Caliphate began building a new capitol city, ***Baghdad***, in Iraq in ***762***. By 800, it became one of ***the*** largest city in the world. It was ***during the following Abbasid period of Moslem history that Arabic learning, mathematics, and science experienced its first "golden age."*** But despite the concentration of wealth and power in Baghdad, and the supposedly universal authority of its rulers within the Moslem world, the Abassid Caliphate did not bring peace to the Arabic world. Instead, religious and political arguments continued, until several new caliphates and kingdoms were formed. In fact, at times it seemed the strife between Sunis and Shi'ites would consume the Moslem world and completely destroy it.

Arabic cultural integrity was also tested by an endless set of invasions by "less civilized" tribes from Turkey, Russia, and the steppes of central Asian. In the end, however, Arabic civilization was re-energized by these peoples, each of whom converted to Islam and formed Caliphates, modelling them after Arabic ones. Thus, despite a steady influx of new converts and numerous reshufflings of Moslem kingdoms, the idea of a single Arabic culture lasted until 1200, while the Arabic language remained the universal means of governmental, religious, and intellectual expression in all Moslem territories.

As Abbasid dominance waned in the 900's, turmoil within the Moslem world increased. Nevertheless, the kingdoms and Caliphates formed in this period continued to nurture scientific work and extend the Moslem dominance over trade in western Asia, North Africa, and the southwestern and southeastern corners of Europe. First, the ***Fatimid Caliphate*** was established in Egypt in the early-900's. Then, after new invasions by Turkish tribes from southern Russia, two new Moslem kingdoms were established, by the ***Seljuk Turks*** in western Asia and ***the Almohads*** in Spain.

By the late-1100's, Almohad Spain had become an important center of Moslem intellectual life, while the Seljuk Turks concentrated on enhancing Moslem power in western Asia, in part by increasing trade with China, India, Africa, and Eastern Europe. But by then it was clear Turkish conquerors like the

Seljuks were not really part of the religious lineage Muhammed and his original followers had established. So a new form of Moslem government emerged in which religious authority remained in the hands of Arabic clerics while political authority was given to non-Arabic secular rulers. At the same time, permanent Moslem trading-posts were established in China, India, and the Swahili cities of East Africa, while Chinese and Indian traders began to make regular visits to Moslem cities, creating a trade in people and products that exposed western Asians and North Africans to "foreign" ideas that greatly enhanced Moslem life while further undermining the Arab identity of the Moslem world.

As a result, ***Hindi numbers*** were adopted by all Moslem merchants at the end of the Abbasid period, while Chinese inventions like paper, printing, the mechanical clock, the wheel barrow, and gunpowder reached the Arabic world in the last years of the Abbasid Caliphate or during the rule of the Seljuk Turks.

However, Seljuk participation in this trade in products and ideas failed to spark a renaissance in Arabic science. Instead, Seljuk rulers, clerics, and merchants promoted a return to "pure" Islamic beliefs, perhaps to prove the original religious fervor of the early Moslems had not been lost, while focusing most of their energies on the economic, political, and military power of their empire. So, while the Moslem world retained a sense of well-being and superiority, as well as its economic health, until the early-1400's, Arabic intellectual work declined in the late-1100's and never fully recovered, just as new migrations and invasions from central Asia dealt what would prove to be the final blow to the Arabic civilization. (NOTE: These developments had a delayed, but equally important, impact on European society, when Moslems passed Chinese and Hindi ideas on to Christian Europe. Meanwhile, as with the Seljuks in western Asia, a conservatism gripped China in the 1200's and 1300's under the Mongol emperors of the Yuan Dynasty. See Chapter 11 and below for more on the Mongols' impact on world history.)

The most energetic and ferocious of the tribes that invaded western Asia in this period was the ***Mongols*** who, led by their warrior-king ***Ghengis Khan***, swept westward and southward from their tribal home at the beginning of the 1200's. Remarkably, by Ghengis' death, the Mongols conquered China, central and western Asia, and parts of Eastern Europe, giving Ghengis an empire that stretched from the Pacific coast of China in the east to the heartland of Russia and Turkey in the west. This made the Mongol Empire the largest the world had ever seen, and one that would not be equalled again until the British Empire of the late-1800's. But by the time Ghengis' grandsons inherited his throne, some territory had been lost and the remaining empire had been divided into three parts: an eastern empire centered in China, a shrinking western one, variously centered in Persia, Afghanistan, and Transoxiana (the area east of the Aral Sea), and a soon-to-disappear empire centered in Russia's European plains.

In the early-1300's, the western Asian descendents of the Mongols converted to Islam and changed their name to the ***Moguls***. Then they began a new cycle of miliary conquest under Ghengis' great grandson, the ***Emperor Timur*** (in Latin, Timerlane). By the end of Timur's reign in the late-1300's, the Moguls ruled Persia, Afghanistan, Transoxiana, northwestern China, and India. Then, from their base in India, Timur's descendants conquered much of Southeast Asia and the islands of Indonesia. However, it was during this period of Mogul expansion that a new tribe of Turks, the ***Ottomans***, swept out of southern Russia and northeast Turkey, converted to Islam, and established their own Moslem empire, which later ruled Iraq, Turkey, the Levant, the Arabian Peninsula, northeast Africa and finally, after the collapse of the Byzantine Empire, southeastern Europe, including Greece.

By the mid-1400's, the Ottomans and Moguls had greatly expanded the territory and cultural influence of Islam. But their ties to Arabic ways were largely symbolic. So, the peoples who were conquered by these Moslem empire-builders were not absorbed into an Arabic culture. Nor did they automatically convert to Islam. In India, for example, some people converted, but most did not. So, while India was deeply affected by Mogul rule, its Hindi and other traditions and beliefs survived. In Malaysia and Indonesia, on the other hand, many local rulers converted to Islam and local cultures largely disappeared, to be replaced by a new culture that merged local customs with imported Moslem ones.

During this period, Moslem traders and rulers based in Turkey, the Levant, North Africa, and Spain continued to spread Moslem economic and political influence further into Africa. Thus, by the mid-1400's, the entire northern half of Africa, nearly to the Equator, was converted to Islam or under the influence of Moslem traders. However, as elsewhere, this did not mean African people were absorbed into an Arabic culture. Nor did most rulers within this expanded Islamic territory support Arabic science. Instead, the Islamic world was swept by a religious and cultural conservatism that encouraged all Moslems to focus on conquest, trade, and the conversion of new peoples to Islam.

Why did this happen? After 1250, Moslem leaders came to believe that ***all truth came from the Koran*** and religious leaders had the right to impose their theological ideas on all Moslems. This proved deadly for science, since many Moslem theologians believed scientific work was a danger to Islam and the authority of the Koran. As a result, the following discussion focuses on the period before 1250, when Moslem science was at its height and the Moslem world welcomed the contributions of both Moslem and non-Moslem thinkers.

Arabic Science And Mathematics

"Arabic" scientists came from every corner of the Moslem world and many races and religions, a fact demonstrated by their names, such as Al-Hindi (the Hindi) and Al-Yakeb Israel (Jacob the Jew). Thus, as with the Greeks, Arabic science was not the work of a single people, one golden age, or one area. In fact, Arabic scientists and mathematicians often moved around within the Arabic Empire, seeking places that offered them the most support, stimulation, and comradery. Nevertheless, there were three places that played unique roles in Arabic science between the 800's and 1250: 1) ***Baghdad*** (Iraq) between 813 and 1050, 2) ***Cairo*** (Egypt) between 970 and 1150, and 3) ***Cordoba*** (Spain) between 1100 and 1250. So, let's begin with Baghdad and work our way westward toward Cairo and Cordoba.

Arabic Astronomy and the Greek Heritage

Baghdad was built in 762 near the ruins of Babylon. But its intellectual dominance began in 813, when ***Al-Ma'mum*** became the Abbasid Caliph and promoted the idea that a belief in Islam could be supported by reason and logic. To encourage the study of philosophy, science, and mathematics, Al-Ma'mum built the ***House of Wisdom*** (Bayt al Hikmah), which contained a school, library, and astronomical observatory.

One of the first great thinkers at the House of Wisdom was ***Al-Kindi***, who was born around 800 in Yemen on the southeast coast of the Arabian Peninsula. Al-Kindi studied philosophy and wrote several books on optics that were the first Arabic works to contain original work on physical aspects of nature. But his greatest contribution was as a school administrator who improved the House of Wisdom's faculty, facilities, and library, which made them more effective resources for later Moslem scientists.

Al-Kindi's work and that of others like him allowed astronomers at Baghdad's observatory to make many entirely new observations, collaborate with engineers to design better instruments. The Arabic passion for improving the design and usage of scientific tools also led Arabic thinkers to focus on the concept of precision of measurement and efforts to discover the kinds of mathematical concepts that would allow astronomical data to be interpretted with far greater accuracy. Moreover, these attitudes greatly affected the Moslem style of scientific thinking and theory-making for the next 300 years. So, let's begin with two important astronomers at the House of Wisdom.

Al-Battani was born in the mid-800's in Harran, a city on the Euphrates in Iraq. After moving to the House of Wisdom, he made many observations of the stars, planets, sun, and moon. In fact, European astronomers considered his body of work the most complete in the world until the 1600's. Al-Battani also used the latest Arabic mathematics to analyze his observations, thereby laying the foundation for the quantitative use of experimental data that characterized the work of most later Arabic scientists.

Al-Buzjani was born in Iran in 940. But he did his best work at the House of Wisdom. By his day, Arabic astronomers had been studying the heavens for over 150 years. So Al-Buzjani decided to compare all the Arabic observations available to him, including those of Al-Battani, to the ones listed in Ptolemy's text, in the hope this work would confirm the correctness of Ptolemy's Model of the Spheres. Instead, Al-Buzjani's work demonstrated The Algamest contained many errors and that Arabic observations did *not* fit the planetary orbits predicted by Ptolemy's Model. Nevertheless, Al-Buzjani could not bring himself to reject Ptolemy's ideas. Instead, he argued Ptolemy's "observational errors" did not disprove his conclusions, a position modern scientists would reject given their assumption that observational flaws automatically call scientific theories based on those observations into question.

After Al-Buzjani, astronomers continued to do important work in Baghdad. But the Fatimid Caliphate's new capitol of Cairo was already attracting many leading Arabic scientists. For example, one of Islam's greatest astronomers, ***ibn Yunus***, worked in Cairo from 977 to 1003, a period that overlapped Al-Buzjani's work in Baghdad. After making thousands of original observations, ibn Yunus prepared his own catalogue of known astronomy observations in the hope he too could use it to "up-date" Ptolemy's 850 year-old text, thereby completing Al-Buzjani's work. Once again, however, Ibn Yunus' found many mistakes in the observations Ptolemy cited, and then argued Ptolemy's model was still correct.

By the early-1100's, Spain's Almohad Caliphate emerged as an important center of Arabic intellectual activity. Thus, while there were Moslem scientists who continued to work in western Asia and North Africa, many scholars and scientists were born in Spain or found the greatest support for their work there. More importantly for the future of science, the existence of Moslem and Jewish scholars and teachers in Spain and Sicily brought the rich Arabic intellectual heritage to the very edge of Christian Western Europe.

The most famous Spanish Moslem (***Moorish***) thinker, ***ibn Rushd***, was born in Cordoba Spain in 1126. After receiving a medical education in Spain, ibn Rushd became the court doctor of ***Prince Yusif***, the caliph in Marrakech, Morocco in West Africa. But ibn Rushd was also a great student of philosophy and science. So, when Yusif asked him to explain these subjects to him, ibn Rushd wrote a series of books on Greek and Arabic ideas about the origin of the Universe, religion, free will, astronomy, and the concept of process in nature. One of these books was completely devoted to commentaries on Aristotle's texts and ideas.

ibn Rushd's books are the most complete accounts we have of Arabic "natural philosophy" and the role Greek thought played in Arabic life. Above all, they demonstrate: 1) ibn Rushd's deep and encyclopedic grasp of Greek ideas, 2) the great storehouse of ancient knowledge that survived in the Moslem world, and 3) the Arabic contributions to Western philosophy. In fact, some ideas cited in ibn Rushd's books were completely original to the Arabs, while those derived from Greek sources were analyzed in a way that reflected the unique and highly refined style of Islamic political and religious writings, which often featured a style that reflected poetic, mystical, and at times legalistic genius of the Moslem world.

When Christian monks in Spain and Sicily began translating Arabic books into Latin, the language of all educated Western Europeans at that time, the most famous and widely distributed was ibn Rushd's book on Aristotle. In fact, in recognition of their great respect for ibn Rushd, Europeans gave him a Latin name, ***Averroes the Commentator***, which had the perhaps unintended effect of convincing many future scholars ibn Rushd had been a Christian European. (NOTE: As with Timur [Timerlane], many important Moslems were given Latin names by Europeans. However, most were mispronunciations or tranpositions of the Arabic names, not honorifics like "the Commentator." See Chapter 7 for more on Europe's increasing openness to Arabic ideas after 1150.)

In the 1300's, Moslem astronomy declined, before having one last period of glory from 1409 to 1449. The sponsor of this brief renaissance was the ***Mogul*** Emperor ***Ulugh Beg***, a grandson of Timur. Like Al-Ma'mum 600 years earlier in Baghdad and Prince Yusif 250 years earlier in Marrakech, Ulugh Beg loved knowledge. So he built a school and the world's largest observatory, a cylindrical stone tower with a diameter of 264 feet that housed the most accurate astronomy instruments ever built, in the capitol of his empire, ***Samarkand***, Transoxiana.

Unlike earlier patrons of science, however, Ulugh Beg was a leading astronomer at his own observatory who spent 40 years measuring the angles that separate the heavenly bodies as they move across the sky. Aside from suggesting Beg may have been less than attentive to his Imperial responsibilities, the remarkable accuracy of the work done at Samarkand's observatory demonstrates the subtle mathematical approaches and language available to Moslem astronomers by that time ***and*** the advances Moslems had made in the construction of scientific instruments. But after Beg was assassinated in 1449, Samarkand's astronomers made no more important discoveries, although the observatory stayed open for another 50 years. Finally, in the early-1500's, an army of Moslem fundamentalists from Afghanistan and Persia invaded the Mogul Empire, destroyed Samarkand, and demolished Beg's observatory, which they saw as a symbol of the dangerous thinking that arises when a person does not follow the Koran.

Other Arabic Sciences And Mathematics

Many Arabic commentaries on Greek philosophy and original works in astronomy were passed on to later European scientists and greatly influenced their work. But most Moslem work on physical questions remained unknown to European scientists. Nevertheless, Moslem scientists made great strides on the mechanics of motion, optics, and gravity, while beginning the difficult job of defining a standardized scientific method.

Three examples should suffice to illustrate this point.

1) The greatest Arabic physicist, ***Al-Haytham*** (Alhazen to Christian Europeans), was born in 965 in Basra, the largest Abbasid city in southern Iraq. As a young man, Al-Haytham worked as a civil servant, while spending his spare time as an "amateur" scientist. By 1000, he was a well-known scientist and the chief minister in Basra's provincial government. Despite these accomplishments, Al-Haytham wanted to devote all his time and energy to science. So, according to later Arabic historians, he faked "going mad" to get himself dismissed from his job with a pension. While we do not know if this worked, we know Al-Haytham moved to Cairo in 1009, and that a wealthy Cairo merchant agreed to pay him an annual salary in return for one copy per year of each of Euclid's Elements and Ptolemy's Algamest, an agreement that illustrates two important points: 1) it took a lot of time and skill to produce accurate hand-made copies of these huge and complex books, and 2) wealthy and influential Arabs greatly valued such Hellenistic "classics" of math and science.

His job as a scribe supported Al-Haytham until his death in 1040. But during his 31 years in Cairo, Al-Haytham also did work on the subject of ***optics*** that led him to reject the Greek (and therefore, Arabic) idea that light comes from the eye and bounces off the objects we see. Instead, At-Haytham said ***beams of light*** are emitted by objects. Then these beams travel in straight lines until they hit other objects, bouncing off them at many angles and continuing on their way until they accidentally strike a person's eye. Thinking of light in this way led Al-Haytham to study ***reflection***, the way light bounces back from shiny surfaces, and ***refraction***, the way it bends as it passes through materials like glass or other liquids, and to do a series of experiments into these concepts that were not equalled until Isaac Newton did similar ones and arrived at similar conclusions about light 665 years later. However, as with so much else that is mentioned in this section, neither Newton nor other European scientist of his day knew of Al-Haytham's earlier Arabic work, even though some historians now call Al-Haytham "the Arabic Newton."

2) ***Al-Khazin***, who was born near the Afghan border in Persia, moved to Baghdad to work at the House of Wisdom and stayed there until his death in 961. While in Baghdad, Al-Khazin wrote on many topics. Most importantly, he was the first person to state there is a force that pulls two objects toward each other (***gravity***), and that its strength ***depends on the distance between the two objects***. He even looked for, but failed to find, an equation that could express this relationship. Clearly, Al-Khazin's work would have been immensely useful to Newton and earlier European scientists as they worked on gravity.

And 3), ***several Arabic scientists tried to define a method for scientists to follow***. These include ibn Sina in Baghdad, 908-946; Al-Haytham; and Al-Biruni, who lived his entire life, from 973 to 1050, in Caliphates in Transoxiana, northern Persia, and Afghanistan, far from any center of Arabic science. While these thinkers failed to completely standardize the methods used by Arabic scientists or define ways to fairly judge experiments, they proposed several ideas that were later incorporated into the solution European scientists found between the 1200 and the 1644.

However, it was in ***medicine and mathematics*** that the Arabs made their greatest and most original contributions to science. While medicine lies beyond the scope of this book, Arabic mathematics was used by all Moslem physical scientists, and later by all Europeans. So we must take a brief detour to examine this important Arabic contribution to Western and world history.

As we have seen, ***Hindi numbers*** were praised by Severus in the 600's. But it was not until the 800's that an astronomer at the House of Wisdom, ***Al-Khwarizmi***, wrote several textbooks that demonstrated their overwhelming usefulness in solving a range of mathematical problems. These texts are the best record we have of Arabic arithmetic and problem solving methods, including their invention of ***algebra*** (an Arabic word). While some of the principles used in algebra had been discovered earlier by the Greeks and Chinese, Al-Khwarismi was the first to systematically define a set of rules and a mathematical language for working with algebraic equations (albeit without the equal sign). As a result, ***mathematicians still call the rules we use in arithmetic "algorithms,"*** a European mispronunciation of Al-Khwarismi's name. (NOTE: Since Europeans learned about Hindi numbers from Moslems, they incorrectly assumed the Arabs had invented them. That is why many people still call Hindi numerals Arabic numerals.)

Other Arabic thinkers concentrated on geometry, the ancient branch of mathematics that deals with points, lines, shapes (squares, circles, etc.) and forms (cubes, spheres, etc.). While geometry was first "invented" by Mesopotamians and Egyptians (at least within the Fertile Crescent) and improved by Greeks, the Arabs refined it and developed a related branch of mathematics called ***trigonometry***, which allowed them to describe and work with angles as completely separate entities.

All Arabic scientists benefitted from the facility and precision allowed by Arabic mathematics, and from the habits-of-mind that came from Moslem work on mathematical concepts and procedures. In fact, when taken together, the bringing together of Hindi numbers, algebra, geometry, and trigonometry constituted a unique Moslem intellectual contribution that proved crucial to ***all later*** scientists who wanted to study the mechanics of motion and the forces of nature, or to more accurately measure, locate, and compare the positions of celestial bodies.

Summary: West Meets East

By 1250, Arabic science had laid much of the groundwork for the creation of modern science. But the completion of this task fell to Europe. Why? Perhaps we can best answer this question by recounting the story of ***Al Mas'udi***, and by re-examining the unwillingness of Arabic astronomers to overturn Ptolemy's Model of the Spheres. Let's begin with Al Mas'udi.

By the late-800's, geographers at the House of Wisdom tried to base their maps on first-hand observations and reliable reports about far away places. Nevertheless, Abbasid maps still included many Islamic biases. Thus, Moslem cartographers always placed Mecca at the center of their maps and continued to rely on rumors and fantastic stories about places they had not visited. These shortcomings greatly bothered Al Mas'udi. So in 915, he left Baghdad to "travel the world." Thirty-five years later, in 950, he returned to Cairo a changed man and a geographer ready to make a world map entirely based on first-hand information from his travels. (NOTE: When Al Mas'udi left Baghdad, the city of Cairo was only 15 years old. By the time he returned, it had become an important center of Arabic intellectual life.)

Al Mas'udi's maps included lands from the Atlantic (Spain and Morocco) to India, and from the Alps and Russia in the north to lands south of the Sahara Desert. More importantly, they ***did not distort*** the shapes, sizes, or placement of the places Al Mas'udi had visited. In fact, Al Mas'udi placed the center of whatever territory was represented by a map in the center of that map, thereby de-emphasizing the unique importance of Islam, the Arabs, *or* the ancient Greeks. Al Mas'udi justified these maps by making the radical statement that ***a scientist should never accept the word of any authority***. Instead, he should check all ideas himself, even if they came from the ancient Greeks or the Koran, the two most respected sources of knowledge in the Arabic world.

Over 100 years later, Al Yakeb Israel took an equally long journey when he travelled from Spain across central Europe into the heart of Russia. Even today, his description of the Slavs and eastern Norse are among the best sources we have on these groups during the Middle Ages. Similarly, in the mid-1300's, a North African Moor named Ibn Battuta travelled across North Africa, Greece, East Africa, western Asia, India, Southeast Asia, Indonesia, and China, and then published an account of his travels in Arabic in 1363 that chronicled a journey that covered far more territory than that claimed by Marco Polo.

Clearly, Al Mas'udi's example deeply affected later Moslem cartographers and travellers to "exotic" places. But we can only speculate about the effect Al Mas'udi might have had *if* his attitude had taken more general root among Moslem scholars and scientists. If so, they might have sought more independence from both ancient Greek authorities and contemporary Moslem political and religious ones. This, in turn, might have led astronomers like Al-Buzjani and ibn Yunus to trust their own analyses *and* reject Ptolemy's Model of the Spheres. In fact, given the quality of work done by many Arabic scientists, it is possible such a breakthrough might have led to a Moslem Scientific Revolution like the one that later occurred in European science.

However, this did not happen. Instead, and despite significantly adding to the world's storehouse of knowledge about nature, Moslem scientists continued to honor the authority of Greek thinkers. Then, after 1200, Moslem religious and political leaders rejected their own scientific and mathematical traditions because they felt they threatened the authority of the Koran and Islam itself, and because they came to value other, more "practical," accomplishments, such as military and economic expansion, more. In other words, Moslem science lost its initial momentum because of limitations placed on it by Arabic thinkers. Then it lost its right to exist because of political and religious forces that were beyond the control of scientists.

As this decline occurred, some Moslem mathematical and scientific ideas were passed on to European thinkers. Thus, in the end, Moslem civilization's role in the history of science was to act as the: 1) guardian and processor of ancient Greek ideas, 2) creator of original ones, especially in mathematics and scientific instrumentation, and 3) "melting-pot" and transmitter of contemporary ideas from their civilization, India, *and* China to Christian Europe. Without these contributions, there might never have been a European Scientific Revolution, a modern European culture, *or* any modern Western science.

CHAPTER SIX

EUROPE: CIVILIZATION ON THE EDGE

With the decline of Moslem science in the 1100's, our story now shifts to Europe. But before turning to this period in European history and science, we must first examine the changes Europe underwent between 476 and 1150, when we "weren't looking."

The Birth of a Western European Culture

Rome and the Germans

At its height around 200, the Roman Empire ruled western Asia, North Africa, and parts of Western and Eastern Europe. This gave the Romans control over the homelands of Mesopotamians, Jews, Egyptians, Greeks, Phoenicians, and Hittites. Through trade and war, Rome also had contact with Persia and the Hindis in India. As a result, Rome's conquest of Europe brought Western Europeans, for the very first time, into contact with the great mix of ideas that had arisen across western Asia and around the Mediterranean over the previous 4,000 years.

Nevertheless, northern Europe remained in the hands of Germanic tribes, who continued to attack Rome's western empire, until Rome was sacked in 476. However, the Fall of Rome did not end Roman influence in Western Europe. Instead, many Europeans continued to think of themselves as Roman citizens, while Roman towns in Spain, France, England, and Germany, often built on ruins of pre-Roman towns, became the main "urban" centers of the Germanic cultures. In fact, as the Germanic tribes struggled to create new political and social structures that would support a more fixed lifestyle, they relied on Roman ideas and practices. Meanwhile, European economic activity and trade continued in a pattern reminiscent of the last days of Roman rule.

In the 500's, Western Europe's Roman heritage was further enhanced by Justinian's reconquest of some western territories, and then, after Justinian's death, by ongoing if limited Byzantine involvement in Italian affairs. However, by 700, the transition to Germanic control and the unstable political and social climate in Western Europe left it increasingly isolated from Eastern Europe, the Mediterranean, and western Asia.

The Church of Rome

Most early Christians practiced their religion in secret, in small groups that were largely isolated from each other. However, when Christianity began gaining large numbers of converts in the 300's, churches were built in Italian and other Mediterranean towns. In an effort to expand their influence, these churches sponsored missionary monks, who were sent to the north and west, into the heartland of Europe, to convert the Germanic and Celtic tribes. Meanwhile, the local bishops who initiated these efforts retained a great deal of autonomy over the important doctrinal, practical, and staffing questions that arose during this period.

This arrangement served the Church well in its infancy. But as Christianity became more successful, the Church needed a better way to resolve disagreements and impose discipline on its members and clergy. As a result, bishops met periodically to pass judgment on important religious questions. However, as the Roman Empire collapsed and the world dominated by Christianity became more chaotic, the Bishops of Rome, Jerusalem, and Constantinople pressed competing claims to leadership over all Christians. Nevertheless, the emergence of a distinct Germano-Roman culture outside Imperial control, and the internal Church fragmentation that made meetings necessary in the first place, made it impossible for ***any*** bishop to exercise universal authority. As a result, by the mid-400's, the Bishops of Rome concentrated on consolidating their authority in Western Europe.

This more limited goal meshed perfectly with the needs of the bishops and Germanic "kings" who wanted to bring order to Western Europe, if only to legitimize their own power. Thus, by the 500's, all Western bishops accepted the Bishop of Rome as the leader of a Western Church that came to be called the ***Latin Church*** (or, Church of Rome). Moreover, as the Latin Church gained greater stature within Western Europe and its leaders defined its beliefs, rules, and structures, the Bishop of Rome came to be seen as ***the Pope***, the sole representative of St. Peter on Earth and the Church's undisputed leader. At the same time, the other leading Western bishops became ***Cardinals***, a title that gave them formal power in the governance of the Latin Church and authority over lesser bishops. In the end, these changes increased the unity of the Latin Church and laid the foundation for its future character as a highly structured and hierarchical institution.

From its inception, the Latin Church was composed of two "branches." First, there was the ***Ecclesiastic Church***, which served the religious needs of the non-clerical members of the Church (the laity). Structurally, the Ecclesiastic Church was made up of a "ladder" of churches that included, from bottom to top, local parish churches, larger town churches, the largest churches in cities (cathedrals), and ***the Vatican*** in Rome, the seat of executive and legislative governance for the entire Church. Each rung of this ladder was staffed by members of the clergy: priests, deacons, bishops, archbishops, Cardinals, and the Pope, all of whom were unmarried men who remained celibate in order to more fully serve God and the Church.

Problems involving day-to-day concerns, religious disputes, or Church policies worked their way up the clerical ladder until they reached the Vatican. There, each problem was taken up by the governmental body empowered to resolve that question and to advise the Pope, who had the ultimate power to make or approve all Church policies. Meanwhile, the Cardinals, who spent much of their time at the Vatican as representives of the area "ruled" by their home cathedral, played key roles in this process through their participation in the Vatican's executive offices and their own legislative governmental body, the College of Cardinals.

While the Pope exercised great influence over the Cardinals, and could over-rule College decisions, their collective will was difficult for any Pope to ignore. After all, the Pope and his advisors understood that the Vatican could not function without the participation and support of the Cardinals, and that every Vatican decision had to pass ***down through*** the Cardinals on its way to the clerical rung responsible for carrying out any Vatican decision. Thus, in reality, like the Pope, Cardinals exercised both legislative and executive power within the Church.

Clearly, this governmental system relied on many Roman ideas. But in time the Church's function and organization became so complex the Vatican and other Church theorists were forced to find entirely new solutions to Church problems. These ideas, called ***Ecclesiastic Law***, became one of the Latin Church's greatest contributions to European society, and to the secular governments that later evolved to manage it.

While the structures and practices described above worked well for most issues that arose within the Church, when very difficult religious disagreements arose, the Pope convened special meetings called ***synods*** or ***councils***. In these meetings, which were modelled on the earlier meetings of bishops, monastic leaders and high clergy, including bishops, archbishops, Cardinals and the Pope, reached decisions that, with the Pope's blessing, became Church law. In fact, most of the major questions of long-term Church belief and policy were resolved in this way.

When the Pope died and the question of Papal succession arose, the College of Cardinals met in Rome to elect a new Pope, almost always from among their own ranks. Once elected, the new Pope was given absolute authority over all Latin Church clergy, including the Cardinals who had elected him. In a larger sense, the viability of the Church's entire system of leadership depended on two doctrinal beliefs that were shared by all clergy and lay members of the Church: 1) every Pope receives direct guidance from God, so ***all Papal judgments are infallable***, and 2) the clergy, under the leadership of the Pope, has the right to make and enforce decisions on any question that arises within the Church, from defining Christian beliefs and setting Church policies to correcting, punishing, or rewarding the behavior of Church members. Moreover, it was this authority that allowed the Ecclesiastic Church to maintain the step-by-step, top-to-bottom institutional control that gave the Latin Church its coherence, stability, and earthly power over Western Europe's secular leaders, who might otherwise have undermined its authority.

To survive, the Ecclesiastic Church's system of governance also had to be flexible. In fact, one of the greatest accomplishments of the Latin Church's governmental and legal system was the balance it achieved between an unquestioning acceptance of top-down authority and the bottom-up involvement of lower clergy in the formulation of policies. Thus, despite times when Popes were weak, factions in the College of Cardinals (or, among monastic Orders) struggled for control of the Church, the Church was forced to take sides in wars or political disputes among Europe's secular leaders, and even one period in which two Popes claimed universal authority, the idea of a centralized Church directed by a divinely-inspired Pope survived.

Between 200 and 300, there was a great rise in mysticism among Eastern Christians. As a result, some men in Egypt and the Levant who wanted to devote themselves completely to "practicing their religion" became ***monks***. Many early Eastern monks lived alone in caves or other isolated places, while others travelled widely preaching the virtues of living a more pious life. In both cases, most monks demonstrated their piety by living very simple lives of great poverty and pain, and by developing and following very strict personal rules and behaviors that "proved" their devotion to God. When several monks shared similar beliefs, they formed small communities that offered their members physical and spiritual support. By the late-300's, this idea of like-minded monks living together spread westward across North Africa into Europe, where communities of monks started building houses called ***monasteries***, an idea that was further entrenched by Justinian when he built hundreds of new churches and monasteries in Western Europe and North Africa in the mid-500's.

Each monastery created its own doctrines and rules, usually in emulation of an early Christian martyr or the founding monk of that monastery. But over time, successful monasteries opened "secondary" chapters to attract other monks who would follow the same rules and beliefs. Eventually, monasteries that followed the same rules, shared the same beliefs, and pledged obedience to the same "head monk" banded together to form ***Orders***. In fact, as monasteries became more important in Western Europe, several men's Orders were established, while separate Orders were formed for women who wanted to serve God and the Church as nuns. Since in many ways nuns lived just like monks, some women's Orders "allied" themselves with like-minded men's Orders.

Altogether, these Orders formed a separate branch of the Latin Church called the ***Monastic Church***, the members of which promised to: 1) accept the rules of their Orders and the authority of those responsible for running them, 2) devote their lives to serving Christ and the Church, and 3) remain celibate and unmarried. In time, some Orders also took on the job of meeting the spiritual, educational, and nursing needs of the Ecclesiastic clergy or some segment of the laity.

These responsibilities gave leaders of Orders great power over their members and, despite their intent to retreat from everyday life, great influence within the larger world of the Latin Church. This "worldly" power and the role of Monastic Church leaders in interpretting Christian beliefs for the Church became the source of much competition. In fact, the difficulty of exercising power within the Church while maintaining an Order's independence led to a de facto system in which Monastic leaders accepted the authority of the Pope while often challenging each other and the authority of Cardinals, bishops in cities near their monasteries, and the lower clergy in the Ecclesiastic Church. Thus, when men's Orders disagreed with decisions taken by the Ecclesiastic Church or local clergymen, Monastic leaders often lobbied Cardinals or the Pope to have the decision changed. And when synods or special councils were called, Monastic leaders competed to play key roles in shaping Church beliefs or, later, in legitimizing or opposing policies that had been enacted.

This may sound like a confusing way to run a Church. But the competition between the two branches of the Latin Church, and among monastic Orders or among Cardinals, gave the Church the flexibility it needed to remain unified for more than 1,200 years. In any case, the combination of the Church's feudal ladder of authority, rigid rules, ***and*** internal disagreements provided a workable system that enabled the Church to adapt to changing situations as they arose in Western Europe.

Western European Education and the Wider World

Among the positive effects of the role played by monastic Orders was the recognition by each Order that some of its members had to become more learned, if only to define that Order's beliefs and religious positions, defend those positions and the Order's prestige against others, and create curricula for the schools each Order ran to train its new monks (***novitiates***).

Monastary school students learned about the Bible, other religious writings, and the specific ideas and practices that had been accepted by their Order. Novitiates who demonstrated a talent for such work could look forward to careers as scholars who would do research, teach in the Order's schools, or copy and write commentaries on important books. In fact, by the 700's, monastic Orders were the only Western European institutions that provided intellectual training and the possibility of a life of scholarship, thereby providing opportunities that were important reasons for poor but intelligent or talented men to become monks. Thus, monastic Orders contributed greatly to the development of Western European culture by promoting the arts and intellectual activity until other institutions developed and took over this role, albeit with different goals and values.

Until the late-1000's, most monastary school students were novitiates or candidates for positions as high Ecclesiastic clergy. Meanwhile, princes and nobles received far less formal education. The education these secular leaders did receive was usually delivered by monks sent by an Order to tutor them in their homes, often in the hope of receiving donations, political support, or protection from a student's parents. In time, several Orders made this kind of work their mission, and allowed princes, nobles, and wealthy laymen into their schools.

Nevertheless, most lower clergymen remained poorly educated, while those destined to be Cardinals or Popes continued to be drawn from the high noble or royal class. Therefore, despite the education monastic schools offered many poor students, it was extremely rare for such students to become Ecclesiastic Church leaders, a fact that ensured the Latin Church's leadership would continue to reflect the secular feudal structure of European society and the interests of Europe's royal and noble leaders.

During this period of consolidation in the Latin Church, which covered the years from 400 to 1000, a similar process was unfolding at the eastern end of the Mediterranean, as bishops there came to accept the Bishop of Constantinople as the Patriarch of the Eastern Orthodox Church, the official Church of the Byzantine Empire. While Byzantine Emperors initially decried this split in Christianity, not least because it undermined their claim to universal secular authority, they were forced to focus their attention on western Asia and the southeastern corner of Europe, the areas in which Byzantium controlled territory, maintained trade networks, and confronted its enemies: the Persians, and later the Arabs, Mongols and Turks. However, this also meant Byzantium and the Orthodox Church, unlike their counterparts in Western Europe, remained in contact with the Moslem civilization of western Asia and the great mix of ideas that had spawned Mediterranean civilization in the first place.

Despite the split between Eastern and Western Europe, and Byzantium's greater wealth and influence during this period, Western European culture did not stand still. Instead, the Latin Church grew more sophisticated and complex, while one Germanic tribe, ***the Franks***, established a stable kingdom in France. When the Franks were converted to Latin Christianity and drove back the Moors when they crossed into France from Iberia in the late-700's, the Latin Church's hold on Western Europe ***and*** the Franks' role as defenders of the Church were both strengthened. In fact, this reality was formally recognized on Christmas Day ***800***, when the Pope crowned the Frankish king ***Charlemagne*** as the new, and supposedly universal, ***Western Roman Emperor***.

The crowning of Charlemagne marks the establishment of a distinctly Western European system of feudal, Church-legitimized, royal government that came to be modeled on the personal example of Charlemagne, a ruler who skillfully consolidated political, economic, and military power for his Crown while promoting artistic and intellectual activities within his realm. In fact, under Charlemagne and his successors, the Frankish kingdom and Western Europe in general experienced a burst of energy and an increasing order called ***the Carolingian Renaissance***. During this period, which lasted until 900, trade within Europe grew; towns became larger and more important (that is, more like cities); there was a boom in the arts and learning in France, Italy, England, and Ireland; and the Church converted several new peoples to Christianity, thereby consolidating its own authority and increasing Western Europe's religious and cultural cohesion.

Aside from legitimizing the Church's claim of spiritual leadership over all secular leaders in Western Europe and Charlemagne's power over other Western European kings, the Papal crowning of Charlemagne also bolstered a process within Western Europe in which there was a tightening of control by central authorities and a redefinition of society according to precise classes. Thus, while it took centuries for this system to reach its maximum effect, the year 800 marks a key moment in Western Europe's ***social*** evolution into a society based on a ladder of authority, with each rank, from Emperor to kings, dukes, lower nobles, commoners, and peasants, owing loyalty and service to the rank above it while having power over and responsibility for the rank below. As a result, with the Church's blessing and support, Europe was changing into a society defined by a set of heirarchical and reciprocal relationships called ***Feudalism***.

In theory, Feudalism gave stability and order to European society by promoting social virtues like honor, purity, loyalty, and chivalry, and the notion that society should be modeled on a well-disciplined family. In reality, however, kings often tried to maintain their independence from the Emperor or increase their power or territory at the expense of other kings or nobles, while higher nobles routinely ignored or challenged the authority of kings or were jealous of each other's power and influence, and so on down the supposedly rigid feudal system to the level of the lowest nobles. Moreover, despite the theoretical reciprocity of feudal relationships, few individuals at any rank fully honored their pledge of protecting the welfare of those beneath them.

Thus, the ***actual*** behavior of Europeans often undermined Feudalism's stated beliefs. But this also made Western European society more flexible than the rules of Feudalism might suggest, which allowed capable individuals to move up a rung or more, displacing others who moved down. In fact, it was not uncommon for "upwardly mobile" secular individuals to cite the rigid rules of Feudalism to legitimize their new-found authority once they achieved it, thereby giving the appearance of political and social orderliness to a situation in which actual relationships were often unstable.

Similar "smoothing over" occurred in the Latin Church whenever: 1) its rules were violated or ignored by bishops or Cardinals who were struggling for personal power or attempting to thwart each other's or Papal authority, 2) an emperor, king, or noble tried to enlist Church approval for their side in a secular dispute, influence Church decisions or appointments, or limit Church influence in secular matters, or 3) Church leaders took sides in earthly matters in order to expand the influence of the Church over secular authorities. Moreover, the greatest risk in these situations was that a conflict might lead to open conflict between a Pope and Emperor or a powerful king over the question of whether religious or secular authorities should have primacy in European life.

Nevertheless, we should not underestimate the role Feudalism played in shaping Western European society. It gave Church and secular leaders a common ideology and a somewhat shared interest in bolstering each other's authority over ordinary Europeans. It also encouraged Europeans to define themselves and others in terms of their rank in society, rather than by their individual talents or abilities. And finally, it gave Europeans a sense they belonged to a single civilization with shared rules and beliefs. In other words, ***Feudalism gave Western Europe a coherency and justification it sorely needed as it changed into a separate, viable, and durable culture.***

After the decline of the Carolingians, Imperial authority was claimed by kings in the area we now call Germany, who, after the ascension of Otto I to the Imperial throne in 962, took on the title of ***Holy Roman Emperor***. Despite Latin Church efforts to support the Imperial and feudal system, however, Western Europe's social and economic structures continued to erode, as did the authority of the Emperor. Thus, by the mid-1000's, the supposedly all-powerful HRE'ors were chosen from among Germany's minor princes (or, "kinglets"), most of whom were powerless outside their own small kingdoms, even within Germany. Moreover, as the HRE grew weaker, other European kings grew stronger, until many commanded more territory, wealth, and authority than their supposed imperial over-lord. So, while in theory the ideals of a feudal Western Europe survived, by 1150 Europe's kings were almost wholly independent of HRE authority, which left European monarchs to an uncertain and chaotic reality in which they often competed with each other with an almost unchecked ferocity.

There were also other reasons for Europe's decline after 900. Above all, during the 800's and 900's, constant raids and a few full-scale invasions by as yet un-Christianized Norsemen (the Vikings) became so bad they disrupted the economic and political life of many areas in Western Europe. As a result, Western European cities became poorer and in many cases smaller, trade within Western Europe declined, and interest in knowledge and learning ebbed, until there were few Western Europeans, including kings, nobles, lower-level priests, or commoners who knew how to read or write. Thus, the strides made under the Carolingians to encourage scholarship, learning, and the arts were turned back, leaving only a small but dedicated monastery-bound group of monks to keep these traditions alive.

Hence, just as the Arabic Empire reached its political and economic, if not intellectual, peak, Western Europe was becoming a poverty-stricken place in which little was left of Roman order or the feudal authority of the Pope and the HRE. Consequently, while Moslem conquests in Western Europe were limited to Iberia, Sicily and small outposts in southern France, ***the Mediterranean became "an Arabic lake."*** Given the hostility between Moslems and Christians during this period, this further isolated Western Europe from the Mediterranean world and the Asian civilizations that participated in the Moslems' trade networks.

Ironically, much of Western Europe's rather limited trade and contact with Byzantium and the Moslem world during this period was carried on through the Norse, who by then had established permanent trading posts and a few stable political units in Western Europe. Meanwhile, other groups of Norse were invading Poland and Russia, where they established trading outposts and a small principality called the Rus (centered in Moscow) that gave them control over the northern trade network that indirectly connected Western Europe with Byzantium and its trading partners further to the East. (NOTE: It was these Norse-Slavic settlements that Ibn Battuta visited in the mid-1300's.)

The Politics of Western European "Countries"

At first these changes brought nothing but decline to Western Europe. However, by 1150, isolation and the diminishing authority of the HRE began to have some positive effects. Above all, several kingdoms and dukedoms grew more stable, powerful, and certain of their own legitimacy as political units. This happened first in Italy, France, England, and Iberia (later, Spain and Portugal). So let's begin by taking a brief look at the political history of these areas in the years leading up to 1150.

Between 950 and 1150, Italy was divided into three areas. Northern Italy was home to dozens of city-states. Central Italy included both city-states and an area controlled by the Vatican called the Papal States. Southern Italy changed hands often, and was sometimes united into a single kingdom. But at other times it broke up into several kingdoms. Sicily, in particular, had several periods in which it was a separate kingdom ruled by non-Italians, including one in which it was ruled by Moors.

At the same time, the Christian kingdoms in northern Iberia began an intense competition for political power, territory, and the honor of reclaiming the rest of Iberia from the Moors. Thus, as the territory ruled by the Moors shrank, the competition and desire to consolidate power among Christian kingdoms intensified.

Meanwhile, France's kings seldom controlled more than their own dukedom, which was centered in Paris. As a result, their influence seldom extended beyond the Seine and Loire valleys. So, much of France was ruled by dukes who acted as if they ruled separate kingdoms, a posture bolstered during this period by the development of local dress, languages, customs, and other habits (that is, cultures) in each region of France. In fact, by 1150, many "French" people felt more loyalty to their dukes and local regions than to France or its king, which made it difficult for any French king to build a strong kingdom. Moreover, some of the strife between dukes and monarchs in France, as in other European kingdoms, was caused by the very system designed to support a king, which made him the duke of one region within his kingdom. For, while this gave a king an independent source of wealth to support his court and the trappings of monarchy, it also made him little more than the equal of other dukes in his realm.

This is perhaps best illustrated by the history of Normandy, a dukedom on the English Channel in western France. To understand the Normans, we must begin in the early-800's, when Norse raids on coastal England, France, and Iberia intensified, and Viking raiders permanently conquered some territories. In 878, a Viking army staged a full-scale invasion of the British isles, leading to the establishment of a kingdom in Britain called ***the Danelaw***. However, the "natives" of Britain resisted their new overlords. As a result, in ***911***, the Vikings were driven out of Britain. When ***Rollo the Viking***, the leader of these "British" Norsemen, led his people across the English Channel, he was made the Duke of Normandy by the French king, both to neutralize this new threat and in the hope Rollo would control (or at least balance) the overly independent nobles in that region of France. In time, the descendants of Rollo and his followers strengthened their hold over Normandy, absorbed many of its local customs, and mixed with the local population to become the ***Normans*** (from Nor[se]men).

According to the rules of Feudalism, the Duke of Normandy owed his loyal support to the King of France. But many Dukes of

Normandy did not see it that way. Instead, they formed alliances with other dukes against the King of France, often to advance their own claims to France's throne. Finally in ***1066, William the Conqueror***, the Duke of Normandy, crossed the English Channel, defeated the Anglo-Saxon armies of Edward the Confessor, and conquered England, not for the King of France but for himself. Later, Norman Kings of England used conquests, marriages, and alliances to also become the Kings of Sicily and Naples and, during the Crusades, the rulers of small kingdoms in the Levant. Thus, while it lies beyond the period covered by this chapter, by 1200 the Duke of Normandy had far more power, land, and wealth than the King of France, which left the latter in the inherently weak position of being the overlord of a noble who was an internal threat as the Duke of Normandy ***and*** an equal or superior as the king of France's most important enemy, England.

England's Norman kings found it equally difficult to control their dukes. But unlike in France, there was the added issue in England of a foreign king ruling a population of ancient and fiercely proud tribesmen who had already resisted several earlier conquerors. In fact, given these obstacles, it is a great testament to the political and military skill of the early Norman kings that, by 1150, they were able to consolidate their power within England while beginning the long process of expanding their kingdom to include Scotland, Wales, and part of Ireland.

When taken as a whole, the increasingly fractured political situation in Europe undermined the authority of both the Church and the HRE. Even the Vatican, which continued to favor feudal relationships and hierarchical order, was unable to bring peace to the volatile world of European politics. Instead, Europe's secular disunity began to affect the Latin Church. In fact, it became increasingly common for bishops and Cardinals to work with local kings or dukes to gain political and religious power for themselves or for their "home" areas.

Summary: Western Europe's Heritage, and a Note on Its Legacy

Until 1100, the monastery schools that trained novitiates and high clergy were the only educational institutions in Western Europe. However, by the early-1100's, cathedrals in large cities began organizing schools that were staffed by local monks and priests. The curricula in these ***cathedral schools*** included a broader range of ideas about Christianity, teachings of the early Greek and Roman Christian Fathers, and Greek and Roman ideas that had been accepted by the Latin Church, including some from Empedocles, Plato, Ptolemy, and Euclid.

Thus, cathedral schools were a reflection of the increasing decentralization of European authority. But those schools also gave Europe a more "inclusive" educational system and curriculum, although they still did not embrace all Greek ideas. In the realm of natural philosophy, most ancient ideas were still ignored or forgotten, while Latin Church leaders continued to ban others they felt contradicted Christian belief. Most importantly, those Greek ideas that ***were*** accepted were taught as if the Greeks had produced no other ideas about nature, there had been no post-Classical scientific discoveries, and there was no ***need*** to make new discoveries. As a result, European mathematics and science stagnated, while Arabic science and math, which were based on a fuller range of Greek (as well as Indian and Chinese) ideas and which showed a livelier interest in creating new ones, remained unavailable to Western Europeans.

There was no single moment when Western Europe re-discovered the full range of Greek ideas or awoke to the possibility of creating new ones. Many historians say this new European attitude reached a peak between 1450 and 1550 during ***the Renaissance***. (NOTE: See Chapter 7 for more on this period.) But in reality this change began long before 1450. This book has chosen the unusual date of 1150 to mark the beginning of this process, because this was when many translations of Arabic books became available in Europe and when Europeans started doing experiments and thinking about ***how*** to do science.

Nevertheless, as we turn to Europe for the rest of our story, we must remember that civilization began in Mesopotamia and Egypt over 6,000 years ago. Since that time, there have been many civilizations that have flourished around the world, through their own intellectual accomplishments ***and*** by borrowing from other cultures and civilizations. In the case of Western Europe and the scientific accomplishments we are about to chronicle, Egypt, Mesopotamia, Israel, Phoenicia, Persia, and the Arabs, all of whose cultures were centered outside Europe, all played key roles in shaping European ideas, as did ancient Greece. Therefore, any fair and complete history of Western science must include these other Western cultures.

More fundamentally, Mesopotamia, Egypt, Persia, India, China, Peru and Mexico, at least, had scientific traditions that did not depend on contact with Europeans. In fact, as we will see in Chapter 11, non-European science was often more advanced than Europe's, a point attested to by the technological and material superiority of several Asian civilizations before the rise of European science; the ideas and technologies Europeans borrowed from other civilizations; and the many European scientists and mathematicians who made discoveries similar to ones made earlier in other civilizations.

In short, as we embark on the European part of our story, we must remember that Western European science and physics has led the world for less than 600 years, while the spread of European culture to the rest of the world began only 450 years ago, when European explorers, conquerors, missionaries, and colonizers brought European culture to (or imposed it on) other parts of the world. In fact, European science has only had a significant impact on most of the world for 200 to 300 years, and in some areas, for less than 100 years.

However, we must balance this understanding with an equal appreciation of what *has* happened in the last several centuries. Once European science was exported to other areas of the world, it evolved into a world-wide effort, giving it a remarkable influence over peoples in every corner of the world. During the early stages of this process, non-European participation in Western science was dominated by individuals of European descent who lived in "Westernized" countries like the United States, Canada, New Zealand, and Australia: in a sense, overseas outposts of European culture. But, in the last 50 years, non-Western scientists from every culture, ethnicity, and race have also made important contributions to Western science, raising the possibility that future non-Western societies will someday use science and technology (including those elements of it that originated in Europe) to dominate Western countries.

In some ways, this has already begun to happen. Countries like Japan, South Korea, Singapore, Taiwan, and Hong Kong (the "Asian Tigers") have become so successful at using Western scientific ideas that they now export ideas about industry, technology, and applied science to Western countries. In the future, the same may be true of China, India, Zaire, Kenya, Argentina, Brazil, Chile, or Pakistan, any one of which may look back on our time and wonder how such backward places as North America or Europe ever played a key role in world science, much as we often do when we look at modern-day Iraq, Egypt, or Greece.

Therefore, as we begin the story of Europe's scientific achievements, we must remember history teaches us that whenever there is a re-mixing of peoples and ideas from various cultures, a process is set in motion that changes existing civilizations and creates new ones. Thus, there is no guarantee modern science will always be called "Western." Or, that Western countries will remain dominant in science in whatever future emerges from the processes presently underway. That said, let us now turn our attention to European science.

CHAPTER SEVEN

EUROPE AND THE ROOTS OF MODERNITY

Given the complexity of European history in the period between 1150 and 1642, we must limit ourselves in this chapter to the events that most directly affected the development of modern physics and astronomy. Consequently, the histories of local Western European areas will be largely ignored, as will Central and Eastern Europe, despite their important contributions to European history. Hopefully, however, the picture painted here will highlight the main forces that shaped Western science.

The Politics of Western Europe "Countries"

By 1150, the authority of the Latin Church and the ideals of Feudalism had eroded so much they could no longer keep Western Europe's dukes and kings from engaging in numerous conflicts with each other. Nevertheless, during the next 300 years, several European countries became more stable, laying the foundation for the Europe that emerged after 1450. So let's begin with a brief "country-by-country" survey of the political developments that most affected Western Europe from 1150 to 1450.

Between 1150 and 1450, French kings increased the prestige, power, and legitimacy of their crown; extended France's physical territory; and fought a series of wars against England that gave the French people the beginnings of a common political and military experience, and enlisted French dukes in a joint effort against a common enemy. So, while conflicts between French dukes and monarchs continued, by 1450 France became a leading European power with a central government that was led by a powerful king who ruled a relatively stable territory.

During this period, English kings relinquished control over Normandy. But they solidified their rule over England and Wales, and less securely over Scotland, laying the foundation for an expanded kingdom that came to be called Great Britain (the United Kingdom). However, as in France, British kings found it difficult to control their nobles. So, when the unpopular King John of Robin Hood legend came to the throne, his dukes decided to work together to thwart John's abuse of his powers. To end the ensuing stand-off, King John and his dukes signed an agreement in ***1215*** called ***the Magna Carta*** that established the concept of the English monarch sharing some power with his dukes. This principle was further entrenched in ***1264*** when the ***Parliament*** was created as a new legislative body that would give nobles a permanent forum for debating "national" questions and exercising influence over royal decisions. In return, Parliament gave British monarchs a forum in which they could muster support from nobles in their struggles against rebellious dukes or foreign powers.

However, most English monarchs soon learned how best to manipulate Parliament to get their way on key issues and to maintain their overall royal powers. Thus, by 1450, Britain became a powerful kingdom with a stable territory and a monarch who exercised authority in much the same way as other European monarchs. Nevertheless, Parliament played a huge role in shaping Great Britain's political system. Above all, British monarchs learned their relationship with Parliament was an important element in the accumulation and maintenance of royal power. And, while it took longer, nobles (and later, commoners) learned to use Parliament as a political tool and as a symbol of their role in the governance of the kingdom, especially in times of crisis. In time, this ***sharing of power and responsibility*** gave Britain's government a stability and degree of support, at least within England, that would become the envy of all other European powers.

Between 1150 and 1450, northern Italy's city-states became wealthier and more independent, in part due to their monopoly over European trade with the Moslems. As a result, by the mid-1300's, each northern Italian city developed its own character and unique sense of a political and economic destiny. Meanwhile, city-states and the Papal States in central Italy also prospered, despite continuing struggles for territory and local power. And, southern Italy continued to have periods in which it was carved into principalities and others in which non-Italians like the Normans and Castillians (the founders of Spain's monarchy) ruled all of southern Italy, including, at times, Sicily. Moreover, the continued existence of three regions within Italy, and the vibrancy of its many local cultures and political units, kept any Italian central government, royal or otherwise, from developing.

During this period, the princes (or "kinglets," as one historian calls them) who claimed over-all German authority and the title of HRE'or were unable to unify Germany or amass the kind of power, even locally, enjoyed by other European monarchs. Consequently, in the late-1200's, Germany's powerful municipal governments formed an alliance, called ***the Hanseatic League***, that promoted the independence of each city and the collective role of German cities in northern European trade. Thus, by 1450, Germany was ruled by a patchwork of proto-royal governments and a collection of powerful local urban ones.

The situation in Iberia gave its Christian monarchs special problems and advantages. As Moorish territory was "reconquered" for Christianity, Portugal, Catalonia, and Castillia emerged as Iberia's dominant kingdoms. Then, in the early-1400's, Portugal established its permanent independence from all other Iberian kingdoms, while the others struggled on until the Castillians drove the Moors from their last stronghold in Iberia in 1492 (an interesting date) and established a unified Spanish throne. Thus, while fighting the Moors delayed the emergence of unified Iberian kingdoms that could control stable territories or act as powers on the larger European stage, by 1500 (but not by 1450) the royal authority used by Portugese and Spanish kings during their "holy wars" against the "Infidels" left them with more power over their nobles and kingdoms than any other European monarchs.

By 1500, France, England, Spain, Portugal, Germany, and Italy were the key Western European political powers. But other countries emerged between 1150 and 1500. Switzerland, set off from the rest of Europe by its Alpine terrain, fought for and gained independence from its larger neighbors by promising to remain neutral in all European wars and by establishing a central government made up of elected representatives of all the Swiss provinces (cantons), thereby creating Europe's first and longest lasting "national" democracy.

At the same time, the Netherlands (Holland), Luxembourg, and Belgium, together the "lowlands countries" along Europe's strategically important northwest coast, struggled to maintain their independence from Europe's larger powers. In fact, each was ruled by France, Spain, the HRE or England at various times before establishing its own independent government and identity in the 1500's and 1600's. Of these small countries, Holland was the most important, because its cities became important centers of shipping, trade, banking, and other business activities for all Western Europeans. Dutch cities also sponsored their own overseas enterprises and developed a unique urban culture that greatly affected future European art and lifestyles, giving Holland a far greater cultural, political, and economic influence than its population and size would seem to warrant. And finally, by 1450, the Viking kingdoms of Denmark and Norway became fully Christianized, permanent, and stable political entities.

The Church, Change, and the Rise of Education

The emergence of some European kingdoms, principalities, and dukedoms as stable, independent political units greatly affected the Latin Church. For, as monarchs, nobles, and other educated Europeans developed their own regional perspectives, bishops and Cardinals were put in the increasingly uncomfortable position of promoting pan-European Latin Church interests in their home regions while promoting the interests of their "home" political overlords within the Church. Thus, while the Pope remained the unquestioned leader of the Latin Church, ***by the late-1400's, the Church became less unified***. However, this did not happen overnight, or without the Church attempting to stop it or adapt, a point perhaps best illustrated by the history of Western European education during this period.

As Europe's economy improved after 1150, many cathedral schools tried to meet the educational needs of nobles, merchants, and others destined for careers in business or government. Then, as the market for education increased, groups of cathedral school teachers established informal "street schools," thereby giving Europe its first partly independent and unregulated educational institutions. Finally, in 1200, the street schools in ***Paris*** (France) and ***Bologna*** (Italy) were given charters by the King of France and Bologna's city government, making them Europe's first ***universities***. Then, in 1209, the King of England granted a charter to Oxford as Great Britain's first university. In fact, over the next 200 years, many city and royal governments started universities in the hope of improving local education and promoting the prestige and importance of their city or country.

Nevertheless, ***all*** university teachers were still monks or members of the clergy. So the Church retained its stranglehold over university personnel and the crucial question of which ideas universities should be allowed to teach. Meanwhile, Latin, the language of the Church, remained the language of all university instruction and intellectual work. However, since universities were not wholly inside the Church, they could not be totally controlled by it. in fact, as universities replaced monastic and cathedral schools as Europe's leading centers of learning, they became more reliant on secular authorities for support and protection, which emboldened some professors to teach Greek and Arabic ideas that had not been accepted by the Church. Moreover, as ***universities introduced more Western European students to non-Christian and secular ideas***, some teachers and students began to question Church teachings about the physical Universe. By 1450, and despite the Latin Church's role in creating them in the first place, universities became the central players in an intellectual awakening that undermined Church authority, in some ways forever.

The Economy of Western Europe

Before 1150, kings, nobles, and the Latin Church dominated Western Europe's economy through their control of landed estates and the agricultural production of the peasants. But between 1150 and 1450, a ***merchant class*** arose that stimulated manufacturing and trade, both within Europe and with the outside world. These merchants were also the first Europeans who did not base their wealth on agriculture, fit into a pre-set rung in the Feudal ladder, or accept the nobles' monopoly of economic or political power. Nevertheless, most nobles did not lose their wealth or privileges immediately. Instead, some grew richer by running their own businesses or collecting taxes from merchants, while those who failed to adjust to the new economy and became poorer still retained their special status as military, social, and political leaders within Europe's Feudal system.

The rise of the merchant class ***did***, however, contribute to significant changes in European society. First, the cities became larger and more important as centers of wealth, political power, and learning. Second, the merchant and higher noble classes became better educated. Third, governments and businesses began attracting talented and well-educated men, for the first time drawing large numbers of them away from the Ecclesiastic clergy and the monastic Orders. And fourth, Europe's economy was re-organized into a centrally-managed pre-Capitalist system that promoted the collective economic advantages of monarchs, powerful nobles, and merchants. We call this system ***Mercantilism***.

Meanwhile, the people who worked in the cities for merchants or in trades, like candle-making or carpentry, formed collective associations called ***guilds***, which represented workers in separate businesses or jobs, to protect their rights and privileges ***and*** provide a level of social support and comradery they had never known. In time, guilds gave ***pre-industrial workers*** a new sense of their worth as people, despite their low feudal status.

<u>The Crusades and the Wider World</u>

Contact with the Moslem world was crucial to the onset and maintanance of these changes. It was the Moslems who first exposed Western Europeans to many ancient Greek ideas, "modern" Arabic ideas, and the products and ideas from Eastern and South Asia that by 1450 stimulated key political, technological, economic, and cultural changes in Europe. However, this contact was seldom friendly. In fact, as Arabic power slipped, at least in the western Mediterranean, several Popes called on Christians to "reclaim" Moslem lands in Iberia and Palestine. After all, to Christians, Iberia was the last Moslem strong-hold in Europe, and Jerusalem and Bethlehem were the birthplaces of Christianity, which made Palestine the Holy Land to all Christians.

Not surprisingly, Moslems saw things differently. After all, Jerusalem was ***their*** second most holy city, the site from which Muhammed was said to have ascended to Heaven. In any case, the territories the Popes wanted to "reclaim" had been in Moslem hands for over 400 years and were ruled by Moslem kings or caliphs who felt they had every right to defend themselves, something they were confident they could easily do given Islam's glorious military history. In fact, to most Moslems of that time, Western Europeans were neither equals nor worthy opponents. They were simply ignorant and backward people who made useful trading partners. Nevertheless, between 1096 and 1270, several Popes called for a "holy war" against Moslems, leading to the mounting of eight military campaigns to the Holy Land and several in Spain. Collectively, we call these campaigns ***the Crusades***.

From a modern perspective, the mounting of the Crusades is one of the most disturbing and puzzling episodes in European history. But we must remember this was a time of great religious fervor in Europe, and that Church leaders and Crusaders sincerely believed it was their duty to rescue the Holy Land and Spain from Moslem control. However, it is also clear Latin Church leaders hoped the Crusades would: 1) increase European unity by getting all Europeans to focus on a common enemy, 2) enhance the prestige and authority of the Latin Church over Europe's earthly leaders, based on its leading a successful war against the Moslems, and 3), re-unify all Christians, including Eastern ones, under the leadership of the Vatican.

In a sense, then, the Crusades were launched to reverse the changes in European society that were already undermining Church authority and the centralized secular authority of the HRE. In fact, these earthly concerns often overshadowed the religious ideals expressed in launching the Crusades. As a result, most were brutal enterprises in which Christians and Jews who lived along Crusade routes were killed or had their property destroyed or stolen by the Crusaders, while the treatment of Moslems was as bad or worse. Meanwhile, many Crusaders, including some kings and nobles, died along the way or in the Holy Land, were captured and imprisoned by the Moslems, or simply disappeared.

The Crusades to the Holy Land achieved only minor and temporary successes, while the final reclaiming of all of Iberia would take another 200 years. Thus, while several Crusades reached the Holy Land, and parts of Palestine, Lebanon, Syria, and Turkey went back and forth between Moslem and Latin Christian control, by the late-1200's the Ottoman Turks re-established Moslem control of Turkey and the Seljuk Turks re-took Palestine and the rest of western Asia, although the last Crusade briefly established several small Latin kingdoms in Greece. Nevertheless, when the Crusades ended, so did the days of Christians controlling the Holy Land, at least for the next 600 years.

Despite the erosion of Byzantine power during this period, the Crusades also failed to re-unite all Christians under the Latin Church. As it turned out, the traditions of Eastern Orthodoxy were just as valuable to its followers as were those of the Latin Church to Western Europeans. So, rather than accept conversion to Islam under the Ottomans *or* Papal leadership, the center of Eastern Orhodoxy shifted from Byzantium to Russia, the emerging super-power in Eastern Europe. Even in Western Europe, the Crusades' provision of a "common enemy" failed to stem Europe's political disintegration or the decline of the Latin Church's authority and internal unity.

However, the Crusades ***did*** expose Western Europeans to the exotic cities and material culture of Islamic civilization, creating, almost overnight, a "taste" for the products of the Moslem world, and the spices and other products Moslems imported from "the East." The sea captains and merchants in Norman-ruled

Sicily and northern Italy were the first to seize upon this economic opportunity by establishing trade ties with Moslem traders. But by the mid-1300's, northern and central Italian cities were well on their way to establishing a near monopoly over this valuable trade across the Mediterranean.

Contacts with Moslems also stimulated trade ***within*** Europe, which accelerated the changes that had already begun there. Thus, in the end, the Crusades ***contributed*** to the erosion of the Feudal system, an increase in Europe's openness toward non-European ideas, a and dissatisfaction with the backwardness of Europe. In any case, as contacts with the outside world continued, Western Europe's isolation crumbled. (NOTE: In 1348-1349, the first European outbreak of the Black Plague threatened all European institutions and killed much of its population. Ironically, this disease was probably "imported" from China along the Silk Road. Thus, the Plague was an unintended "product" of Europe's new-found openness to Asian products and Moslem trade.)

These changes happened slowly, and with different effects in different parts of Europe. Conflicts among Europe's countries, or as often between nobles and monarchs within countries, continued to disrupt Europe's development. Famines, epidemics, and the power of feudal authorities and the Church, which was often used to block change, also continued to hinder Europe, keeping it from changing as quickly as it might have done. Thus, progress toward a "new" Europe was not easy or steady.

However, by 1450, many of the changes begun in the 1100's took root. The merchant class and cities grew larger and more important. New wealth was created. Europe's universities grew more numerous, independent, and open to ideas that included ones from other civilizations and new ones created by Europeans. Once begun, this was a self-sustaining process. For, as universities continued to educate the future managers of Europe's cultural, intellectual, and economic activities, it nurtured the ideas, including scientific ones, that would eventually give Europe much of its cultural, economic, and political power and character.

A New European Awareness

Before the late-1200's, European maps pictured the world as a flat circle divided into three areas by a "T." On most ***T-O maps***, as they came to be called, North Africa was above the T, Europe to the left of it, and Asia to the right of it. Thus, the top of the T represented the Mediterranean as the center of the world. Meanwhile, the entire world was pictured as being surrounded by a single ocean, the outer limits of which were enclosed by a circular border. And finally, the Garden of Eden was assumed to be a real place south of the known world, filling part of the space above the T. (NOTE: T-O maps with North at the top contained an upside-down T.)

T-O maps did not include any other continents or accurate outlines of Europe, Asia, or North Africa, even where Europeans knew about some geographical details. Thus, besides expressing the limits of European geographical knowledge during this period, it is clear the real purpose of T-O maps was to represent Church ideas about the Earth (and Heaven). However, by the late-1200's, European cartographers began making more realistic maps of inland Europe and its coastal waters, the territories most travelled by European merchants. Meanwhile, Arabic merchants and the first translations of Arabic books were providing Europeans with their first real geographical information about a much larger part of the Afro-Eurasian landmass. As a result, by the early-1300's, some European world maps began to include more realistic (if still inaccurate) outlines of Europe, North Africa, and Asia. Some of these maps even included rough depictions of the Arabian Peninsula, India, China, and Southeast Asia.

As European maps improved, European interest in the Orient (East Asia) increased. Studying these maps encouraged people like Marco Polo and his uncles to attempt to travel to China, while the popularity of Marco Polo's account of his adventures when it was published in the early-1300's further increased interest in "the mysterious East." Most strikingly, the image of the world suggested by Polo's account matched what Europeans were learning from Moslem maps, including ones that depicted the travels of ibn Battuta in the mid-1300's. As a result, ***by the 1360's***, and for the first time since the heyday of Alexandria, ***some European maps began picturing the world as a sphere***, while a few included such exotic places as Japan. (NOTE: Marco Polo's book was the first secular "bestseller" of European history. It was so popular, scribes could not copy it fast enough to meet demand. Recently, however, some historians have questioned whether Polo ever reached China, or if he merely travelled to Persia and repeated stories about China and the Orient he heard there. If this turns out to be true, we will have to amend the above account and say Polo's only contribution was that he transmitted Moslem stories about the rest of Asia to a wider European audience.)

In 1410, Europeans made their first Latin translations of Arabic copies of Ptolemy's Geographia, thereby rediscovering his 1,260 year-old picture of the world as a sphere roughly 2/3 its real size. While Europeans were already well on their way to picturing the Earth realistically ***before*** this discovery, Ptolemy's book added to their geographic knowledge and gave Europeans a new framework for organizing their ideas about map-making that included: 1) a standardized two-dimensional map-projection of a spherical Earth, 2) the division of the world into climate zones, and by a grid of lines similar to latitude and longitude, and 3) a defined (if incorrect) ratio between the East-to-West size of the Afro-Eurasian land-mass and that of the circumference of the Earth. Despite its flaws, this Ptolemaic framework proved invaluable to Europeans over the next 100 years.

By the 1430's, intellectuals in Italy, where contact with the outside world was most direct and educated people had grown increasingly fond of Classical Greek and Roman ideas, began to push the Latin Church to change its doctrines to reflect new discoveries. As a result, in 1439, ***Cosimo De'Medici*** (the "leading citizen" and de facto ruler of ***Florence***) invited the Byzantine Emperor, Pope, and Patriarch of Constantinople to a meeting in Florence that was also attended by Byzantine and Florentine merchants and scholars. The goals of this meeting, as spelled out by Cosimo, were to: 1) heal the rift between Eastern and Western European religious and political leaders, 2) reconnect Western Europeans and Latin Church authorities with their Classical Greek roots, and 3) strengthen Florentine trade with Byzantium and, through them, with Asia.

Given these sweeping goals, it is not surprising that Cosimo's meeting was less than a total success. However, the Florentines were so impressed by the wealth of their Eastern visitors ***and*** their discussions about ancient Greek philosophers that Cosimo decided to forge a new trade alliance with Byzantium and open a Neo-Platonic Academy in Florence. In a sense, this brought Italian thinkers to the point Arabic thinkers had reached in the 900's, when they elevated ancient Greek ideas to the same status as their own Islamic religious principles. But in Western European hands, studying Greek and Arabic ideas soon led to a spirit of questioning that encouraged scientists, artists, and others to value ***individual creativity*** and ***new knowledge*** as an end in itself. We call this movement ***the Renaissance***.

As the Renaissance spread northward and westward across Europe between 1450 and 1550, it changed many aspects of Western European culture. In fact, most historians believe the Renaissance was ***the*** seminal "event" in the transformation of Europe into a modern society. Unfortunately, we have to limit ourselves here to just two brief examples of the important changes initiated during the Renaissance.

1) Before the Renaissance, Latin was the only spoken and written language used by Western European universities, scholars, writers, and the Church. At the same time, each region in each country had its own spoken language (***vernacular***). So, by 1400, Europe had one "international" intellectual and religious language, Latin, and hundreds of local ones. In fact, the lack of "national" languages was a serious drag on efforts to unify any country, even under a strong monarchy. Thus, when Renaissance writers began publishing books in their own vernaculars instead of Latin: a) Latin, and therefore the Latin Church, began to lose its hold on Europe's intellectual life, b) the regional language most used by writers or a royal court evolved into that country's "national" language, and c) other regional languages began to disappear. Moreover, in the end, these linguistic changes greatly enhanced the the development of "national" cultures.

And, 2) Italian architects and artists developed new ways to use interlocking triangles and grids to represent three-dimensional forms on two-dimensional surfaces (the Renaissance Perspective). While this may seem like a minor innovation, except in the world of art, these ideas, which were pioneered by Leon Battista Alberti, were soon used by cartographers and engineers to picture abstract spatial concepts more precisely. In time, these ideas also revolutionized European navigation, the placement of unknown parts of the world on maps, ***and*** scientific thinking, thereby contributing greatly to other fundamental changes in Europe and to its relationship with the rest of the world. Moreover, there are many other examples of Renaissance innovations in one field creating widespread intellectual changes and indirectly revolutionizing other fields.

The Age of Exploration

In the early-1400's, ***Prince Henry the Navigator*** of Portugal brought together Italian experts in navigation, map-making, and ship-building to help him and his advisors plan voyages to West Africa, whose kingdoms, according to the Moors, had vast stores of gold. As a result of gathering this information, between 1420 and 1433, Portugal mounted several voyages of exploration that established colonies on the Atlantic Ocean islands of the Canaries and the Azores, as well as several small trading-post-sized colonies along the west coast of Africa. During this first phase of exploration, Portugese explorers returned with ivory, exotic furs, some gold, and slaves, all of which were traded in Europe, thereby enhancing Portugal's wealth and political standing. Although most Europeans did not realize it at the time, these early Portugese voyages also initiated Western Europe's direct contacts with the "outside" world, its use of non-European resources, ***and*** the horrific European-run African slave trade that plagued the world for the next 400 years.

The commodities found in West Africa were valuable to Western Europeans and helped secure Portugal's independence as a fledgling kingdom. But the gold available there did not live up to Portugese expectations. So they decided to use their new naval technology and geographical knowledge to push on further into the unknown. Thus, by the 1460's, Portugal explored the west coast of Africa beyond the mouth of the Congo. As these voyages continued, the goal of exploration changed to a quest to find a way to sail around Africa into the Indian Ocean, and then on to "the Indies" (India, China, Japan and "the Spice Islands" [the Mollucans in Indonesia]). After all, if Portugese kings and sea captains could find a sea route to South and East Asia they could bypass, or perhaps even supplant, Moslem and northern Italian traders. Moreover, these Portugese voyages and meetings such as the one hosted by Cosimo de'Medici began as the Byzantine Empire was being conquered by the Ottoman Empire, an event that cost Europe its only Christian contact with western Asia and the Orient.

From the beginning, Portugal's rulers, explorers, and merchants tried to keep their discoveries a secret. But word soon leaked out. So, when the Italian ***Christopher Columbus*** proposed in 1488 that he could find a route to the Indies by sailing west across "the unknown ocean" and his proposal was rejected by the Portugese, he sought the backing of Ferdinand and Isabella, the rulers of the new kingdom of Spain, who after much hesitation decided to back him. (NOTE: By the 1480's, Portugal had a committee of experts that evaluated proposals by would-be explorers. That committee rejected Columbus' plan on the grounds his estimate of the overall size of the Earth was too small and that of the width of Eurasia too large. Thus, the distance to be covered across the western ocean, aside from presenting unknown dangers, would be far longer than Columbus estimated, reasoning that turned out to be correct. Despite our myths about Columbus, however, no one ever said the Earth was flat in response to his proposal, or to any other during this period.)

On the eve of Columbus' first voyage, ***the goal*** of "voyages of discovery" ***was to find routes to the Indies, not to discover new lands or explore the unknown world***. But that is exactly what they did. Between 1488 and 1522, Diaz sailed around Africa into the Indian Ocean for Portugal, Columbus discovered the Americas for Spain, Cabot explored North America for Great Britain, da Gama reached India (with the assistance of an Indian navigator he met in East Africa) for Portugal, and Magellan (or at least one of his ships, after he was killed in the Philipines) circled the world for Spain, proving, at last, that the world is a sphere and the seas are continuous. Along the way, explorers from Spain, Portugal, France, England, Holland, and Italy also discovered ***the world is much bigger than Ptolemy had said***, and that ***there were many new lands and peoples to conquer***, a far more revolutionary discovery than exploration had been meant to provide. In fact, in less than 40 years, these discoveries completely changed the European perception of the world and their place in it.

We call this period Europe's ***Age of Exploration***, although it is worth noting that it actually overlaps the Renaissance. In any case, like the Renaissance, the Age of Exploration profoundly affected every aspect of European life. So let's briefly examine three examples that illustrate this point:

1) The fortunes of exploration changed the balance of power among European "countries." Spain's discovery and conquest of the incredibly rich civilizations of the Incas in Peru and Aztecs in Mexico and Central America in the 1500's, and Portugal's trade with South and then East Asia, made Spain Europe's dominant naval power, gave both great wealth, and threatened to make them the only Imperial super-powers in Europe, a possibility formally embodied in two treaties negotiated by the Vatican in 1494 and 1527 that divided the entire world between Portugal and Spain. As importantly, the advantages that came from having an empire gave

Spanish monarchs many opportunities to increase their influence within Europe, a goal they advanced through royal marriages and alliances or, when necessary, military action. In fact, there were periods during this "Spanish century" when Spanish kings ruled Austria, France, Holland, and parts of Italy and Germany.

None of this stopped other countries from mounting their own efforts to reach Asia, find new lands, conquer still-undiscovered civilizations, or establish colonies. For, by the early-1500's, all Europeans understood such discoveries might provide untold wealth and power for a country, as well as prestige and personal riches for a monarch, explorer, or merchant. Moreover, as the stakes involved in empire-building increased, British, French, Dutch, and Italian sea captains stepped up their challenges to Spanish supremacy at sea, by raiding Spanish ships that carried rich cargos back to Europe from the Americas. Not surprisingly, such piracy heightened tensions between Spain and Europe's other seafaring powers, inflaming a hostility that was also fueled by religious differences that emerged in the early-1500's between countries like Spain and Portugal that remained in the Latin (Catholic) Church, and England, Holland, and parts of Germany and France that left the Latin Church to form Protestant Churches. (NOTE: See below for more on this split in Western Christiandom.)

By the early-1500's, "national pride" alone dictated that no European country could let others get all the glory or credit for discovering new lands or increasing Christianity's hold on the peoples Europeans discovered. Of course, as the leading power in Europe, Spain saw things differently. Thus, in ***1588***, the Spanish sent the largest fleet Europe had ever seen, ***the Armada***, to the English Channel to teach the Protestant British and their pirates a lesson. In response, the British sent out a much smaller fleet of small and maneuverable ships.

When a storm struck the Channel, the British attacked. In the following battle, the Spanish admiral made several tactical mistakes, many Spanish captains panicked and "ran for the open sea," and the Spanish ships that remained were set on fire and sunk. Moreover, the defeat of the Armada ***tipped the balance of naval power from Spain to Great Britain*** and encouraged other European monarchs and captains to step up their raids on Spain, which further undermined its economic supremacy.

2) Exploration gave Europeans new information about the world, much of which supported ideas promoted by Renaissance thinkers. Thus, while Europeans continued to see it as their duty to spread Christianity to the lands they discovered, exploration made it obvious many Latin Church teachings (and by the 1530's, those of the Protestant Churches) and ancient Greek ideas were wrong. As a result, educated Europeans came to believe new knowledge could be gained in three ways, by: a) studying a wider range of ancient Greek ideas b) exploring or observing the world

directly, or c) doing new scientific or scholarly work. As a result, exploration increased the rebelliousness and intellectual curiosity of many European intellectuals.

And, 3) since Europe's monarchs sponsored exploration and ruled the colonies as "crown land," empire-building increased the power of monarchs and decreased that of nobles. Equally, since merchants often provided monarchs with the money for exploration and had a hand in colonial trade, merchants became wealthier and more powerful. So, the political and economic changes that began in Europe before 1450 were accelerated by exploration and its institutional offspring, colonization. In fact, by 1600, empire-building became a central activity of European politics and the focus of much Mercantile planning. By then, Great Britain, France and Holland were winning this race, which ensured ***their*** status as super-powers and gave them the inside track on future discoveries and colonies, changes that, not incidentally, increased the wealth and prestige of those countries' leaders "at home."

Before leaving this topic, it is worth pausing to ask why Europeans were the first to explore the world? Why not the Arabs, Indians, or Chinese, each of whom had a richer history of wealth, intellectual accomplishment, and technology than Europeans? The answer to this question lies in Western Europe's geographical location and its ***cultural choices*** relative to those of the other Afro-Eurasian civilizations of the 1400's. A comparison of these civilizations should also help explain why Europe became such a technological and scientific success in the next 400 years.

The Arabs were ideally situated to control the territory between Europe and the other civilizations of Asia and Africa. So they were able to trade directly with everyone who interested them. They could reach Eastern Europe, North and central Africa, China, and India by land; and sail across the Mediterranean to Eastern and Western Europe, and around the Indian Ocean to India, the Swahili cities of East Africa and, after the Mogul (Mughal) conquest of India, to Southeast Asia and the island kingdoms of Indonesia. As a result, despite having the technologies needed for long ocean voyages, including excellent sea-going vessels and map-making and navigational skills, the Arabs felt no need to find new trading partners in as-yet undiscovered lands. In fact, the Moslem rulers and merchants who controlled Eurasia's key trade routes wanted to ***discourage*** any efforts that would uncover competing routes or new geographical knowledge, if only to guarantee their profits from the trade that already existed.

The same could be said about the Hindis. After all, by 800, Indian merchants established trade ties with Persia, the Arabs, and other Moslems in Western Asia; China; the Swahilis in East Africa; and many civilizations in Southeast Asia. In fact, long before the inclusion of India in the Moslem world in the early-1400's, monthly merchant voyages across the Indian Ocean demonstrated that India had the technology and skills needed for trans-oceanic and perhaps global exploration. However, like the Arabs, the Hindis were already well-situated as middle-men in a web of rich trade relationships, which kept them from having a reason to embark on their own age of exploration. (NOTE: This begs the larger question of why there is so little record of ***indigenous*** Indian powers attempting to conquer areas beyond South Asia, despite India having successfully defended itself against attacks like those mounted by Alexander the Great and Persia, and its rich history of battles for territory among states within India. This lack of militaristic expansionism is in stark contrast to Moslem urges, not to mention European ones.)

But why did China fail to "discover" the world? After all, the Chinese, like the Europeans (Japan and Korea aside), were at one end of the great trade network that indirectly tied all Afro-Eurasian civilizations together. In addition, China invented and was the first to use many of the skills and technologies that were needed to explore the world, and which other civilizations, including the Arabs and Europe, later used. Why, then, did not China use these advantages to explore and conquer much of the world? We may never know. But perhaps we can find part of the answer in the period between 1405 and 1433, when two Chinese emperors commissioned seven voyages of exploration to Southeast Asia and India, at least two of which reached Persia, Saudi Arabia (including one visit to Mecca), the Red Sea, and the East coast of Africa, perhaps within 500 hundred miles of its southern tip! Thus, these voyages crossed a much greater distance than any early European voyage of discovery, including Columbus'. Moreover, one Chinese fleet was on the verge of sailing into the Atlantic Ocean 70 years before European explorers, going in the opposite direction, reached the Indian Ocean.

The admiral who oversaw these Chinese voyages of exploration was ***Zheng He***, a Moslem (perhaps a Mogul) from northwestern China. Amazingly, Zheng's first voyage in 1405 employed a fleet of ***317 ships***, including 62 treasure ships that carried gifts for unknown rulers, on the assumption those ships would return with even greater treasures. The largest of the fleet's ships was over 300 feet long, while ***the entire fleet carried 27,870 men***, including an army and a corps of doctors who, among other duties, oversaw the on-board cultivation of vegetables to eliminate the risk of scurvy. Most impressively, Zheng's third voyage employed a fleet of 70 ships that still managed to carry 30,000 men, including crew, diplomats, and an entire army.

Despite these impressive numbers, and the transporting of whole armies and other official passengers on several journeys, none of Zheng's voyages were designed to extend China's empire or go to war with other peoples. Instead, their goal was simply to satisfy Chinese curiosity about the rest of the world and enhance the prestige of China's Emperor. Thus, Zheng returned from each voyage with tribute for China's emperor, exotic plants and animals, and, in a few cases, foreign rulers who were received as honored guests on "state visits" to China. In fact, the sole purpose of Zheng's second voyage was to represent China's Emperor at the crowning of the Prince of Calcutta in India, while his fifth voyage returned 17 foreign rulers to their homes in South and Southeast Asia after stays at China's Imperial court.

By comparison, Columbus' first voyage, a full 87 years after Zheng began his voyages, employed a fleet of 3 ships, the largest of which was 100 feet long, manned by a total of 90 men, all of whom were ships' officers and crew. Thus, the tonnage of Zheng's first fleet was over 500 times that of Columbus's, while Zheng transported 280 times the people Columbus did. If nothing else, this demonstrates China's: 1) technological and financial capacity to mount larger and more complex voyages of exploration than Europeans could, even 87 years later, and 2) China's greater confidence in its sense of the world, its technology, and the successful outcome of its mission. In fact, it is staggering to think that each of Zheng's larger fleets transported more people than any ocean-going fleet would, anywhere in the world, until the world wars of the 20th Century.

China's naval confidence was well founded. Long before 1400, Chinese ocean-going junks had multiple, staggered masts and sail designs that made them efficient in any wind. They also had multi-layered, compartmentalized hulls that could be loaded and unloaded with ballast or sea-water as conditions warranted. And lastly, the Chinese had far better astronomy-based navigational tools and skills than anyone else in the world. While by 1450 many of these technologies were arriving in or being invented in Europe, some of them had existed in China for almost 1,000 years, which gave the Chinese a lot of practice perfecting their usage, an important technological advantage in itself.

Amazingly to us, and despite the success of Zheng's voyages, government-sponsored exploration stopped after 1433. Thus, while China continued to demonstrate its naval skill by strengthening its sea trade with Southeast and South Asia, later Ming and Ching emperors failed to see the point of exploratory voyages. After all, Zheng's voyages and all other inter-cultural contacts had proven China was superior to all other cultures. Hence, there was no Chinese effort to follow up on Zheng's discoveries or explore the possibility of finding unknown civilizations, simply because the Chinese believed the trade they already had with India, Korea, Japan, Southeast Asia, and the Moslems of western and central Asia brought them all they needed from the outside world.

However, it is clear China had the technology needed to explore the entire world, while Arabic and Indian voyages suggest they too could have mounted cross-Atlantic or cross-Pacific voyages long before Europe. Thus, ***we must conclude Europeans were the first to explore the world simply because they were the only "civilized" people in Afro-Eurasia who were isolated enough from other civilizations with which they wanted to trade to feel a need to explore the world***. Moreover, once they developed or borrowed the technologies that made such voyages possible, this need drove Europeans to an inadvertant discovery of new lands.

The act of exploring also helped create a European belief in aggressive risk-taking, a trait that proved useful in many ways, not least in Europe's drive to conquer other peoples ***and*** in its development of a sustained scientific culture. However, while it is not central to our story, we must also acknowledge that this brazenness contributed to a European obliviousness to the worth of other cultures and peoples, a trait Columbus demonstrated when he first touched land on San Salvador. For, despite thinking he was in Japan, Columbus planted the flag of Spain and claimed his "discovery" for his king and the Catholic Church. Apparently, it never occurred to Columbus that if he were right about his location, he was in territory already "owned" by a powerful kingdom perfectly capable of capturing him and his men, or of killing them all.

New Knowledge in Europe

The rise of universities, the merchant class, countries as stable political entities, cities, the Renaissance, the Age of Exploration, the running of colonies, and increasing trade within Europe *all* made education and knowledge more important. In fact, Europe's continued development hinged on "new" technologies that could facilitate the production and sharing of knowledge. ***Paper*** and ***printing*** proved to be those technologies. Paper was invented in China around 100, reached the Moslem world around 800, and Christian Europe in 1150, while printing was invented in China around 800, reached the Moslem world in the 900's, and Europe around 1370, where it was first used to produce novelty items like playing cards, a good example of cultural bias determining the short-term usefulness of a technology. However, in 1454, a German named ***Johann Gutenberg*** improved the printing press by inventing moveable type and began using it for printing books. (NOTE: As we will see in Chapter 11, a Chinese printer invented moveable type over 400 years earlier. But his invention did not have the same effect in China as Gutenberg's did in Europe.)

Before 1454, the only way to reproduce a book in Europe was by hand, a job almost always done by monks who, not surprisingly, only copied works that interested them or at least did not offend their religious beliefs. Even when a small private book copying industry developed in the early-1400's, the slowness of such work and the biases of those doing it limited the spread of new ideas, including scientific ones, within Europe. In theory, printing could change all this. But the first European printed books were the Bible, other religious treatises, and the works of ancient Greek and Roman thinkers, many of which were printed to *look* like hand-copied books because printers assumed book-buyers valued the artistry (and imperfections) of hand-copied books so much they would not buy ones that looked different.

Consequently, Europe's first printed books *increased* the influence of old and Church-approved ideas. But it was not long before new literary and non-fiction books were being printed. At first these works were written in Latin. Within a few years, however, some books, like those by Cervantes and Dante, were printed in the vernacular (Spanish and Italian in these cases), a change the Church saw as undermining its authority. Moreover, the existence of "secular" printed books *caused* writers to express ideas that questioned Church doctrines by offering those with rebellious ideas access to a larger audience. In fact, by the late-1400's, paper and printing caused a European "information revolution" (a familiar term today, but one that could just as easily be applied to Sumerian writing, the Phoenician alphabet, or several other innovations in the past) that was outside the Church and, therefore, beyond its control. In time, these changes, along with ones initiated by the Renaissance and Age of Exploration, destroyed Western Europe's religious unity forever.

The Reformation

Between 350 and 700, the Latin Church expanded its influence as the only Christian Church in Western Europe and western North Africa. Then, when North Africa was conquered by the Arabs, the Latin Church did all it could to maintain its influence in Western Europe. Consequently, by 1150, it exercised great power over every aspect of Europe's religious and political life, as symbolized by the elaborate rituals and physical structures of the Church; its role in the coronation of kings and emperors; and the role Popes, Cardinals, and bishops played in mediating or settling disputes among earthly leaders.

In a larger sense, the Latin Church was involved in *every* aspect of European life, including charity, education, the arts, the staffing of courts and royal governments, the rites of birth, marriage, and death, and the punishment of wrong-doers. By 1400, the Latin Church was an institution with large ecclesiastic and monastic "staffs," extensive land holdings, spectacular churches, thousands of smaller ones, and many monasteries and convents.

To support all this, the Church collected donations from lay members and accepted gifts from powerful people who wanted to demonstrate their wealth and influence through public giving, or who needed Church forgiveness ("indulgence") for some wrongdoing. The wealth amassed by the Church was used to support its clergy, maintain the Church's properties (monasteries, estates, and churches), provide daily religious and other services to Church members, build great and beautiful cathedrals, and commission works of art, many of which were placed in churches. And finally, as symbols of the power and authority of the Latin Church, some was used to build and maintain the Church of St. Peter's and Vatican City in Rome, and to support a luxurious life-style for the high clergy, and the Pope's "royal court" in the Vatican.

By the early-1400's, many high clergy were living like European kings and nobles. However, changes brought on by the Renaissance encouraged people, including some monks, to more freely express their opinions about the need for Church reform. As the calls for reform increased in the late-1400's, the Vatican's response wavered between calling for an end to the most obviously corrupt practices and defending the Vatican's right, according to the doctrine of Papal infallibility, to punish anyone who questioned its authority.

In 1517, a German monk named ***Martin Luther*** nailed a list of his complaints against the Latin Church to the door of his church in Wittenberg. At first the Vatican tried to negotiate with Luther to avoid a greater crisis. But after four years, it abandoned this approach and demanded Luther declare his total acceptance of the authority of the Pope and his local bishop, including over the question of the validity of his original complaints. When Luther rejected these demands in 1521, he knew he was committing the far more radical act of rejecting the leadership of the Pope over Western Christianity. Not surprisingly, in response, Luther was ***excommunicated*** from "the body of the Church." To the Church, that ended the matter.

But Luther could not be silenced that easily. His ideas, while not new, struck a chord among many people, not least with monarchs eager to free themselves from the authority of the Pope and local Cardinals and bishops. In any case, Luther responded to his excommunication by forming a new Church and by translating the New Testament (the Christian part of the Bible) into German. Given Luther's original desire to reform the Latin Church, and the attitudes of those who soon followed his example, we call this fracturing of Western Christianity ***The Reformation***.

Among those who emulated Luther, the most important were Ulrich Zwingli and John Calvin. Zwingli was a Swiss clergyman who preached a more radical rejection of Latin Church practices than Luther and formed his own Church in 1519, which, if nothing else, proved those opposed to the Latin Church would not remain unified. Zwingli's actions also ignited a Swiss civil war in which he was killed. But his Church survived, making Switzerland a haven for other anti-Latin Church activists like John Calvin, a French lawyer who went to Switzerland in 1536 in order to safely offer the broadest justification yet for rejecting the Latin Church and Papal authority yet.

All Reformation leaders rejected the authority of the Pope. But they also criticized each other. Thus, by 1540, there were separate Lutheran and Calvinist "camps." Within each of these camps, there were several Churches (or denominations), each with its own doctrines. Nevertheless, we call all Churches formed in this period the ***Protestant Churches***, because they were born out of protest against the practices of the Latin Church, and in recognition of a protest held in 1529 by Luther's supporters at a Latin Church synod called the Diet of Speyer, in the hope the Latin Church would finally reconcile itself to Luther's ideas. In fact, it was after this failed protest that the term "Protestant Church" came into vogue.

By the early-1600's, most of northern Europe was in Protestant hands, while a revitalized Latin Church, now called ***the Catholic Church***, controlled southern Europe. But in some countries, Protestant areas were surrounded by Catholic ones, or vice versa, a pattern that sparked repeated outbursts of violence and intolerance. In the end, Poland, Italy, Spain, Portugal, southern Germany, Ireland, and parts of Holland and Switzerland remained Catholic, while France's kings returned to Catholicism after flirting with Protestantism, leaving France predominantly Catholic with some Protestant pockets. Meanwhile, England, northern Germany, Denmark, Norway, Sweden, Scotland, and other parts of Switzerland and Holland became Protestant. However, in several countries, conflicts among various Protestant Churches lasted until one gained the upper-hand and became the official Church of the monarch and most of his subjects, thereby replacing the Catholic Church as that country's official Church.

Of all the European countries that embraced Protestantism, England was the only one that did so for essentially non-religious reasons. In ***1534, King Henry VIII*** formed the ***Episcopal Church*** for personal and political reasons (to legitimize his right to divorce or execute his wives and to remarry so he could produce a male heir to his throne). Hence, by royal decree the Episcopal Church became the official ***Church of England*** and England's Catholic Church was abolished, with its monasteries and lands siezed or closed. Not surprisingly, this period in British history was marked by a great deal of sectarian turmoil, before the Episcopal Church solidified its control over England (but not all of Great Britain) in 1688, 150 years later.

Aside from rejecting Papal authority, all Protestant Churches except the Episcopal Church limited the importance of the clergy, reduced the ostentatiousness of churches, simplified church services, emphasized literal interpretations of the Bible, and made greater daily moral demands on the behavior of their members, who were expected to return to a simpler, more personal, and stricter version of Christianity. But ***the founders of the Protestant Churches did not make these changes to diminish the importance of Christianity or the authority of religious leaders.***

In fact, as we will soon see, Protestant leaders were often as eager as Catholic Church ones to exercise moral and intellectual control over their congregations and members.

Nevertheless, the Reformation rendered all religious leaders less powerful than earlier Popes had been in the Latin Church. Moreover, ***the idea that one religious leader could pass universal judgment on new ideas or speak for all of Christiandom died with the Reformation***. As a result, the competition among the Catholic Church and all Protestant Churches, and among the monarchs who championed them, played a large role in later wars among European countries, their competition for colonies, and the growth of some particularly entrenched European national hatreds.

Despite our tendency to see the Reformation as marking or causing Europe's transformation into a more rational society, the splintering of Western Christianity was seen by advocates on ***all*** sides as proving the apocalyptic predictions of earlier Christian mystics and the Bible were about to come true. Thus, in the short-run, the Reformation actually ***increased*** Europe's irrational spiritualism. For example, when scientists sympathetic to or hostile to Luther heard about his challenge to Papal authority in 1517, they looked for celestial signs of an impending cataclysmic event. When it was noted that all the known planets would be in conjunction (close together in the sky) in "the sign of Pisces" in February 1524, Vatican supporters predicted Northern Europe would experience natural disasters that would initiate the final battle between good and evil and the triumph of the Latin Church, followed by the end of the world. At the same time, Luther's defenders claimed this conjunction signaled the triumph of Protestantism over the Latin Church, and the ushering in of a world peace that would presage Christ's return to Earth.

Few thinkers took issue with these predictions or their astrological underpinnings. In any case, when no dire or blessed natural event came to pass, but Europe was swept by a Peasant Revolt against feudal overlors, both sides claimed vindication. Thus, while it is important to note the "revolutionary" events chronicled in this chapter, we must also note that Europe continued to mix science with mysticism for 200 years after the Renaissance, Age of Exploration, and Reformation. (NOTE: See Chapters 8 and 10 for more on these issues.)

A Very Brief Summary

In ***very*** broad terms, Western European history between 700 and 1642 was divided into three periods. First, events between 700 and 1150 established a separate and viable Western European culture. Second, events between 1150 and 1450 eroded some of this "traditional" Western European culture and laid the foundation for a new one. And third, events between 1450 and 1642 weakened old institutions and ways of doing things, while creating new ones. As a result, and despite the survival of vestiges of the earlier European culture, a new and more modern European society emerged after 1642. As importantly, the Age of Exploration and Europe's ensuing colonization of other continents guaranteed these changes would eventually affect every corner of the world. In other words, the changes noted in this chapter pre-saged similar changes in all cultures around the world.

CHAPTER EIGHT

EUROPEAN SCIENCE: THE RULE OF SPIRITUAL AND PHYSICAL LAW

It is wrong to say Europeans did no science before 1150. Some was done, especially on practical problems like improving Europe's calendar. Early Christian thinkers also examined the relationship between their beliefs and studying nature. The most influential of these thinkers was ***Saint Augustine***, who spent most of his life in monastaries in North Africa during the 300's. Augustine did no science himself, but argued ***nature is God's work***. So, studying nature is a way of understanding God. However, the big questions, such as why nature is the way it is, can only be answered by faith in God. Hence, ***Christians can do science, but they cannot fully understand nature through science.***

The development of modern science would require six (6) innovations: 1) a scientific method that would tell scientists how to do their work and how to evaluate the work of others, 2) improved measurements, to make observations more useful in constructing theories, 3) the idea that measurements could never be perfectly accurate, 4) new mathematical language that could be used to describe physical phenomena, 5) institutions that would give scientists some intellectual freedom from secular and religious authorities, and 6) success in making better pictures of nature, to give scientists "ammunition" against those who wanted to maintain unscientific ideas. As we will see, all of these innovations were initiated in Europe between 1150 and 1642.

The Arabic Sources

The first translations of Arabic scientific texts into Latin were made by a monk named Constantine the African around 1050. But it was not until after 1100, when the Crusades exposed Europeans to a wider range of Moslem knowledge and more Christian monks came into direct contact with Moslem and Jewish scholars in Iberia and Sicily that many translations were made. In Spain, the leading translators were Adelard of Bath and Robert of Chester, both of whom produced Latin copies of Euclid and al-Khwarizmi on mathematics and astronomy, and Gerard of Cremona, who translated Arabic versions of Ptolemy and commentaries on Greek science. By the early-1200's, Michael Scot was doing similar work in Sicily under Norman patronage by translating al-Batruji's books on astronomy, ibn Rushd's on Aristotle, and other Moslem and Jewish works. Soon after, monks in other parts of Europe began translating Arabic scientific and mathematical writings, although monks in Spain and Sicily continued to play the largest role in Europe's discovery of Greek and Arabic ideas.

By the mid-1200's, many Arabic books had been translated. But printing had not yet come to Europe. So, newly translated books were not available to a large audience, while those that were available often contained translation errors. Nevertheless, whenever university teachers were exposed to Arabic and ancient ideas, they began to include them in their curricula. At times, the Church silently tolerated this. But at other times, Vatican authorities objected on the grounds these ideas had been created by pagan Greeks, Moslems, or Jews (all non-Christians), or simply because they contradicted Christian beliefs. As a result, the Vatican declared many ideas unChristian (***heretical***) and made it illegal to teach them. However, some teachers ignored Church bans or simply wait until they were not being enforced. (NOTE: In the 1400's, the Church became more aggressive about heresy. In that later period, some people were declared heretics simply for owning or reading Arabic books on mathematics.)

The Beginnings of European Science

In the early-1200's, scholars at Europe's new universities, such as ***Robert Grosseteste, Roger Bacon*** (Grosseteste's student), and ***Albertus Magnus*** in England, tried to mesh Aristotle's writings with Church beliefs. The most important of these men was Grosseteste, the Bishop of Lincoln. After reading Aristotle in Latin, Grosseteste did experiments on sound and light and studied astronomy, thereby becoming the first European to do scientific work on physical questions. Grosseteste also defined ***a three step method for constructing theories about nature***, which stated that a scientist should start with an ***observation***, then he should think up ***causes*** for what he observes, and lastly he should create a ***theory*** that could explain the connection between his observations and their causes.

This was the first European statement about the scientific method since the Greeks and Romans. This alone made it important. But Grosseteste also defined science in a very specific way: as an ***inductive*** process in which scientists should proceed from ***empirical evidence*** (an observation) to a general ***theory***. Aside from echoing Socrates' reasoning about how best to find "the truth," Grosseteste's method implied a scientist should not base his theories on the opinion of any authority. Seen in this light, the articulation of Grosseteste's method marks the moment when European science once again took up the ancient Greek challenge of "making nature more natural." Consequently, some historians consider Grosseteste the "father" of all European science.

Given the religious climate of this period, Roger Bacon retreated from Grosseteste's position and argued authorities should be balanced against each other. Thus, a scientist should consider the wisdom of both Christian and non-Christian thinkers. But to do this, Bacon needed better translations of Arabic books. So, he became a patron of translator-scribes, thereby ensuring others would have access to more accurate copies of Arabic books. Nevertheless, not everyone agreed with Bacon on the question of "authority." In fact, in a purer echo of Grosseteste's thinking, Albertus Magnus argued a scientist should reject the word of ***any*** authority and learn the truth by observing nature directly. For, to Magnus, science is simply "not believing what you are told," a thought reminiscent of Al Mas'udi's statement 300 years earlier.

These men were the first Christian Western Europeans to *use* scientific principles to study or think about nature. But their work would not have led to further scientific discoveries if the Church had not responded to their challenge by creating a new intellectual framework that allowed Christianity and science to be seen as complimentary ways of honoring "God's work." In the late-1200's ***Thomas Aquinas***, a leading Latin Church theologian of the day, stated that ***nature is the work of the "invisible and ever-living hand" of God***. Thus, God's role in nature is not observable. So, observations, rhetoric, and human-made ideas are incapable of demonstrating the existence ***or*** nonexistence of God. In other words, the proof and character of God's presence is a theological question that is beyond the authority of science.

Aquinas' ideas became the foundation for the ***Scholastic Movement***, which dominated Europe for over 200 years. Above all, Scholasticism created a subtle, legalistic, and intellectually acceptable balance between faith and "earthly" experience, including that gained from scientific observations.

In the early-1300's, this new intellectual context allowed ***John Duns Scotus*** to re-examine and question some of Aristotle's ideas about astronomy and mechanics. In the following years, ***Thomas Bradwardine*** carried this work further by observing the flight of an arrow and showing that no existing theory, Greek or Christian, could correctly explain its flight-path or change of direction and speed. In fact, Bradwardine showed the arrow's behavior needed an entirely new description, and perhaps a new theory. In the meantime, no authority could make an incorrect theory correct. While Bradwardine was unable to come up with a theory that explained what he observed, his use of Grosseteste's method, respect for observation over authority, and meticulous reasoning demonstrate the kind of scientific thinking possible under Scholasticism. (NOTE: See Chapter 10 for more on the problem of the arrow in flight and its eventual solution.)

In the second half of the 1300's, ***Nicole Oresme*** stated that ***all moving objects***, such as arrows, balls, and heavenly bodies, ***have momentum, a form of energy*** carried in the object. In fact, objects in motion are like moving parts in a giant mechanism, an idea Oresme probably got from the mechanical clocks that had just been introduced into Europe from China. Thus, much as Hellenistic gadgets demonstrated fundamental principles of nature, Oresme reasoned mechanical clocks proved Aquinas' "invisible hand of

God" had set a "mechanical" Universe in motion. But after that, the heavens continued to move in a way that could be explained by scientists using scientific laws and concepts such as momentum.

Oresme also understood that before scientists could explain the "workings" of a mechanical Universe, they would have to find better ways to describe motion. So, he tried to create ***a more precise geometric language*** that could be used to picture different types of motion. For example, Oresme saw steady acceleration as an upward-sloping ramp and steady deceleration as a downward-sloping ramp, with the ramps' tapered (narrow) ends representing the object at rest. Then he made pictures of combinations of these shapes. For example, since a horizontal plane represented constant speed (zero acceleration), an object that gained speed before "leveling off" was represented by an upward-sloping ramp leading to an elevated level platform. These pictures were Europe's first "graphic" models of scientific concepts. Without this kind of ***mathematical modeling***, later scientists would not have been able to conduct meaningful experiments on motion, translate the paths followed by moving bodies into mathematics-based graphs, or analyze the forces those graphs represented. Consequently, ***Oresme is sometimes called the "father" of European mechanics.***

Despite Scholasticism, Oresme understood his ideas might be seen as contradicting the idea of a "living God" whose hand is present at all times and in all things. So, he avoided saying his ideas were proven scientific facts. Instead, he said they were ***mere speculations***. Thus, while Oresme's ideas show how much of nature was becoming part of science's territory, his behavior shows he was uncertain of his right to express such ideas. In any case, Oresme and most other scientists of his day agreed with St. Augustine and Aquinas that humans could only explain ***how*** nature works, leaving the Church to answer questions like ***why*** nature is the way it is. Or, to put this idea in Christian terms, "why God created the Universe as He did."

Before leaving the 1300's, it is important to note that the re-discovery of Babylonian, Egyptian, and Greek knowledge during this period also rekindled an interest in ***alchemy***, an ancient "science" devoted to two tasks: 1) turning base (non-precious) metals into gold, and 2) creating a chemical soup that would give humans eternal life. While we now know alchemy is based on superstition, people of that time believed it was as much a science as astronomy or mechanics. In fact, alchemists often carried out detailed experiments that explored characteristics of fire, metals, other substances from the Earth, and samples of living tissues, tasks that required improved laboratory equipment and step-by-step recipes for doing experiments. Thus, ironically, alchemists pioneered many of the laboratory methods and equipment later used by modern chemists and other experimental scientists.

An Old Model Changes, Astronomy and Other Matters

In the early-1400's, northern and central Italian scientists began doing experiments that led to new theories and knowledge in geography, chemistry, zoology, anatomy, and botany. But ideas about physics and astronomy did not change. Why? Some historians argue leading Renaissance thinkers were simply more interested in the arts, humanities, and "soft" sciences, rather than the "hard" mathematical sciences like astronomy and physics, while others argue Renaissance thinkers respected ancient Greek thinkers too much to question their basic philosophical assumptions.

When ***new physics and astronomy ideas finally did emerge after the Reformation, beginning in 1543***, they owed a great deal to earlier work by scientists in Persia, the Moslem world, India, and China; the scientific work that had been done in Europe since 1200; and Renaissance attitudes. However, the new ideas that emerged after 1543 did more than simply refine earlier ones. Those relating to astronomy and mechanics completely changed the way humans thought about nature and their place in it. As a result, we call the discovery of those ideas ***The (European) Scientific Revolution.***

To understand Europe's Scientific Revolution, we must begin with the Greek model of nature accepted by Europeans in 1500. 1) The Earth is at the center of the Universe. 2) The other heavenly bodies go around the Earth in circular orbits. 3) Each type of heavenly body is trapped in its own sphere. 4) The inner sphere, in which nature can change, contains the moon, comets, and Earth. 5) The outer spheres, in which nature cannot change, contain the planets, sun, and stars. 6) The objects in the inner sphere are made from air, fire, water, and earth. 7) The objects in the outer spheres are made from ether. In fact, the stars imbedded in the outermost sphere are very tiny and relatively close to Earth. And, 8) within the inner sphere, objects moving other than toward the surface of the Earth are under the influence of unnatural forces, and therefore in an unnatural state. Hence, there are two types of motion: forced (unnatural) and unforced (natural), the latter of which moves all objects to the surface of the Earth. In other words, an object at rest (in stasis) is in a completely different state than one in motion.

Some of these ideas had been accepted by the Romans and early Christians, while others came from Arabic sources in the 1100's and 1200's. In fact, by the late-1400's, the Latin Church had incorporated many previously-banned Greek ideas into its official view of nature. Thus, ironically, some ideas that had helped scientists question Church authority in the 1200's and 1300's were used by the Latin Church to supress scientific work and new conclusions in the late-1400's and 1500's.

Nevertheless, by then, many European scientists understood there were inconsistencies in the ideas that had come from Plato, Aristotle, Ptolemy, and Empedocles, and in the way European Churches embraced some ideas and rejected others. For example, Pythagoras had argued all heavenly bodies, including the Earth, orbit a fiery ball, an idea rejected by Western Christianity because it implied God had not placed humans at the center of the Universe, ***and*** because it disagreed with the approved Ptolemaic view of the Model of the Spheres. However, Pythagoras' ideas on the mysticism of numbers were accepted. To many scientists, this and other examples demonstrated that Western Christianity's ban of some Greek ideas and embrace of others was arbitrary, and not part of a divinely-inspired truth about those ideas or nature.

To astronomers in particular, these doubts were long overdue. For, ***by 1510, it was clear the observed orbits of the planets did not fit Ptolemy's model of the Universe***. To make them fit, astronomers had to add extra epicircles to the ones already in Ptolemy's text, further violating the still beloved Greek idea that the Universe is governed by beautiful rules describable by simple mathematics. To many astronomers this was more than an inconsistency. Here was a great and vexing contradiction.

Copernicus: The Seeds of Change are Sown

One of the people who studied the criticisms of Ptolemy was a Polish astronomer named ***Nicolaus Copernicus***. As the Catholic canon of Frauenburg and a respected astronomer who had studied science in Italy, Copernicus was asked by the Church's Lateran Council in 1514 (three years before Luther's break with the Latin Church) for help in reforming its Calendar. After studying his own and earlier European astronomical observations, Copernicus decided the only way to correct Ptolemy's theory and construct a more reliable calendar was to ***place the sun at the center of the Universe*** with the Earth orbitting it, like all other planets.

This was a truly revolutionary idea. But Copernicus upheld other parts of Ptolemy's theory by insisting all planets move in circular orbits within a single sphere, and that the planetary sphere takes up almost all the space in the Universe. Thus, the stars are tiny bits of light that orbit in an outer sphere that is only a little bigger than the sphere holding the planets. In any case, Copernicus was able to use his theory to calculate the radii of the largest orbit of the known planets within 1% of its modern value and to suggest that the sun might not be in the exact center of the planets' concentric (to him) circular orbits (while Copernicus did not know this, this implied the planets' orbits were "eccentric" ellipses).

Copernicus's theory also provided the first good explanation for Ptolemy's "ugly" planetary orbital epicycles. According to Copernicus, a planet's orbit would look circular if viewed from the surface of the sun. But since the Earth is also orbitting the sun, the combination of our motion and that of the other planet makes it look like the other planet's orbit has loops in it.

Despite his success in matching predictions based on his theory to observational evidence, Copernicus knew his theory disagreed with Christian teachings. He also understood that if the Earth is not standing still, it must be moving in relation to the stars. So, an earthly observer should be able to see the stars' orbits shifting in relation to the Earth. But nobody had observed this stellar shift. Therefore, lacking evidence he felt he needed and fearing the reaction of Catholic Church leaders, Copernicus decided not to publish his ideas. Instead, he shared them with friends, who encouraged him to have them printed. Finally, in ***1543***, the year of his death, Copernicus published his new theory in a book entitled <u>Of the Rotation of Celestial Bodies</u>. But just to be safe, Copernicus dedicated his book to the Pope to demonstrate his devotion to the Catholic Church and his hope that his ideas might be acceptable to Vatican leaders. (NOTE: The stellar shift Copernicus proposed was found by astronomers after the invention of the telescope, long after Copernicus' death. See Chapter 10 for more on this issue.)

The story of Copernicus illustrates an important point about the Scientific Revolution that is often misunderstood. Although his theory questioned the position of the Earth and humans in the Universe and contained major scientific insights of lasting value, it did not reject all Christian or Greek ideas. Rather, as Copernicus explained, Ptolemy's model had to be wrong because it was too complicated, thereby violating Plato's and Pythagoras' belief in a simple Universe. Thus, Copernicus "fixed" Ptolemy's model partly because it no longer fit Greek, and therefore Renaissance, ideals of "truth" and "beauty." This was hardly a radical motive for proposing a new way to look at the Universe.

Radical or not, when Copernicus' ***heliocentric*** theory was published in 1543, ***Martin Luther and John Calvin declared it a heresy*** on the grounds it disagreed with Biblical truth. In particular, the Bible states God made the sun stand still during the battle of Jericho, which was a great miracle ***because*** the sun normally orbits the Earth. Therefore, Copernicus' idea must be heretical. However, most scientists of Copernicus' day were Catholics who were not bound by Luther's or Calvin's opinions. So, when the Catholic Church kept silent on this issue, many continued to work on Copernicus' ideas.

At first glance, the Vatican's silence on this question is puzzling. But in 1543, the Church was preoccupied with the war Catholic monarchs and clergymen were waging against Protestant forces across Europe. In any case, discoveries by explorers and scientists in the last 100 years had already forced the Vatican to modify its ideas about nature and geography several times. Perhaps Catholic Church leaders believed it was dangerous to side with Protestant leaders against a Catholic. Or, that it was better to remain silent until Catholic theologians had a chance to examine Copernicus' theory, which might lead to its rejection or to the discovery of a way to incorporate it into the official Catholic view of nature. Or, lastly, Vatican leaders may simply have failed to understand the real meaning and importance of Copernicus' model. Whatever its motive, ***the Catholic Church took no action against Copernican ideas for 60 years and declared no official position on the Ptolemaic and Copernican models until 71 years after Copernicus' ideas were published.***

Religious questions aside, astronomers soon noticed they still had to add ***some*** (if fewer) epicycles to planetary orbits to make their observations fit the new theory. Nevertheless, in a striking example of ***deductive thinking***, since Copernicus' theory "felt right" to astronomers, many accepted it without convincing observational proof, on the assumption future observations would verify its correctness. Strangely, this was especially true in England, where books published around 1550, including ones used by students, contained pictures of Copernicus' ***solar system***.

Little changed in this "debate" until the late-1590's, when an Italian professor named ***Giordano Bruno*** gave speeches all over Europe that promoted new mystical and scientific ideas, including Copernican ones. According to his contemporaries, Bruno was so theatrical he often seemed to be nothing more than a charlatan who was only interested in fame and fortune or, in the spirit of Venice where he lived and taught, in outraging tradition-bound Vatican and Jesuit officials. But this is unfair. While not a scientist himself, Bruno was serious about merging mystical and scientific ideas. He was also the first to challenge the parts of Copernicus' theory that were still rooted in Greek beliefs, by arguing that the Universe is infinite and the stars are very large and far away. In fact, Bruno speculated that there might be other stars that were the centers of their own solar systems.

In any case, it is a mistake to contrast Bruno's mysticism to the attitudes of supposedly more scientific thinkers of his time. Many key figures of the Scientific Revolution, including Brahe, Kepler, and Newton (all of whom we will meet shortly), openly promoted similar beliefs. In fact, it is one of the main ironies of our story that many of the authors of modern science held beliefs in the occult that were on the extreme fringes of and sometimes in opposition to more rational Christian thinking of authorities within the Catholic and Protestant Churches. (NOTE: For example, Luther was opposed to astrology because he believed it was a form of pagan worship, while Newton spent more time and energy on astrology than he did on math and science.)

As Bruno's fame grew, he outraged Protestant and Catholic leaders, as well as many nobles who had formerly supported him. When Bruno lost the protection of these secular leaders, Vatican officials ordered Bruno to Rome to face the ***Court of Inquisition***, a Catholic judicial body given the job of identifying and rooting out heretics, an important task given the climate of distrust and fear caused by the Reformation and its aftermath. In any case, when the Court of Inquisition convicted Bruno of believing and promoting unChristian ideas in 1600, it ordered him to recant his heresies. When he refused, Bruno was tortured and burned at the stake. This made Bruno the first martyr of the new scientific age, or at least of his idea of freedom of thought and speech.

Clearly, Bruno misjudged the Catholic Church's changing attitude toward science, and the forces that were moving the Vatican toward a renewed defense of Catholic beliefs, including Papal infallibility. Nor did he understand the Vatican's need to keep its most conservative and devoted defenders happy. In any case, by 1600, powerful "enemies of science" within the Catholic Church were determined to see the Vatican take a more active stand toward scientific heresies.

<u>Stevins, Brahe, and Kepler: Evidence Makes Theory</u>

Before leaving the 1500's, we must discuss three other scientists. ***Simon Stevin***, who worked in Holland, studied ***the mechanics of levers*** (how they lift objects) and the way objects move on a ramp (an inclined plane). To many historians, this work makes Stevin ***the "father" of modern experimental physics*** because: 1) it raised questions about the forces acting on moving objects (***dynamics***), 2) he developed a more precise mathematical language to describe the geometry involved in motion, thereby continuing the work Oresme had begun 200 years earlier, 3) he promoted modern science, including Copernican ideas, and 4) in 1585, he proposed all scientists use a single system of measurement and a number system based on ***decimals, including fractions*** such as 0.4.

This was a new idea for Europeans. But the Sumerians had introduced a similar idea about 3,000 BC, albeit using base-60 instead of base-10 numbers, while the Chinese used true base-10 decimal fractions as early as 200 BC, if not earlier. In the European context, however, Stevin's decimal fractions and standardized metric measurements eventually made it easier for scientists to fit the measurements and numerical expressions that arose in scientific experiments into simpler patterns, and to compare results from several experiments in order to evaluate their usefulness when creating theories about nature. Moreover, when European scientists embraced these tools, they greatly enhanced the role of mathematics as the "language" of science, as Latin disappeared as the international language of all ideas.

In the late-1500's, a Danish astronomer named ***Tycho Brahe***, designed and built metal astronomy instruments and a large observatory on a Danish island that were far more accurate than earlier ones. But Brahe understood that ***no*** instrument could be perfect. So, he calculated his instruments' margin of error. This concept of ***precision of measurement*** allowed Brahe to correct his data before using it to construct his theories, a task he thought would prove Ptolemy correct. However, before Brahe could complete this work, he was exiled from Denmark for being in a duel in which his nose was cut off (Brahe wore a metal "cup" over the tip of his nose for the rest of his life). As a result, when he received an offer from a German prince to build a new observatory there, Brahe moved to Germany. Once settled in his new home, Brahe hired a young German mathematician named ***Johannes Kepler*** to analyze his life's observational work. When Brahe became ill and neared death in 1601, he made Kepler promise to continue to job for which he was hired.

(NOTE: Before Brahe, European astronomers relied on the horizon as their primary reference line for describing the position of heavenly bodies. But Brahe used the Chinese method, which desribed celestial positions according to intersecting angular globes on an instrument called an armillary sphere. Some historians believe this shows Brahe learned about Chinese methods from Arabic sources, which made Kepler's work possible. However, other historians point out we have no evidence of such a transmission from China to western Asia to Europe. So this may be a case of independent invention.)

Aside from proving the correctness of Ptolemy's model, Brahe believed his observations would validate several popular Biblical and mystical Christian predictions, as well as the widely-held belief of his day that Judgment Day was imminent. Thus, when he discovered a new "flaring" star (nova) in 1572, Brahe said its appearance "proved" civil disturbances would soon sweep Europe, preparing the way for Judgment Day. However, Brahe also wrote that the existence of novas, when taken with his observation of the 1577 appearance of a "new" comet, disproved two Aristotelian ideas: 1) within the inner spheres, the heavens are unchangeable, and 2) comets only exist within the moon's sphere. In other words, Brahe's thinking, like that of many of his contemporaries, reflected a mixture of scientific and pre-scientific beliefs that were shaped by the sense of doom caused by the chaotic aftermath of the Reformation.

Despite Brahe's expectations, when Kepler finished analyzing Brahe's data he concluded that ***neither*** Ptolemy's nor Copernicus' model matched it. So, Kepler decided to analyze the orbit of just one planet. As a result, in ***1609***, Kepler published a book that stated ***Mars*** orbits the sun (not the Earth). But the shape of that orbit is not a circle. It is an ***ellipse***. Hence, Copernicus' basic assumption is right and Ptolemy's is wrong. Moreover, in 1619, Kepler published a second book, called **Harmony of the World**, that extended this model to all the known planets of his day. It is this theory, with minor adjustments, that we still use today.

Given the by then well-established assumption that all scientific ideas had to be supported by mathematics, Kepler's 1619 book also included: 1) drawings of the geometric structures that make up his model, 2) a detailed analysis of the mathematics of circles and ellipses, and 3) algebraic equations for ***the First and Second Laws of Planetary Motion***, which state that a ***planet encloses an equal area of space in equal periods of time during its orbit***. Or, to put this idea in terms of Galileo's experiments on mechanics, planets accelerate as their distances from the Sun diminish and decelerate as those distances increase.

The publication of Kepler's two books was one of the most important events in European history. But, again, it is one of the great ironies of history that Kepler butressed the "proof" of his model by stating that the dimensions of his elliptical orbits were ***caused*** by their being "filled" by invisible polyhedrons that are in a spiritual harmony with each other (thus, his book's title), reasoning that echoed Pythagoras' Orphic ideas.

In more general terms, Kepler believed his insights were part of God's plan to reveal the working of nature to humans as ***a final sign*** before destroying His creation. Given these attitudes, it is truly remarkable his work played such a large role in the birth of modern science and the modern world. Moreover, although Bruno was dead by this time, Kepler agreed with Copernicus by insisting the Universe is small and almost entirely taken up by our solar system. Thus, the stars are very small objects relatively close to the Earth. As we will see in Chapter 10, this aspect of Kepler's model caused a great deal of trouble until the late-1700's, when astronomers proved Bruno was right.

Galileo Galilei

As Brahe and Kepler were doing their work in astronomy, an Italian physicist named ***Galileo Galilei*** was re-examining Aristotle's idea that some kinds of motion are natural and others unnatural, ***and*** questioning Ptolemy's picture of the heavens, the two most basic tenets of the Christian description of nature.

In 1588, Galileo re-created Aristotle's study of the flight of an arrow shot upward at an angle to the horizon. During this experiment, Galileo observed the arrow following a ***parabolic flight-path*** in which it leaves the bow-string at the angle it has been pointed, changes direction to a more horizontal path as it rises until it reaches a horizontal position at the top of its flight, and then falls to Earth in a curve that perfectly mirrors the path of its ascent. Galileo also stated that these ***changes of direction*** are accompanied by ***changes in speed***. Thus, as the arrow rises, it ***decelerates*** until it has a vertical speed of zero (0) and a diminished horizontal speed. Then, as it descends, it gains vertical speed, or ***accelerates***, in the opposite direction, while continuing to lose horizontal speed. Thus, each component of the arrow's direction and speed changes as it flies through the air.

Galileo understood these changes of speed and direction (together, changes of ***velocity***) are due to the pull of the Earth acting in the opposite direction as the upward component of the force applied by the bow-string ***and*** air resistance acting against both the vertical and horizontal components of the force applied by the string. More generally, Galileo understood this meant an object will remain at rest when the forces acting on it "cancel each other out," or mathematically add up to zero (0). Thus, an arrow is stationary before it is released because the downward force exerted by the Earth is balanced by the upward force exerted by the archer holding up the bow. And the arrow comes to rest at the end of its flight because the ground is pushing up on it in balance with the Earth's downward pull on it. Hence, ***objects in motion are those affected by forces that are out of balance***. Moreover, when Galileo compared this picture of motion to Oresme's concept of momentum, he suggested an object in motion would stay at the same velocity forever unless a new force acts on it. However, Galileo was unable to find a set of mathematical equations that represented this simple concept.

This work and other experiments Galileo did on gravity and falling objects, including his famous use of the Tower of Pisa as a giant piece of experimental equipment, helped make Galileo the most respected and well-known scientist in Europe. So, when Kepler published his book on Mars in 1609, he wrote Galileo to ask for his support. However, Galileo refused, possibly for one or all of these reasons: 1) he was not ready to reject Greek ideas, at least without personal experimental evidence, 2) he was unconvinced by Kepler's mystical logic, or 3) the religious climate in Italy made it too risky for Galileo to publicly state a pro-Copernican (and therefore pro-Kepler) position, at least without truly compelling observational or experimental evidence.

It was not long, however, before Galileo changed his mind, in part due to an invention called ***the multiple lens telescope***. Ideas about telescopes had been circulating in Europe since 1590. But the first workable one was not built until 1608. Later that year, a Dutch salesman showed one to Galileo's prince and patron, claiming it could be used as a magnifying or spy-glass. However, when Galileo saw this demonstration, he immediately recognized the telescope's potential as a scientific instrument and began working on ways to improve it so it would be a useful astronomical tool.

This was one of the most fateful unions of science and technology in world history. Within months, Galileo began using his telescope to observe "the heavens." As a result, in ***1610*** he published a book that described seeing mountains on the moon, discovering the Milky Way is countless individual stars (not a gaseous cloud, as had been previously thought), identifying four moons orbiting Jupiter, and seeing that Saturn (who's rings Galileo incorrectly described as "horns" representing two small stars circling it) is far from a simple or perfect sphere.

Aside from providing important new data on celestial bodies, these observations ***disproved three features of the Ptolemaic model of the Universe***: 1) since it is the only stationary body in the Universe, only the Earth (at the center of the Universe) could have moons orbitting it, 2) the Earth is the only celestial body that can have an irregular surface, since all others would have been worn smooth by flying through space, and 3) all celestial bodies must be smooth spheres, the most perfect three-dimensional form. Hence, the heavenly bodies must be unchanging. Given these Ptolemaic assumptions, Galileo's first telescopic work convinced him to support Kepler, since it seemed logical to assume that the Earth with its moon is a planet just like Jupiter with its moons. In fact, since the moon has a rough surface and Saturn appears to have "horns," the Earth's imperfections do not prove it is at rest at the center of the Universe. Moreover, ***none of Galileo's observations suggested the Earth is a unique body or that it is at the center of the Universe.***

By the time Galileo announced these discoveries, the Catholic Church had already executed Bruno as a heretic. It was also embroiled in the Thirty Years' War, a struggle in which Catholics were again fighting Protestants for territory and souls from France to Austria. As a result, Church conservatives were more determined than ever to change the Church's "liberal" stance toward scientific ideas. Nevertheless, Galileo ignored this gathering storm by publicly stating his support for Kepler, and then quietly returning to his own work on mechanics and astronomy as if nothing had happened. Amazingly, however, the Church did nothing, preferring to ignore Galileo's declarations, either in deference to his fame or because Galileo lived in Pisa, a university city under the control of Venice's independent city government, which gave Galileo some degree of protection from Vatican leaders.

However, in a move that probably demonstrates Galileo's naivety more than any desire to provoke a confrontation, in 1610 Galileo moved to Padua and then Florence, where conservative influences and Vatican control were stronger. Nevertheless, when Galileo resumed his work in Florence, the Catholic Church made no immediate demands he change or withdraw his comments about Copernican ideas. As a result, Galileo continued to communicate privately with Vatican "liberals" in the firm belief that the

Church would eventually revise its picture of the Earth's place in the Universe in light of modern scientific ideas.

This was a terrible mistake. For, ***in 1614 the Vatican banned Copernicus' and Kepler's ideas as heresies***, and summoned Galileo to Rome, where he was told he could no longer believe, promote, or teach the opinion that Copernican ideas were true or proven. After once again attempting to convince the Church to change its position, in 1616 Galileo agreed to all the Church's demands.

To the Vatican, that settled the issue. But Galileo still believed Church dogma would eventually change. So, as the Thirty Years' War dragged on, he returned to his work and renewed his lobbying of liberal Cardinals on behalf of modern science, even though both of these actions violated the Church's 1614 ban of Copernican ideas ***and*** Galileo's 1616 promise to honor that ban. However, once again, the Vatican did nothing. In response, and in a stunning demonstration of how poorly he gauged the temper of his times, Galileo published a book in 1623 that ridiculed the theories being defended by the Catholic Church, praised modern science, and gave his own ideas on ways to improve the "modern" scientific method.

Leaving religious issues aside for the moment, the most important part of Galileo's 1623 text was its ***refinement of the Grosseteste method*** and its statement that: 1) science must start with ***experiments that render observational data,*** not just general observations, and 2) since experimental results may cause scientists to propose new theories, ***the modern scientific method must include a way to standardize the use of experiments to prove or disprove new laws of nature***. In other words, science should endlessly alternate between experimentation and theory-making, and therefore between inductive and deductive reasoning.

<u>The Battle Over "Truth" Comes to a Head</u>

Whether Galileo meant it or not, his 1623 book amounted to a "declaration of war" by modern science on the Catholic Church. But, incredibly, after again failing to get the Vatican to change its views on modern science and the structure of the Universe, Galileo asked for and was given permission by a leading Cardinal (and Galileo believed, indirectly by the Pope) to prepare a new book that would ***fairly*** present the Greco-Christian and "modern" scientific points of view about nature so a neutral observer could decide which should be believed.

In ***1632***, Galileo delivered his much awaited manuscript, **<u>The Dialogue</u>**, which was written in Italian. In it, Galileo used the format of a Socratic discussion, as witnessed and judged by a reasonable man, to compare the two world views at issue and to show why scientific ideas were superior to Greco-Christian ones. Before circulating this book, Galileo asked for and was given permission to include a Vatican blessing on its title page. In return for this "seal of approval," Galileo agreed to include a statement that he considered Copernican ideas mere theories, not proven facts, a statement almost identical to Oresme's self-imposed disclaimer in the 1300's.

Despite the more neutral tone of The Dialogue compared to Galileo's 1623 book, Church conservatives were appalled the Vatican had given approval to a work that questioned Church dogma. Thus, with the Pope's blessing, Galileo was again ordered to Rome, this time to face the Court of Inquisition. Among the new charges brought against Galileo were that he had ignored the Church's 1614 position on these questions and his 1616 promises to abide by that position, and that his 1632 book was written in Italian, which proved he ***intended*** to corrupt minds.

At first, Galileo was optimistic he would be found innocent. But as his case proceeded, he finally understood the seriousness of his position. Consequently, by the time he was ***convicted of heresy in 1634***, Galileo was ready to accept any demands the Court would make in order to avoid excommunication, torture, or a possible death sentence. Thus, as part of his sentence, Galileo agreed to: 1) apologize for stating incorrect ideas, 2) state he never did or would believe those ideas, 3) promise to stop promoting, studying, or conversing about ***any*** opinion having to do with astronomy, 4) accept the banning and public burning of his 1632 book and a life sentence of house-arrest, and 5) publicly state ***"I hold Ptolemy's opinion to be very true and undoubted."***

Despite these denunciations, Galileo's private support for Copernican ideas never wavered. So, incredibly, when he returned to his home to begin his sentence, Galileo immediately began negotiating with his Vatican friends for a reconsideration of his case, while at the same time arranging to smuggle a copy of The Dialogue to his supporters in France, a Catholic country that was more independent of Vatican influence than Italy and therefore freer to translate his book into Latin in preparation for its publication in Holland.

Clearly, the Church hoped the sentencing of Galileo would send a strong message about faith and obedience to other Catholic scientists. But, surprisingly, Galileo's punishment had little impact on his supporters, many of whom simply redoubled their efforts to ensure others would learn of his work. Nor did Galileo's house-arrest stop him from continuing his experiments, or from publishing one last book in 1640 that examined the laws governing the motion of pendulums. But by then, an eye infection had left Galileo blind. So, despite the excellence of his last experimental work and a network of supporters in Catholic ***and*** Protestant countries who revered him for his stand and his entire life's work, in 1642 Galileo died broken and alone.

Science, Truth and Nature: A New Reality and Ethic

New ideas in astronomy brought the struggle between science and Greco-Christian ideas to a head. But it was a French Catholic mathematician, scientist, and philosopher named ***Rene Descartes*** who re-examined the purpose of science and reframed the new Galilean method in a more abstract philosophical and mathematical language. In fact, by the time Descartes' most important ideas were published in 1637 and 1644, the latter being the year of his death, he successfully constructed the first definition of modern science that ***purposely addressed the basic metaphysical issues raised by the doing of science.***

According to Descartes, a conclusion is only scientific if it is based on concepts ***or*** observations that can be shown to be "true." Thus, since observations (of nature or in experiments) are based on subjective sensations, they can only be verified by analyzing them using up-to-date mathematics. It therefore follows that ideas and observations must be stated as mathematical formulas or contribute to the creation of a mathematical model. In fact, ***abstract thoughts, like those embodied in mathematics, are the only way humans can verify the reality of ideas, sensory perceptions, or existence at all*** (hence, his famous quote, "I think, therefore I am"). Moreover, in the context of science, the precision and strength of a model's mathematics is the only way to evaluate its truthfulness. Consequently, scientists must reject vague thoughts, ones that start with the authority of ancient thinkers, or those that contribute to descriptive theories that cannot be verified. Thus, the search for truth must ***always*** start with an abstract idea.

In other words, ***Descartes turned Socratic logic upside down by arguing that truth can only be found through deductive logic.*** As radical as this sounds, by this time, and without a prior statement of these principles, scientists were already doing their work this way. In fact, a modern reader of late-1500's scientific treatises is struck by the fact that the work of defining and treating mathematical terms and ideas is often given greater prominence and space than any description of nature, however revolutionary that description later turned out to be.

Descartes' second (1644) book also provided the first satisfactory explanation of Galileo's experiments on motion. Descartes said a moving object will continue to move with an unchanging speed and direction (its current velocity) unless a force acts on it. Thus, ***an object at rest will stay at rest, while an object in motion will stay in motion.*** Therefore, these two "states" can be explained by the concept of ***inertia, the tendency of any object to resist a change in its momentum.*** Accordingly, an object at rest is just a "special case" in which the velocity of the object is zero (0) and the laws of motion apply equally to all objects.

The concept of inertia unified motion and stasis under a single physical law. But Descartes still could not produce equations that fit all the kinds of motion that had already been described by scientists. So, ironically, he failed to produce a scientifically true model for motion, at least as he defined truth. That said, Descartes did invent several mathematical ideas that proved indispensable to later scientists, including an imaginary three-dimensional grid that allowed geometric and algebraic expressions to be treated as different expressions of the same problem. For those who did scientific work from 1650 to 1895, these ***Cartesian coordinates, as they were called, were an essential tool in describing shapes, forms, space, or any process involving displacement in space, such as motion***. In fact, students still learn Cartesian coordinates in high school mathematics and use them when doing most physics assignments.

Within the realm of astronomy, Descartes speculated the heavens are filled with swirling vortices, or eddies, that move all celestial bodies. Therefore, ***the Earth is moved, but does not move of its own accord***. In other words, the Earth goes around the Sun. But its "natural" place is at the center of the Universe. At first glance, this bit of double-talk appears to have been designed to satisfy the Vatican and Church conservatives. But Descartes apparently came to believe his own logic on this matter. For, he later claimed graphs he produced proved the existence of "spacial eddies," a bit of reasoning that, to modern readers, illustrates the danger of ***really*** believing observations and experimental results are indistinguishable from speculative ideas as long as both are accompanied by mathematical "proofs." (NOTE: To modern physicists, abstractions ***are*** as "real" as empirical data. But they have worked out a way to judge the usefulness of speculative ideas by using rigorous mathematical criteria. See Chapters 10 and 11 for more on this question.)

Despite the subtlety and breadth of Descarte's thinking, some of his contemporaries disagreed with his definition of truth. ***Francis Bacon***, an English scientist who should not be confused with the earlier Roger Bacon, argued that no scientific theory should start with abstract thoughts, since they are always subjective, no matter how mathematical or scientific they sound. In fact, only an observation or experiment will do, although Bacon failed to address Descartes' more troubling assertion that observations themselves are subjective products of our senses.

While Bacon rejected the whole idea of verifiable speculations, he offered some pretty sweeping speculations of his own. Most importantly, he said that since the observations and experiments of the previous 100 years had shown that mechanical "laws of nature" determine all processes in the Universe, all material substances must be made up of tiny, unseen "atomic" particles whose interactions drive the mechanics of nature. Despite its entirely speculative nature, this was the first "modern" statement of the atomic theory. Moreover, Bacon's reasoning about the connection between the structure of an unseen micro-world and the behavior of the macro-world turned out to have great merit.

Nevertheless, Francis Bacon is best remembered today for his statement that ***the goal of science is not to understand nature, but to give humans dominance over it***. By itself, this statement is ideological, not scientific. And it was not original. In fact, Genesis 1:28 in the Bible states God made Man to be Lord over all the beasts of the Earth, sea, and sky. So, the idea that humans have a right to dominate nature already had a long history as a cornerstone of Western philosophy and civilization. But Bacon's restatement of this principle as a scientific motive has become an important aspect of the modern Western attitude toward nature, leading some people to argue that the discoveries of science have become less of a blessing to humans than a threat to nature, including to humans, who are, after all, part of nature.

Before leaving this period, we must take one last detour to consider the work of another Englishman, ***William Gilbert***. Gilbert did experiments on ***electricity and magnetism*** that by 1600 showed the Earth is a giant magnet, a startling discovery that made him famous and led Kepler to guess magnetism might be the force pulling all planets toward the sun. We now know, of course, that Kepler was wrong in this. Moreover, when gravity was demonstrated to be the force at work in the solar system in the 1680's, scientists decided Gilbert's work was of little importance, a judgment that kept them from re-addressing the question of magnetism, or Gilbert's work, until the 1820's.

Galileo: Man of Science

It is difficult to measure Galileo's importance. His work on mechanics, astronomy, the use of mathematics as a scientific tool, and the scientific method were among the most important in the history of science. But so was that of Copernicus, Brahe, Kepler, Stevins, and Descartes. Moreover, none of these men's work would have been possible without earlier contributions by Grosseteste and Oresme, to cite only European examples. So, in that sense, Galileo was just one particularly bright star in a galaxy (and long line) of bright stars.

What set Galileo apart was his defense of science against religious authority, although in this regard, like Copernicus before him, Galileo was clearly an unwitting revolutionary. After all, he never thought his discoveries were inconsistent with

Catholic belief, a proper interpretation of the Bible, or Vatican authority, all of which he accepted as eternal truths.

In other words, as with many other important moments in world history, Galileo apparently failed to understand the true meaning of his actions and ideas, or the environment into which he deposited them. It is also clear Galileo failed to see that Western European Christian leaders were already losing their power to keep scientists from thinking what they wanted to think. Or, that ***his*** rebellious stand against Catholic Church dogma would further undermine the authority of the Church he loved so much. Nevertheless, Galileo's confrontation with the Catholic Church gave Europe's next generation of scientists a remarkable degree of independence from religious authority. In fact, despite the many later scientists who continued to embrace spiritual notions and profess great religiosity on a personal level, all scientists of the late-1600's and beyond did their work as if it had no connection to their personal beliefs or the official positions on scientific questions taken by ***any*** Church. (NOTE: See Chapter 11 for more on this question.)

Summary

Between 1150 and 1642, Europeans greatly improved their understanding of nature and established science as a separate body of knowledge with its own methods, ethics, and institutional settings. The people who created this ***scientific culture*** often spent part of their lives studying or working in countries or cities other than those in which they were born. Thus, even though Europe was becoming more "nationalistic," scientists went where they were invited or could best do their work, freely sharing their work and ideas with other scientists.

The insights into nature gained by 1642 guided scientific work in the next stage of our story. But it was the Grosseteste-Galileo scientific method and the mathematical language and reasoning created by Oresme, Stevins, and Descartes that most shaped future scientific work. For, ***after 1642, all scientists started with specific experiments, and based their theories on their interpretation of the results of those experiments. Then, they did more experiments to test the theories their experiments suggested, making science an endless process, the goal of which became the creation of purely mathematical models as descriptions of their ideas.***

Most scientists continue to work this way today. But modern physicists also accept Descartes' (ultimately, Pythagoras') idea that they can start with a mathematical statement they accept as true, or one they think might be useful in directing future scientific work. Thus, as strange as it may sound, much of the physics done in the last 100 years has been founded on ***completely artificial mathematical models*** that suggested possible observations or predicted the outcome of specific experiments, many of which could not be done until decades later, when scientists overcame the technological limitations of their day. So, while Galileo's ideas about the scientific method have dominated science for over 360 years, Descartes' have had an equal effect on the work of physicists in the last one hundred.

It was seldom the goal of the scientists who worked in the years covered by this chapter to reject Greco-Christian models. But their observations and experiments forced them to criticize, and then reject, the old models. Thus, like the Hellenic Greeks 2,000 years earlier, European scientists in this period made nature more natural. But unlike the Greeks, the work Copernicus, Bacon, Descartes, Brahe, Kepler, and Galileo did pointed toward ***a single model*** of nature, the completion of which would have to await new discoveries in mathematics. By 1642, science had many of the "tools" necessary to take that next step. As we will see in Chapter 10, this, above all, was the greatest gift of science between 1150 and 1642.

CHAPTER NINE

EUROPE: THE ONE REMAINING SUPER-POWER

By 1873, the end of the time covered by this chapter, people in Europe's colonies or former colonies, most of whom were of European descent, were making important contributions to modern (Western) science. Then, after 1945, people of all races, on all continents, began making such contributions. But this shift to a ***world-wide scientific culture*** did not begin until the 1870's. We can therefore concentrate here on European events. Even within this context, however, the complexity of European history will once again force us to limit ourselves to those ideas and events that most affected the development of modern physics.

European Politics and the First Age of Empire

Despite Spain and Portugal's headstart as Imperial powers and their status under the Papal treaties of 1494 and 1527, other European powers continued to explore and claim new territories. Then, when Spain's Armada was defeated in 1588, Great Britain became Europe's leading naval power, while Dutch, French, and British seamen, merchants, and governments increased their attacks on Portugese and Spanish shipping and expanded their own trade with non-European areas. As a result, by 1642, France, Britain, and Holland passed Spain and Portugal as traders. Soon they would also pass them as empire-builders as well.

While these powers dominated European affairs between 1642 and 1873, there were other important political entities during this period. In the late-1600's, 1700's, and early-1800's, German and northern Italian cities continued to exercise great cultural and economic influence as centers of business, banking, trade, the arts, and learning, while Sweden, the Hapsburg Empire, and Poland all became northern and central European powers. Then, by the mid-1800's, these powers declined, and Prussia, Russia, and the Austro-Hungarian Empire became northern and central Europe's main powers. Almost all of these (and many smaller) governments were led by monarchs or would-be monarchs, such as princes, kings, queens, emperors, empresses, tsars, and tsarinas, except for Italy's city-states, Switzerland, and the cities in Germany and Holland. So, Europe's immediate political destiny rested with countries ruled by monarchs, especially Great Britain and France.

A Changing Monarchy

Great Britain

Hostility between England's Catholics and Protestants began in 1534, when Henry VIII established the Anglican Church, even though the Anglican Church retained most of the rites and beliefs of Catholicism. In fact, people who were more imbued with the radical spirit of the Reformation in England, Scotland, and Wales formed other Protestant Churches. By the late-1500's, the members of one of these Churches came to be called the ***Puritans***, because they advocated living a simpler, sterner, and more disciplined life than was the custom in other British Churches. After tensions among Catholics, Anglicans, and Puritans intensified, a bloody civil war erupted in 1642.

The ensuing period of British history is too complex to recount here. But its outcome is so important to our story we must note the following highlights: 1) At first, the Puritans gained the upper hand, formed a government, and ***executed the king*** so they could rule Great Britain and a large part of Ireland without a monarch. 2) Puritan brutality toward others throughout Great Britain and Ireland, which the Puritans tried to conquer as well as intolerance of non-Puritan ways, as reflected by measures like the closing of all theatres (including the one started by Shakespeare in the previous century), led to a renewal of the Civil War. 3) When the Anglicans regained control of Parliament, the heir of the slain king was placed on the throne. 4) The new king proved ineffective and civil war erupted again. 5) When the Puritans again regained control over Parliament, they formed a new government that forced the king to flee to France. And finally, 6) the Puritan government once again proved incapable of building a lasting and peaceful regime and collapsed.

By 1688, this situation had become intolerable. So, when the Anglicans regained control of Parliament in that year, they decided that, to ensure Britain had a capable monarch, ***Parliament should pick the next king***. Thus, in an exercise of Parliamentary power called ***the Glorious Revolution of 1688***, it selected a relative of the deposed line of English kings who was a noble in the Dutch royal house, ***William of Orange***. As hoped, William was an able military leader and ruler who led Anglican forces to a final victory over the Puritans and Catholics in 1690. (NOTE: The Gregorian Calendar we use today, and which Catholic countries used by that time, places the Glorious Revolution of 1688 in February 1689. But the Julian calendar used in England at that time set New Year's Day at Easter, which placed these events in February 1688. Despite the confusion arising when comparing dates in Protestant countries to those in Catholic ones during this period, historians have decided to continue using the date the English used at that time for this epoch-making world event.)

Before 1688, European monarchs believed their right to rule came from God, a concept referred to as ***divine right monarchy***. This God-given authority gave a monarch power over his nobles and, through them, his people. While a monarch might share some of his power with his nobles, as English monarchs did after the signing of the Magna Carta and the establishment of Parliament, all political legitimacy was still derived from the monarch.

The Glorious Revolution of 1688 turned this theory on its head, by deriving the choice of the monarch, and therefore his right to rule, from Parliamentary authority. On a more practical level, this adjustment to Britain's system of ***Constitutional Monarchy*** also had immediate effects on the operation of Britain's government. During the rule of William of Orange, for example, Parliament acquired the right to approve ***all*** royal requests for money, whether they were for waging wars or paying for domestic programs and the running of the monarch's household.

Many British people were in favor of Parliament having these new powers. But most were uncomfortable that they were the result of the murder of one king, the exile of a second, and the arbitrary appointment of a third (according to existing political theory). What rules, if any, could be used to legitimize ***any*** monarch in such a system, especially when a rebellion occurred, a dynasty ended, or Parliament chose to name a new king? After all, it seemed obvious that the most repugnant of Puritan actions of the previous 45 years had been based on the same authority as the Anglican naming of William of Orange as king. So the question remained. How could the actions of Parliament in 1688 be justified? Or, to put this question in a more positive context, how could those actions be seen as laying the foundations of a stable and workable government for Great Britain's future?

In ***1690***, an English philosopher named ***John Locke*** answered these questions in a book called <u>Two Treatises on Government</u>. Locke argued ***all individuals possess rights to life, liberty and property*** that come directly from God to "the people," not from God to the monarch to the people, or (for that matter) from God to Parliament to the people. To protect these rights, the people may let a government, such as one led by a monarch, rule them. They may even give that government great power. But, the people have a right to "services" in return, including public safety, competent government, and protection of their individual rights. If a monarch fails to provide these services, s/he is breaking his/her contract with the people, and is no longer a legitimate monarch. In that case, the people have a right to "remove" the monarch and name a new one. Locke further argued British monarchs between 1642 and 1688 ***had*** broken their contracts with the people. So the people, through Parliament, had acted correctly in killing one, expelling another, and naming a third. In the end, then, the people had actually replaced two illegitimate monarchs with a legitimate one. (NOTE: After being accused of treason by the Puritans in 1683, Locke fled to Holland where he befriended William and Mary of Orange. Thus, while his 1690 book is one of the most important documents to the development of modern democracy worldwide [including for the United States], it is not without personal bias and historical context.)

Locke's reasoning in Two Treatises rested on two assumptions that had developed in Great Britain during the previous 100 years. First, "the people" are a collection of individuals, not parishes, families, guilds, or other Feudal groupings. Thus, the individual is the basic unit of society. And second, a person's rights rest on his right to own and use property. Therefore, ***Locke's contract*** granting the government ***its*** legitimacy was modelled on a commercial contract between two private parties. In that sense, ***Locke's entire radical argument rested on the rather conservative notion of preserving the economic relationships that emerged with the rise of the middle class and Mercantilism.***

Locke provided the foundation for Great Britain's modern form of government. But as Parliament's power grew, its leaders came to understand they needed a broader base of support, and new rules and structures that would help Parliament meet its new responsibilities. In time, three changes reshaped Parliament: 1) its lower house, ***the House of Commons***, which represented the broadest constituency in British society, came to dominate Parliament, 2) political parties were formed that ran candidates in Commons elections, creating voting blocs within Parliament, and 3) the leader of the party with the most Commons seats became the Prime Minister, making him the head of a cabinet of members of Parliament (usually from his own party) responsible for proposing and, with the consent of Parliament, enacting laws and government policies. Thus, by 1900, the Prime Minister became the legislative and executive leader of Britain's government, while the role of the nobles and their House of Lords was reduced, as was that of the monarch, who became little more than a figure-head of Great Britain as a nation.

France

In France, things happened differently. From 1661 to 1715, France was ruled by ***Louis XIV***, a king who embraced three ideals: 1) his right to rule came directly from God, 2) the monarchy should be more powerful than ever before, and 3) France should dominate Europe. But Louis understood that to accomplish these goals he first had to diminish the independence of his nobles. So, he built a magnificent palace, ***Versailles***, and held court at it with a glamor that emphasized the importance of his office and France as a nation. In fact, as Louis had hoped, France's leading nobles could not resist spending their time and energy at Versailles, both to court his favor and to impress each other with their stylishness and influence in such a glamorous court.

Louis also enacted policies that increased his influence. First, he sponsored several monumental government programs, such as improving France's navy, its coastal defenses, and internal commercial waterways, that established his over-riding importance in France and the impossibility of any duke matching his vision and influence. And second, Louis took action against any noble who challenged his authority, either by revoking his privileges at court *or* by taking away his control over the land and taxes that were any noble's source of wealth and power.

Louis' international ambitions rested on France already having a special place in European affairs. After all, in Louis' day, France had Europe's largest population, economy, army, and navy, while French styles in architecture, music, art, clothing, and literature had become fashionable among educated people from Russia to Spain, creating Europe's first "French craze." Thus, when King Charles XII of Sweden attacked Denmark, Poland, and Russia in order to build a Swedish empire, Louis responded by forming alliances with other European powers to contain Sweden's ambitions. However, Louis also saw this as an opportunity to assert his right to expand France's and his own personal influence beyond France's borders. In the end, these "foreign policies" increased Louis' sense that there was no distinction between his own person and France itself. Hence his famous quote: "L'etat c'est moi" (I am the State).

In 1701, Louis organized a series of diplomatic and military campaigns to stop Charles and dominate France's other potential enemies. These actions made Louis immensely popular at home with ordinary Frenchmen, which further legitimized his power within France's governmental system. But by 1714, Louis' ambitions had also plunged Europe into thirteen continuous years of war, which led other major European powers, including Great Britain, Spain, Holland, Sweden, the Hapsburg Empire, and several German principalities, to form a series of alliances, usually under British leadership, to stop him. As a result, while Charles XII's ambitions were crushed in 1709 when his armies were defeated by those of Peter the Great of Russia, which incidentally signaled the emergence of Russia as a European power, it was France's defeat in 1714 that proved to other European countries they could use alliances to construct a ***balance of power*** that would stop any country from conquering all others.

The big winner in France's defeat was Great Britain. For, its military and diplomatic successes solidified its status as Europe's dominant power. In fact, ***after*** 1714, Great Britain's naval and military leadership enabled it to expand its trade in Europe and with Europe's colonies in India, the Americas, and Africa, which provided Britain with the wealth it needed to further improve its internal transportation system and enhance manufacturing and banking in England and, to a lesser extent, in the rest of Great Britain.

The effects of France's defeat were just as momentous in France. When Louis XIV died in 1715, French nobles took back the powers he had seized from them. Then they pushed for more political and economic autonomy, initiating a ***decentralization of power*** that severely limited the popularity and effectiveness of

France's next kings, Louis XV and Louis XVI. Moreover, as the job of "paying down" the debt Louis XIV had accumulated grew more pressing and burdensome, the government's need for revenues made Louis XV and XVI even more dependent on the nobles who controlled France's tax-collectors and provincial economies.

Thus, unlike in Great Britain, the struggle between French monarchs and nobles never led to the establishment of a workable Constitutional Monarchy or the sharing of power with the French people. Instead, Louis XV and XVI clung to the now-outdated notion that they were all-powerful divine-right monarchs, while, in reality, France's monarchy grew weaker and more isolated from the French people. (NOTE: In 1302, the French government created a body analogous to Britain's Parliament called the Estates-General. It had three houses, one each for nobles, commoners, and Latin Church leaders. However, the Estates-General was never effective and was dismissed by King Louis XIII in 1614, not to be recalled until the eve of the French Revolution in 1789.)

The Age of Enlightenment

By 1715, it was obvious to many Frenchmen that Great Britain, with its Constitutional Monarchy and the beginnings of an industrial economy, was becoming a wealthier, fairer, and more open society, while France was becoming a poorer, less fair, and more corrupt one. As a result, French intellectuals began writing about the responsibilities of government and the rights of "the people", initiating a period called ***the Age of Enlightenment***. (NOTE: Some historians define the Age of Enlightenment as a broader phenomenon that began in the 1680's, which should include Locke and other thinkers in England, Germany, and elsewhere.)

Despite these calls for new rights for common people, France's government refused to change. Perhaps for this reason, French thinkers developed a very different view of rights and freedoms than had Locke. In fact, ***French ideas came to be based on a new definition of human beings that owed a great deal to the success science***, and particularly astronomy and physics, had had in describing nature. After all, the work of Copernicus, Brahe, Kepler, Galileo, Descartes, Francis Bacon, and Isaac Newton (whom we will meet in Chapter 10) had shown humans could discover the laws of nature by following a scientific method that utilized precise mathematics. As we will see in the next chapter, these ideas changed the way scientists did their work after 1642. But by 1730, scientific successes also impressed many non-scientists. So, France's Enlightenment thinkers argued France should use the modern scientific method to discover the nature of human beings. Then they should use that definition to find scientific solutions to France's social and political problems.

All Enlightenment thinkers did not agree on one definition of "the nature of Man." But most believed ***all*** individuals are inherently equal and good. Therefore, each person has ***natural rights***, including those to ***life, liberty, and equality*** (but, not property). When taken as a group, the people also have a right to a government, including perhaps one headed by a monarch, that represents the desires of the people and allows the people to fulfill ***their*** "natural" character. These ideas elevated the concept of "nature" to a position of great importance, which led thinkers like Jean Jacques Rousseau to romanticize it. As noted in the introduction, these attitudes still affect us today.

This was a new way to look at individuals, the people, and government. After all, Locke's definition of rights and freedoms had not assume humans are naturally equal or good. Instead, Locke said individuals have certain rights, whether they are good or evil, equal or unequal. Moreover, these rights come from God, not some scientific definition of human beings. As importantly, Locke assumed humans and governments are imperfect. That is why society needs a contract to balance competing responsibilities and rights and to strike compromises between the interests of the individual and the government, and just as importantly among individuals. In fact, according to Locke, these compromises inevitably ***limit*** people's freedoms, equality, and liberty.

French ideas about human rights were also more egalitarian and universal than British ones. First, they did not hinge on Mercantile notions of the individual as a property owner. And second, French Enlightenment thinkers were not as bent on preserving existing social and economic privileges while creating new governmental structures. In any case, it was the French version of ideas about politics and the individual that spread throughout Europe and took root, leaving a legacy that affected all European philosophical and political thinking in the next century, which we call the Age of Reason. Nevertheless, in the short run, the French government refused or was unable to change, and made no credible response to the criticisms of Enlightenment thinkers or to the needs of the French people.

The Age of Revolution Part I: The American Case

Despite its defeat in 1714 and the dissatisfaction expressed by Enlightenment thinkers, France still had a large and wealthy economy, an impressive army and navy, a sense of its own status as a major power, important North American colonies (including Canada and the area west of the Ohio River from the Great Lakes to Louisiana), and great cultural influence throughout Europe. So, while Great Britain was clearly winning its competition with France, France was not yet ready to accept second-class status.

As a result, tensions between France and Britain continued to mount until full-scale war erupted between them in North America (the French and Indian War) in 1754 and in Europe (the Seven Years' War) in 1756. When Great Britain once again defeated

France in 1763, France was forced to give Britain its American colonies, except for the Louisiana Territory to the west of the Mississippi that France sold to the United States in 1803. Thus, while the Peace of 1714 tipped the balance of power in Britain's favor, it was the Treaty of Paris that ended the Seven Years' War that made Great Britain the ***only*** European power with an expanding colonial empire and the resources to develop its full economic potential. However, Great Britain's business and government leaders understood it made more sense to dominate the economy of Europe than to try to rule it. So, the period after 1763 saw Great Britain create a new kind of regional and global Mercantile and industrial system that later served as a model for all would-be powers in Europe and elsewhere around the world.

As these events were reshaping European politics, British colonists in America increasingly demanded the same rights as those given to people living in England, in part because they believed Locke's writings and Parliament's new role as a forum for people exercising their rights applied to them as "overseas Englishmen." As a result, by 1763, Parliament gave the American colonies the right to organize their own governments with limited powers over local matters and the de facto right to express their opinions to Parliament about issues that affected America. But these reforms did not stop Parliament from introducing new taxes to pay off Great Britain's war debt, and from levying those taxes against all British citizens at home ***and*** in England's colonies. When Parliament passed these tax measures, however, American colonists protested they had not been properly represented in the Parliamentary deliberations that led to their imposition.

Taxation disputes aside, other British actions also fanned colonial anger, including Parliament's decision to guarantee the rights of French Catholic settlers in all parts of Canada and to give Canadian settlers the right to settle in the lands west of the Ohio River. Moreover, as American dissatisfaction grew and the British response to colonial complaints stiffened, many colonists came to believe America should be an independent country. Hence, when meetings of disgruntled colonists and protests against British colonial policies led to skirmishes with British troops and a British decision to increase its military presence in America in 1775 and 1776, colonial leaders declared America's independence from Britain.

The American Revolution had begun. The course of this war is too complicated to chronicle here. However, when Great Britain surrendered in 1781, the American colonists established a system of government based on their fears about absolute governmental power, and the political language and ideals that had developed in England from the Magna Carta in 1215 to Locke's 1690 writings on the relationship between government and the people. In fact, by 1791, America's "Founding Fathers" wrote three documents, the Declaration of Independence, the Constitution, and the Bill of Rights, that formed ***a written contract*** between the people and a government that would rule without a monarch or any official religion, although, as with Locke, individual rights would still be seen as coming from a Christian God. As importantly, these documents established the United States as ***a nation of citizens***, not a country held together by, or subject to, the government that ruled it.

Many Europeans hoped the American Revolution would become a model for Europe. But its effect would have been greater if Great Britain's position in Europe, or the world, had been weakened. Instead, Great Britain strengthened its hold on India, Canada, and its Caribbean colonies, trade between England and the United States grew, and Great Britain remained the most powerful country in Europe. In any case, by 1789, events in France forced all Europeans to abandon thoughts of the "grand American experiment" and pay more attention to a crisis in Europe itself.

Revolution Part II: The French and the Rise of Nationalism

Even after the American Revolution, France's government and nobles, some of whom had fought for the Americans in their struggle against Great Britain and its monarchy, continued to deny the French people the rights and freedoms Enlightenment thinkers believed they should have. If anything, corruption and resistance to change worsened. As a result, when a protest broke out in Paris against the royal government's tax policies in 1789, it quickly spread throughout France.

The French Revolution had begun. But there were differences between the American and French Revolutions. Above all, the American Revolution was led by the colonies' most educated, rich, and capable individuals, who retained their control over the institutions of the newly-formed nation. The leaders of the French Revolution, on the other hand, saw the old leaders (the King, nobles, and clergy) as the problem. So, their goal was to replace the old society (the Old Order) with a ***New Order***. Moreover, according to Enlightenment logic, the people would know the New Order had been established if ***they*** judged the government were meeting their needs in a scientific way. In other words, if the Revolution's leaders remained popular, anyone who disagreed with them could be seen as a representative of the Old Order and an enemy of the people. By the same logic, if those leaders became unpopular, they thereby became, or always had been, enemies of the people and agents of the Old Order.

During the first stage of the revolution, the royal family was imprisoned and other Old Order leaders were executed or fled to countries still ruled by monarchs. It was not long, however, before some of those who had initially led or supported the

Revolution were singled out as agents of the Old Order. When these suspicions spread, the resultant ***Reign of Terror*** made it impossible for ***any*** government to rule France effectively or build a peaceful society that could fulfill the Revolution's promises of democracy and social renewal. Nevertheless, Europe's other monarchs did nothing to intervene or to restore Louis XVI to his throne. Instead, they waited, on the assumption the Revolution would collapse under the weight of its own incompetence and disorder. In fact, it was not until 1793, when Louis and his family were executed, that Europe's other monarchs finally formed alliances to fight the spread of the French Revolution to their own countries ***and*** to return France to a "rightful" monarch.

As this second phase of the Revolution began, Europe's monarchs were confident their armies would easily defeat the army of the New Order, since it lacked the leadership and discipline provided by a monarch and the nobles who served as officers in all other major European armies. What those monarchs did not understand, however, was that France had changed into a country of ***citizens***, a people who saw themselves as being bound together by a shared history, territory, and language, and a common political, economic, and social destiny. In fact, the Revolution had reinforced these sentiments in three ways. First, unlike French monarchs, many of whom were foreign-born or only partly French (a necessity to maintain healthy royal blood-lines throughout Europe), the leaders of the New Order were commoners who were "born and bred" Frenchmen. Second, as in the United States, France's Revolution promoted the idea that all power, including that of a government over its territory, flows from the people who "inhabit" the territory and historical experience of that country. And third, revolutionary leaders consciously worked to destroy any remaining vestiges of French regionalism, both to build their New Order and to defend France against its enemies.

Consequently, and despite the Reign of Terror, many French people felt a renewed sense of pride in their country. In fact, many assumed other European peoples who had unique histories, languages, and ancestral territories, like the Hungarians in the Hapsburg Empire or the Scots and Irish in Britain, would follow France's example and stage revolutions that would lead to their "rebirth" as nations, in many cases through the break-up of long-standing empires and the fall of European monarchies. Not surprisingly, such talk strengthened other monarchs' resolve to defeat France. But France's new government fought back, raising a huge army of citizens who felt they were fighting for themselves and their nation, not their government. So, despite continuing confusion at home and some disorganization within the army, France's ***citizen army*** did very well on the battlefield.

Nevertheless, the need to raise, outfit, and provide an army with officers, training, and supplies proved a terrible burden for the French people and their government. Thus, while it soon became clear France could not be defeated, it was also obvious France could not defeat all its enemies or establish an orderly government at home. Thus, in ***1799***, France's government collapsed, and the job of forming a new government and fighting France's enemies was given to the army's most able general, a commoner named ***Napolean Bonaparte***.

The story of Napolean's rise and fall, his contributions to French society (especially his modernization of its educational and legal systems), and his reinstatement after France's first attempt to restore its monarchy, is too complicated to tell here. But, it is important to our story to note that by 1815: 1) Napolean's defeat once again rid Europe of a French leader who was trying to build a pan-European empire, 2) Great Britain was strengthened by its display of international leadership, and 3) France entered a period in which it restlessly searched for a way to form a lasting government that would reflect its Enlightenment and revolutionary heritages, while restoring France to its "rightful place" as a leading European power, tasks which in some ways still preoccupy it today.

Nevertheless, French ideas about nationhood endured. Thus, in 1830 and 1848, feelings of nationalism contributed to several revolutions in other European countries. However, when these revolutions failed, European monarchs who ruled more than one nationality were left with almost the same territories they had ruled before 1789, a remarkable accomplishment for Europe's "Old Order" given the rhetoric and turmoil of the intervening 60 years. But there were exceptions. Most prominently, civil wars in the late-1860's finally led to the creation of a unified Italian nation, while Germany's cities and principalities were finally unified under Prussian leadership in 1870.

Perhaps most importantly, the French Revolution's excesses left many Europeans feeling that liberal or radical thinking would always produce disorder and discontent. Thus, after 1848, Europe entered a conservative and largely peaceful period founded on an Austrian-brokered balance of power that kept "local" wars from involving all of Europe, or from destroying the governments of existing countries, until the outbreak of World War I in 1914.

A Changing Economy

Colonialism in The First Age of Empire

So far we have concentrated on politics. But economic factors were equally important in shaping the changes that swept Europe. By 1763, Great Britain ruled Europe's largest empire and dominated Europe's trade with the rest of the world, although Spain still had significant American and Asian holdings, and several other European powers, like Holland, France and Portugal, maintained small coastal colonies in Africa and Asia. During this period, Europe's African colonies provided slaves, salt, wood, gems, and precious metals; Asian ones provided luxury products, including spices and tea; and the colonists in the Americas produced food, cotton, and wood for ship-building. Since their agricultural economy depended on cheap labor, the Americas also became Europe's largest market for slaves, which European powers supplied by capturing or buying slaves in Africa and then "exporting" them to the Americas, often by way of the Carribean.

The story of colonialism and slave-trading in Africa is too important to be treated as an aside, here or anywhere else. But, in the context of our story, it is important to note that Europe's highly profitable and horrific slave trade was carried on from fortress-colonies along Africa's coasts. Thus, despite European claims of "owning" all of Africa and the catastrophic nature of Europe's slave trade in any area it touched, most sub-Saharan Africans continued to live in traditional tribal cultures ruled by their own leaders or in cultures that merged Moslem and traditional elements until the 1870's, by which time the slave trade had ended. In fact, in 1830, Great Britain became the first European country to make slavery and slave-trading illegal throughout its empire (Canada had done so earlier within its borders), while the United States abolished slavery in the 1860's during its Civil War. But by then, European economies, as well as those of many colonies and former colonies, were not as dependent on the labor slaves could supply. So, slavery disappeared in European-controlled areas, even where there were no specific laws banning it. (NOTE: Slavery continued in a few African European colonies, like Angola, until the 1960's, where it was used as an economic tool ***and*** as a strategy of intimidation of the indigenous African majority until those colonies gained their independence.)

In Asia, the pattern was different. After all, the purpose of exploration had been to trade with India, Sri Lanka (Ceylon), China, Japan, and Indonesia. So when contact was established with Asian civilizations in the 1500's and early-1600's, Europeans already knew they were ruled by sophisticated governments. In any case, the immensity of many Asian "countries" forced Europeans to stay in small colonies along the coasts, first in India, and then of China, Indonesia, Cambodia (Kampuchia), Thailand (Siam), Burma and other countries. In theory, the treaties European governments signed with existing governments in these countries allowed European traders the right to operate throughout Asian countries without having to rule them. But in reality, this arrangement depended on European threats to any "native" government that limited the rights of European traders. In fact, in China, this European practice came to be called Gunboat Diplomacy.

In general, these threats and an occassional show of force worked. So, as in Africa, Europeans stayed in small colonies or "foreign trade zones" in cities along Asia's coasts, from which they controlled trade in large areas, at least until the 1840's. However, in China, frustrations with these arrangements and the corrupt practices of China's leaders led to: 1) the outbreak of the first Opium War, 2) the almost complete collapse of China's government in the 1870's, 3) a series of reactionary populist peasant movements designed to re-establish Chinese honor, and 4) as part of the "punishment" for the above "native" actions, Britain's being given a 100 year lease on Hong Kong in 1897. (NOTE: After tentatively opening its ports to Portugese and Dutch traders in the 1500's, Japan shut its doors. Then, it established trade ties with the United States in the 1850's, before once again severing all contacts with the outside world, not to reopen its doors to outsiders again until after Japan developed its own modern military and economic institutions in the 1890's.)

Above all, European colonial practice ***before*** 1870 was based on the fact that trade with Asia and Africa was not as efficient or important to Europe as trade with the Americas. First, lacking a Suez Canal and given the naval technology of that time, voyages to and from Asia and East Africa were extremely long and arduous. Second, with the exception of slaves, Asian and African trade provided luxury goods, which, while appreciated by Europeans, were not as important as the raw materials the Americas provided. And third, the genocide of Native Americans through warfare, land policy, disease, and, in the case of Latin America intermarriage, as well as the availability of land, attracted a huge population of European settlers to American colonies, uniquely during this period, that provided Europe with a new market for its products. Thus, European powers concentrated on controlling trade in Africa and Asia, while only ruling large territories in the Americas.

During this first Age of Empire, Europe's colonies greatly contributed to its economic well-being. But the incredible growth of European manufacturing, trade, and banking in this period was just as dependent on a ***dramatic increase in Europe's internal population***. Thus, while some countries, provinces, and cities suffered declines during the 1700's, Europe as a whole became more populated and prosperous, which guaranteed a steady growth in all sectors of its economy and an increasing demand for raw materials, many of which could only be found in the colonies. Consequently, countries like Spain that depended too much on colonial wealth declined in economic and political importance, while more successful powers like England, France, and Holland established a network of activities at home, within Europe, and between Europe and its colonies. Among these, Great Britain was already in the best position to capitalize on this situation.

First, after 1688, Constitutional Monarchy made Britain the most stable and fair society in Europe, with rights to life, liberty, and property (including the buildings, land, and wealth generated by businesses) that allowed people to contribute to Britain's wealth without fearing persecution or the loss of property many people faced in other European countries. Second, Britain had the world's best and largest navy, army, and merchant marine. And third, Great Britain's trade arrangements, advanced manufacturing, and naval supremacy generated the wealth needed to build new roads and canals, and to dredge rivers at home, which gave Britain Europe's best transportation system.

These economic factors greatly contributed to Britain's defeat of France in 1714 and 1763, while those victories, in turn, contributed to Britain's strength as an Imperial power. Thus, by the mid-1700's, Britain was in the best position to take advantage of the opportunities for increased trade and wealth that were emerging in Europe and its "dependencies."

The Industrial Revolutions

There were, however, limits to Great Britain's ability to respond to these opportunities. Most importantly, no one could make goods fast enough to satisfy the demand for products like textiles. So, starting around 1730, machines were invented that sped up the production of ***cotton*** thread from raw cotton, much of which came from the Americas. Then machines were invented to speed up the production of cotton cloth from cotton thread. Many of these machines were larger than those they replaced. And, they worked best when there were many machines and workers together in one place, since this allowed all steps of turning raw cotton into finished cloth to be done efficiently. Thus, the buildings erected to contain the new textile machines became the world's first ***factories***. We call the invention of this kind of manufacturing ***the First Industrial Revolution***.

By 1770, England's factories were far superior to those in other European countries. But their efficiency was limited by the need to use muscle power, primarily from animals, or water power from waterfalls and rapids, to run factory machines. Thus, there was a great need for a new machine that could provide power to run other machines. The ***steam engine*** was to be that invention.

The steam pump was invented in 1698. But it was not until the 1770's that British improvements produced a steam engine that could power factories, thereby increasing their efficiency and profitability. But the invention of the steam engine illustrates an important and often misunderstood point. ***Inventors were seldom scientists. Some were not even well-educated in the sciences***. They simply developed machines and processes to solve practical problems. Often nobody could provide a scientific explanation for ***how*** a technology worked until years after its introduction. In the case of the steam engine, the ability of wood or coal to produce steam, or of steam to do work by rotating or moving a part of a machine, could not be explained until the mid-1800's, when scientists finally understood energy transformations and the principle of conservation of energy in a "closed system." In other words, ***science does not always preceed or drive technology***.

All factory machines and steam engines were made of ***iron***, while steam engines burned wood or coal. But over time, ***coal*** became the preferred fuel because it was easier to handle and, unlike wood, was not needed for the ship-building industry. Thus, the use of steam engines and other machines: 1) increased the demand for coal and iron, 2) created a need for better machines for the mining industries that provided them, and 3) spurred the development of ***new processes*** to improve the quality of coal and iron. By 1850, only 80 years after the invention of the steam engine, new machines and processes had been invented to answer many of these needs. In most cases, the British took the lead, both as inventors and in the application of inventions to industry. So, each step toward ***industrialization*** increased Great Britain's, and especially England's, economic advantages over other European countries.

During the First Industrial Revolution, the manufacturing, processing, and selling of ***textiles, coal, and iron were the keys to any Western country's economic power***. But inventors saw other ways machines could be used. Thus, by 1850, steam engines were powering railroads (in England, and then in the rest of Europe and the United States) and ships, some of which had hulls made from improved iron that was soon replaced by steel. These breakthroughs made it possible to travel further and faster than ever before, greatly increasing the efficiency, volume, and profitability of trade between distant places. Since Britain led the world in these innovations, this technological revolution also increased its economic advantages over other European countries, as well as its ability to take full advantage of its far-flung empire. Finally, the economic growth caused by these changes led to the building of the Suez Canal in the 1860's, which made the Mediterranean Sea an "arm" of the Indian Ocean.

(NOTE: Despite this depiction of the First Industrial Revolution, it is important to note the Chinese invented cast iron around 300 BC and carbon steel around 600. In fact, by 1000, some of their ships were metal-clad, ***long*** before similar discoveries were made in Europe. But the Chinese never coupled these metal technologies with energy-producing machines like steam engines or internal combustion engines. So they never experienced a transportation revolution similar to the one that reshaped Europe after 1850.)

After 1870, ***electricity*** and ***oil*** replaced wood, coal, and water as the main sources of power. Then, by 1900, inventions in electrical generation, electrically-powered motors, oil and gasoline production and processing, internal combustion engines, and ***steel*** and ***chemical manufacturing*** became the keys to wealth for any industrialized country. Consequently, we call the period after 1850 ***the Second Industrial Revolution***. (NOTE: Some people think the invention of information machines like the computer has created a Third Industrial Revolution. Others like to say we have entered the first Post-Industrial Age.)

During the Second Industrial Revolution, other Western nations closed the economic and technological gap with Great Britain, in part because Britain relied on old machines and industries while other countries' were willing to embrace new ones. Thus, by 1900, American inventors and industrialists had transformed the United States into a world-class economic power; Germany, France, and Japan were emerging as industrial powers; and Russia would soon enter the race under its then-new name, the Soviet Union. Moreover, Japan's emergence as an industrial power demonstrates that "industrial" and "Western" are not the same thing. As a non-Western culture, Japan demonstrated it was an industrial power in 1898, when it used modern weapons to defeat Russia in the Russo-Japanese War.

A New European Society

The Industrial Revolutions affected every facet of Western society. But their effects were felt first in the cities, where most factories were built. After all, cities provided factory owners with: 1) large local populations that could provide workers and consumers for a factory's products, 2) other industries that could provide some of the materials or machines needed by a factory, 3) good transportation systems, including access to ports for getting overseas raw materials to a factory and a factory's product to its markets, 4) the collective community-wide wealth needed for investing in business, and 5) banking systems to provide a factory owner with the capital he needed in a manner consistent with operating a business.

As a result, the First and Second Industrial Revolutions saw old cities grow larger and new ones appear where none had existed before. Wherever key raw materials were available, new factories appeared and the population grew, as people abandoned small towns and rural areas for the opportunities of city life. But as cities grew bigger, they also grew dirtier and more crowded, while the gap between the rich and poor increased. This happened first in England, and then in the rest of Great Britain. But by the late-1800's, there were ***industrialized urban areas*** throughout Western Europe and the northeast United States. In fact, for the first time in European history, more people lived in cities than in rural areas, and "industry" (including government, manufacturing, banking, and trade) created more wealth than agriculture.

By the late-1800's, this economic revolution created a new and often difficult situation for many Western Europeans. But we must remember that ***before*** the 1800's, few Europeans owned land or had a chance to better themselves. Most could not read or write. Only the wealthy or extremely lucky got an education. While people became ill often, few received medical treatment. And, the medical treatment that was available, even to those who could afford it, was not very good. As a result, most people did not live very long, if they survived childhood at all, while those who did survive, faced other difficulties. In particular, many women and children were treated very badly, while most people were trapped in a cycle of poverty they had no hope of escaping. In other words, the Industrial Revolutions did not make life bad, they just made it bad in a new way.

Nevertheless, many urban dwellers found life in the "new" Western society very difficult. First, they were forced to work long hours for low pay. Second, the need for more and cheaper industrial laborers forced many women and children to go to work in factories and mines, where they suffered the same dangers and risks as their adult male co-workers. And third, since little attention was given to making machines or factories safe or clean, many workers were injured or became sick at work. People's health was also affected away from work, as factory wastes began to poison urban environments. In fact, European cities became so crowded and dirty it became impossible to maintain public sanitation, provide garbage removal and clean water, or control the spread of diseases in the local population.

For the first time, men were unable to "protect" their wives and children from the dangers of everyday life. Nor could they base their "special" place in the family or society on being the only ones earning a living. In fact, many people (including some men) soon found it impossible to find work at all, a reflection of the social dislocation caused by urbanization ***and*** the over-population of cities in relation to the services and economic opportunities they could provide. These changes also undercut European social beliefs and institutions, such as the special status and protection of women and children, the supportiveness of the extended family, and the value of the individual.

Clearly, many of these European social ideals had always been ignored or abused in many families and society as a whole. But belief in these ideals was an important foundation for other institutions and morals. As a result, in the 1800's, some workers, women, and educated men began pressuring governments to pass laws that would protect workers, restrict the use of child and woman-labor, limit the number of hours worked by anyone in a week, provide a safer work-place, and give some protections to the poor. Meanwhile, the guild system disappeared and workers started organizing unions and associations to force employers to give them many of the same things, along with higher pay.

Great Britain was the first to address many of these issues or pass socially-conscious laws. But others soon followed their lead. Napolean, for example, established schools and scholarships for poor French students, including girls. Then, in ***1819, Prussia*** became the first "country" in the world to have a ***public school system*** that forced (or allowed, depending on your point of view) all children to go to school. As access to education increased, ***literacy*** began to increase in Western countries, to the highest levels in any society in history. As the infant and childhood death-rate fell, more people got better medical care and began to live longer. And finally, the periods of famine that had always plagued Europe became less frequent, severe, or wide-spread.

Industrialization also created a large ***middle class*** of skilled workers, managers, businessmen, government workers, and professionals who, by the 1870's, ***replaced the nobles as the style-setting class in European society***, a sure sign the middle class was receiving most of the advantages industrialization was creating. However, neither the Industrial Revolutions nor the ascendency of the middle class solved the age-old problems of inequality and unfairness within European society. There were still rich and poor people. And, the social problems associated with inequality continued, despite a new middle-class conviction that people (at least middle-class men) should have more rights, freedoms, and opportunities to improve their "positions" within society than ever before.

Ironically, this belief in opportunity and social justice made the unfair treatment of women, children, and the poor harder to accept than it had been before the Industrial Revolutions. Thus, by the late-1800's, industrialization caused a tidal-wave of social protest and criticism of Western society ***within*** Western countries. For, while European society was arguably fairer than it had been before industrialization, many Western people became less tolerant of the unfairness still in European society.

Summary: A New Age of Colonialism and Its Legacy

The Second Industrial Revolution caused Western nations to again seek colonies to provide cheap sources of ***raw materials*** like food, metals, wood, and cotton; and items such as silk, spices, porcelain, and jewels that were needed by Europe's new processing industries or by those who sold luxury items to the expanding middle-class in Western societies. In some cases, such colonies, especially populous ones like India, could also provide European industries with larger markets for their products and generate new wealth in Europe, since "trade" with these colonies was always organized by European companies or governments to take maximum advantage of "natives" in the colonies.

After 1870, first Great Britain, then France, and to some extent Germany, Italy, Belgium, the United States, Sweden, and

Denmark renewed their efforts to claim colonies. In some cases, European powers seized territories that had never been colonies before, while in others, wars among Western powers led to a re-shuffling of colonial empires. The United States, for example, gained Puerto Rico, the Philipines, and control of Cuba and Panama from Spain after winning the Spanish-American War in 1898, while the First World War was partly motivated by conflicting European colonial ambitions.

However, several First Age of Empire colonies, especially in the Americas, gained their independence during this period, while for the very first time, European powers established colonial governments in Africa and Asia that ruled very large territories, including inland areas. As a result, traditional rulers were replaced by Western ones, while many non-Western peoples and cultures were damaged or completely destroyed. By 1900, most of the world was divided into Western-controlled empires and newly-emerging nations that were former Western colonies, making the business of ruling or dominating large areas of the world an important aspect of Western economic and political life.

Thus, the majority of non-Western people first felt the full weight of Western colonialism just as Western nations were giving their own people more political rights and freedoms, and learning to treat their own children, women, and poor more humanely. But, non-Western people were still given few rights, little education, inadequate housing, food, and health care, or the economic benefits that flowed from the colonial system. However, "natives" were expected to accept or even welcome this treatment and the "benefits" of being ruled by Westerners. So, despite the end of slavery, ***the gap between how Westerners treated each other and how they treated non-Westerners grew wider and more obvious***. Perhaps for this reason, Western people began to justify their treatment of non-Western people by more explicitly arguing that the "European race" (a biological misnomer to begin with) is superior to all other humans.

In any case, by the 1930's and the eve of World War II, Western powers tightened their grip on both their new and old colonies, increased their reliance on ***racism***, and destroyed the cultures and self-respect of many non-Western peoples, some of whom had built civilizations long before being colonized by Europeans, at the very least demonstrating that Europe's success as a colonizer did ***not*** depend on it being a "higher" or more civilized culture, or, conversely, on conquered cultures being "simpler" or less civilized.

Between 1945 and 1970, most of the remaining colonies of Western nations regained their independence. But the nations that emerged have continued to depend on Western political ideals and governmental structures, while many of their borders were based on those drawn by former colonial rulers. As a result, most newly independent nations, especially in Asia and Africa where indigenous peoples had not been eradicated or assimilated into a superimposed European culture, included many traditional cultures or tribes. Not surprisingly, most of these nations still face many problems, including: 1) hostility and warfare among ethnic, tribal, and religious groups within each nation, and with those in neighboring nations, 2) a shortage of adequate housing, health care, food, and other "tools" needed to overcome the poverty caused or worsened by colonial rule, 3) an inadequate supply of educated people or the institutions and resources needed to create a class of trained people, 4) continued economic domination by Western companies based in Western countries, and 5) corruption and self-promotion among the native elites who emerged to rule many of these new nations.

These problems have made it impossible for people in former colonies to return to their traditional cultures or the political structures that existed before European colonialism began, ***or*** to build modern nations based on Western political technologies and ideas. So, despite independence, most remain poor and unstable, while their people remain undereducated, unhealthy, and underfed. In short, these nations are still suffering the effects of colonialism and the economy of the Second Age of Empire, although it is important to note that in the last decade, some former colonies have finally begun building healthier indigenous economies, albeit often without simultaneously building stable and workable political systems.

All of this may seem peripheral to our story. But the lingering effects of European Imperialism are very relevant when assessing the role of European culture, including ***modern science*** in the modern world. In fact, in the end, ***we must temper our praise of these developments with an understanding of their costs, not only to people in Western countries, but to the rest of the world.*** Above all, we must recognize that the benefits of modernity, science, and the wealth generated in the last 250 years have not been equally shared by all humans. Or, by all societies, even today.

CHAPTER TEN

SCIENCE TRIUMPHANT: A MATTER OF ENERGY

By 1642, most scientists understood the Greco-Christian picture of nature was wrong. They also had a scientific method in place that allowed them to do and evaluate their experiments. In the years following 1642, science also became an important and accepted field of study within European society. In fact, there was so much science done, we must limit our discussion here to a few astronomers, physicists, and chemists who contributed most to the picture of nature that replaced the Greco-Christian one.

The search for a new model of the Universe began with the unexplained ***forces*** implied by Galileo's mechanics of motion and Kepler's planetary orbits. Kepler's model required a force that could pull the planets toward the sun. Otherwise, they would fly off into space in a straight line, in the direction of the force that had made them move in the first place. At the same time, Galileo's studies in mechanics stated one of the forces that acts on a moving object pulls it toward the Earth, although objects can also move because of other imbalanced forces acting on them.

Perhaps Kepler's and Galileo's forces were different. But most scientists believed (like Bruno, earlier) that the Universe was a single system obeying the same laws of nature, although nobody could describe forces in a way that tied all existing observations together. To accomplish this task, someone would first have to create equations that could describe motions that do not trace out straight line or circular paths, as well as ones in which the velocity changes.

This was a real road-block. After all, according to Kepler, the planets move in elliptical orbits. So, their distances from the sun, direction of motion, and speed are always changing. Meanwhile, Galileo stated objects can follow complicated flight-paths, decelerating and accelerating as they move, including the apparently simple case of an object falling to Earth and the more complex one of an object propelled into the air. Therefore, any new theory about motion, or about all of nature for that matter, would have to include equations for acceleration, deceleration, straight-line and circular paths, ellipses, and parabolas.

Descartes and Kepler were the first to try to find ways to calculate the ***instantaneous velocity*** of an object moving as Kepler's planets and Galileo's objects did. While both failed, ***Descartes' approach of dividing irregular curves into smaller and smaller slices***, thereby calculating the average velocity over smaller and smaller units of time, laid the groundwork for all later attempts and the eventual solution to this problem.

Gravity and Calculus

Isaac Newton was born in England in 1642, the year of Galileo's death, two years before Descartes', and as Great Britain's Civil War began. By his twenties, Newton was considered Europe's most brilliant scientist and mathematician. When an English astronomer named Edmond Halley sighted a comet in 1684 and speculated its orbit was an elongated ellipse, an argument broke out among scientists about the meaning of this discovery. Strangely, at least to us, much of this argument focused on the question of whether the Biblical Flood was caused by an earlier visit of Halley's comet. To resolve this debate and better track the comet, Halley asked Newton to tackle the mathematical problem of elliptical orbits. In return, Halley promised to pay for the publication of any book Newton wrote that solved this problem. As a result, in ***1687*** Newton published **The Principia**, which outlined a new math called ***The Calculus*** that solved all the geometry problems at hand, including acceleration, deceleration, ellipses, and parabolas.

The Principia also included ***equations for gravity***, the force that holds the planets in their orbits and pulls objects toward the Earth, that stated the greater the mass of an object, the greater its gravitational pull. And, the greater the distance between any two objects, the less pull they exert on each other. Or, to put these relationships more precisely, ***gravity varies with the square of the mass of two objects, and with the inverse of the square of the distance between those objects***, ideas that echoed ones proposed by Al-Khazin in Baghdad 700 years earlier.

When taken with calculus, Newton's ***Laws of Gravity*** allowed scientists to calculate the amount of gravity ***any*** pair of objects exert on each other, irrespective of the distance between them or their masses. As importantly, the Laws of Gravity could be represented by a few "beautiful" equations, thereby upholding scientists' hope for simple laws of nature. In fact, to many historians, the ideas included in The Principia represent the single greatest accomplishment in all science history.

Newton later claimed he invented calculus and the laws of gravity 20 years earlier, but did not publish his ideas until Halley asked him to do so. While it will soon be apparent how self-serving this story was, we now know Newton invented a form of calculus and defined the relationship between gravity and distance in 1666 when he was 24 years old. However, when he tried to use his equation to calculate the orbit of the moon around the Earth, he came up with impossible numbers. Only later, in 1687, when he returned to this problem, did he discover his ideas were correct but that he had been using an incorrect value for the radius of the moon's orbit. When he corrected this mistake, he was able to show that predictions based on his equations for gravity matched the observed values for the moon's orbit.)

As important as Newton's Laws of Gravity were, they did have limitations. First, there might be other forces acting on matter or the tiny particles Francis Bacon suggested make up matter. Second, Newton's equations do not say what gravity is, or what it is in matter that causes it. Third, they do not explain how two objects could be far apart and pull on each other. And fourth, his equations do not explain why ***gravity acts instantly***, seeming to take no time to travel across the space between two objects. Nevertheless, when taken with his Laws of Motion and Conservation of Momentum in a closed system, which formalized some of Decartes' ideas, Newton's Laws of Gravity ***unified*** Kepler's astronomy and Galileo's mechanics under a single model of motion.

The Laws of Gravity also suggested comets do have elliptical orbits, and that Halley's comet had passed by Earth before and would do so again. While he ignored the question about the Biblical Flood, Newton claimed this proved comets are the agent by which God keeps His Creation from "running down" (again, the Chinese mechanical clock image) before Judgment Day. In other words, despite the modernity of his equations, Newton assumed, like most earlier scientists, that the Universe is a mystical and temporary reality ruled by God's will, not by any discoverable laws of nature.

Nevertheless, to other scientists, Newton's equations suggested: 1) while the laws of nature are difficult to discover, they are mathematically simple, 2) force, mass, and distance alone describe motion, 3) the Universe is an ***infinitely large*** system in which all motion obeys the same laws. Thus, there are no spheres or separate realms in space and ***all motion is natural***, 4) the Universe has bits of matter scattered throughout it. In fact, motion involving any object, anywhere in the Universe, is the result of forces caused by and acting on matter, and 5) the space between two objects, except for the amount of that space, plays no role in the amount of gravity acting on them. So, although ***space*** "carries" gravity, it (and time, for that matter) is ***a passive backdrop to the mechanical drama played out by forces and matter***.

Newton later decided his view of nature needed a kind of space in which gravity and light could be transmitted over great distances at incredible speeds, or perhaps instantly. So, Newton proposed space is filled with an ***ether***, a universal fluid not unlike the one proposed by Aristotle some 2,000 years earlier. In fact, ether must be disturbed by matter, but still be massless. Otherwise, it would exert gravity on other objects, which would be obvious when calculating the orbits of celestial bodies.

Calculus, the Rise of the Individual, and Nationalism

Just as Newton was publishing his discovery of calculus, a German mathematician named ***Gottfried Leibniz*** was publishing ***his*** discovery of it in Germany. When others looked at both men's work, it became clear Leibniz's version was stated in terms that made it easier to use than Newton's, just as IX and 9 are symbols for the same number but using 9 makes it easier to do arithmetic. However, Newton alone proposed equations that put calculus to work to solve scientific questions. In a perfect world, both men would have shared credit for inventing calculus, and everyone would have used Leibniz's version while embracing Newton's application of it in his Laws of Gravity. But that is not what happened. What did happen, and why it happened, explains a lot about Newton as a person, the changing role of science in Europe, the institutions that sustained it, and the relationships that were developing among nations and scientists during this period.

During the 1600's, scientists began to identify themselves more narrowly in terms of their "nationalities." At the same time, countries began to express their nationalism by trying to become leaders in manners, literature, music, art and other intellectual accomplishments. One way a monarch or prince could promote his kingdom's or principality's leadership, as well as his own importance, was to become a ***patron*** of universities and entirely new institutions, royal societies for science and royal astronomy observatories.

The first two societies for science were formed as offshoots of literary societies in Italy in the mid-1500's, during the Renaissance. But these remained isolated occurrances until the first ***Royal Societies for Science were formed in England in 1660***, France in 1666, and Germany in 1700. Meanwhile, ***France built the first national observatory for astronomy*** in Paris in ***1671***, and England built one in Greenwich in 1676. By the early-1700's, almost every European country, as well as many principalities and cities, had its own scientific society and/or observatory.

The formation of England's Royal Scientific Society also served non-scientific motives. First, during Great Britain's civil war, its Anglican educated elite wanted to promote Anglican interests against Catholic and Puritan ones. So the Royal Society was partly founded to promote the idea that scientific opinions matched Anglican theological ones, and that the needs of English scientists' would best be served by the continuation of the monarchy, which could offer financial and other kinds of support to science. And second, from 1660 to the early-1700's, many British scientists and humanists, especially at Cambridge where Newton did much of his work, embraced a Christian version of Neo-Platonic ideals that was a conservative backlash ***against*** Francis

Bacon's mechanical (materialistic and soul-less) description of the Universe.

In other words, one goal of the founders of England's Royal Society was to reinject an element of Christian spirituality and humanism into modern science. In fact, the Royal Society's first published works were "natural histories" of the Earth, Ireland, Wales, and England that placed Biblical "events" and prophesies into those areas' geological record as scientific facts. (NOTE: Despite their pseudo-scientific content, these works were the first to use questionaires to gather information. This technique and others used in similarly bogus studies published by England's Royal Society later proved extremely useful to scientists.)

In a larger sense, of course, universities, scientific societies and national observatories all reflected the needs of the individuals and political entities that peopled and supported them. However, in time, these institutions also changed the way scientists did their work. Above all, officially supported observatories gave scientists a chance to work with instruments and facilities that were too expensive for individual scientists or universities to build or maintain, while scientific societies provided an opportunity to publish papers and give public talks, which allowed scientists to share their discoveries with other scientists and "prove" who, and which country, should get credit for a discovery. By 1700, this was no small matter, since a scientist who made an important discovery could expect honors, fame, wealth, and support for his work, while his country could claim his discovery proved ***its*** superiority.

While scientific societies were meant to serve the needs of scientists and their patrons, they also stimulated a great deal of public interest in science. In fact, by the early-1800's, ***science became so popular***, amateur scientists began to make important contributions and lectures given by scientists became major public entertainments, giving science a place in ***everyday life*** not unlike that of the arts or the humanities. However, by the late-1800's, the cost and complexity of scientific equipment and the increasing specialization of science drove scientists back into the university setting, both for training and to do their life's work. Thus, by the early-1900's, universities regained a near monopoly over science. Meanwhile, the arcane mathematical language of modern science made it increasingly difficult for scientists to explain their work to mass audiences, or for non-scientists to maintain an interest in science, which further isolated science within our culture. (NOTE: In the past 30 years, universities have shared their role in scientific research with corporate and government research facilities. But this has not revived direct communications between scientists and the public-at-large, or increased popular interest in science.)

The rise of nationalism, individualism, universities, and scientific societies offered science an unprecedented level of support and appreciation. But these changes also had some negative effects, especially on the behavior of scientists.

To cite one famous example, after the publication of The Principia, Newton convinced England's Royal Society to form a committee to rule on his and Leibniz' claims of authorship of calculus. We now know Newton secretly picked this committee's members and helped write their final report. Not surprisingly, the Royal Society decided Newton invented calculus and Leibniz was a plagiarist. As a result, Newton's version was used in England while Leibniz's was used in the rest of Europe, where the verdict of England's Royal Society could be ignored. This may explain why later English mathematicians made little progress in calculus, while French and other European ones made a great deal. In any case, Leibniz's version of calculus was not accepted in England until 1810, 123 years after its discovery!

However, Great Britain was not alone in this irrational nationalism. At the time of Newton's discoveries, Louis XIV ruled France. So French scientists did not accept Newton's "English" Laws of Gravity, Motion, or Momentum until the 1730's, when Voltaire, a leading Englightenment philosopher and literary figure, formed a committee to get French scientists to accept Newtonian ideas. In other words, French scientists rejected Newton's epoch-making laws until a change in French attitudes and kings made it possible to embrace those laws.

(NOTE: When the Royal Society branded Leibniz a plagerist, he abandoned mathematics forever and became the head librarian for a German prince who wanted to turn his collection of books into one of the world's first "open to the public" libraries. The classification system Leibniz created for this library later served as the model for all modern cataloguing systems, including the Dewey Decimal System. So, while Leibniz never got over how badly he was treated by Newton and England's Royal Society, he ended up making ground-breaking contributions in two fields.)

The Study of Light

As important as they were, Newton's contributions to science were not limited to his Laws of Gravity, Motion, or Conservation of Momentum; or calculus. In fact, he made important scientific discoveries on many subjects. However, we must limit ourselves here to just one more subject that interested him and other physicists of his day, light.

Ever since the days of ancient Greece, scientists had been fascinated by light and its properties (how it spreads, why it bends in some media, why it bounces off some surfaces, etc.). However, in 1642, no one could say for sure if light were a material, like other substantive objects in nature, or if it took time to travel across space. Or, if it did move, whether it always travelled at the same speed.

In 1676, a Danish astronomer named ***Olaf Roemer*** proved the light from celestial bodies takes time to travel to Earth, and that ***the velocity of light is constant throughout the Universe***, which he was able to calculate. This was an important breakthrough for those studying light and optics. But this discovery also had great meaning for all physicists, because it offered powerful proof that the Universe is one big system and that there are simple, universal, constants that govern its most important features. (NOTE: Before Roemer, few scientists believed light took time to cross space, and no one thought the speed of light would be a fundamental constant of the Universe. But this should not surprise us. After all, even after Roemer, it remained impossible to measure the Speed of Light in relation to everyday experiences on Earth or in a laboratory because light moves so fast it appears to arrive at an observer at the same time, no matter how far away the source of light. In fact, it would be a long time before scientists had laboratory equipment sensitive enough to verify the Speed of Light in earthbound experiments.)

It was in the context of this renewed interest in light that in 1704 Newton published his second great book, **The Opticks**. In it, Newton said ***light*** is a stream of particles, or ***corpuscles***, that travel through space in straight paths as ***beams***. Moreover, when light beams collide with particles of matter, the light corpuscles vibrate, which explains why light sometimes looks like a wave despite "really" being a beam of corpuscles. (NOTE: To avoid confusion, we will continue to call Newton's light-particles "corpuscles," and his matter-particles "particles.")

To prove his theory, Newton did a series of experiments on ***refraction and reflection***, the results of which seemed to match his picture of light as beams of corpuscles. The equations Newton created to explain these experiments also convinced Newton that, as with gravity, the existence of light corpuscles implies space is filled with an ether. After all, if it were empty, particle vibrations might happen, but the beams they generate would not be able to reach or affect other areas of space or particles in other regions of the Universe. Moreover, neither Newton nor other Europeans knew that scientists at the House of Wisdom in Baghdad had carried out similar experiments and arrived at similar conclusions 700 years earlier, albeit without precise mathematical equations. As a result, Newton received credit for inventing these ideas and, in 1705, became the first person ever knighted for scientific discoveries.

As with calculus, Newton had a competitor in the study of light. At the beginning of the 1700's, a Dutch scientist named ***Christian Huygens*** argued light is ***a wave of energy*** going through space. According to Huygens, when a light wave collides with matter, the wave's energy is transferred to that matter, which makes it vibrate and send out new waves that later collide with other pieces of matter. However, like Newton, Huygens proposed space must be filled with ***ether***. After all, Huygens could not see any other way that motion like that involved in vibration or a travelling light wave could occur. (NOTE: In the early-1900's, Albert Einstein showed there is no such thing as ether. According to Einstein, space-time is empty and non-directional. But its underlying structure plays an active role in all interactions involving matter and energy, including the transmission of light beams/waves. So, both Newton and Huygens were wrong about space. See below and Chapter 11 for more on this question.)

Huygens' ideas on light were the first formal statement in European science that a process in nature is ***not*** the result of the presence of matter. After all, Newton's descriptions of gravity and light assumed they result from interactions of pieces of matter or the existence of light corpuscles, whereas Huygens' description, which he suggested might also apply to other forms of energy, implied light waves exist without involving matter at all. Not surprisingly, Newton claimed he alone should get credit for "inventing" ether and got England's Royal Society to mount a campaign to convince other scientists Huygens was "wrong" about light, although it is clear scientists should have kept looking at light from both perspectives until further evidence resolved the problems inherent in both theoretical descriptions.

In the end, scientists rejected the concept of light waves because they did not believe energy could exist independently in the Universe ***and*** because Huygens disagreed with Newton. After all, by 1704, when The Opticks was published and Newton's attacks on Huygens began, Newton was so respected by other scientists they found it difficult to imagine he could be wrong about anything. As a result, scientists did not revisit the question of light waves until the mid-1800's. (NOTE: Even today, light remains a partly unexplained phenomenon. However, one of the major achievements of 20th Century physics is a model of light that allows it to be both a wave and beam at the same time. In fact, Huygens' equations are remarkably similar to some wave equations scientists use today, while Newton's corpuscles pre-figure the modern idea of photons.)

When taken as a whole, Newton's work has had a greater influence on science than that of any other person in history. With calculus and his equations for gravity, motion, and light, he created a completely new way to describe the Universe. But Newton also used his fame to discredit other scientists whenever he thought their ideas undermined his, which undoubtedly delayed many advances in mathematics and physics. However, he was not unique in this. In the 1700's, it was not unusual for national pride and individual jealousy to keep new ideas from being fully explored or accepted, tendencies that have occasionally plagued science ever since. Nevertheless, the curiosity and integrity of most scientists, as well as the modern scientific method, have prevailed. In fact, looking back on the last 300 years, it is remarkable how freely scientists have shared their ideas, tested new ones, and accepted the ones that proved "useful," a truly impressive feat given the pressure on nations and scientists to compete for the status, recognition, and wealth that often flow from scientific breakthroughs.

Building a Newtonian Universe

Astronomy and Newton's Model

As soon as The Principia appeared, scientists looked for ways to apply ***Newtonian principles*** to other aspects of nature. As a result, astronomers sought new observations of the celestial bodies that would test the Laws of Gravity, while physicists and chemists looked for ***mechanical*** ways to explain other forces, in the hope of finding a single description of the Universe. Let's begin with astronomy.

Edmond Halley used the Laws of Gravity to analyze the orbit of "his" comet and predict it would next appear in 1758. When this proved correct, scientists saw it as a powerful proof of Newton's ideas. It is also important to note that when Halley published his ideas, he used a new format called ***the scientific article***, which proved to be a far better vehicle for modern scientific discourse than the book-length treatises used by earlier European scientists. This inovation and Halley's role as the patron and instigator of some of Newton's most important work made Halley as significant a figure as a facilitator of science as he was as a scientist. (NOTE: Halley's Comet had been seen many times before. The earliest record of it is from around 2,000 BC in Mesopotamia [before Babylon], while the first Chinese record is from 613 BC. Amazingly, by 1600, ***before*** Halley's and Newton's births, Chinese astronomers had recorded multiple sightings of many comets, distinguished at least 372 different ones, and become very adept at predicting the re-appearance of some comets, including Halley's. They accomplished all this ***without*** a theoretical understanding like Newton's Laws of Gravity or Kepler's orbital model. If nothing else, this proves there is more than one way to make accurate predictions.)

Other astronomers used Newtonian ideas to study the planets. Many realized that if Newton were correct, each planet would be affected by gravitational effects from the sun ***and*** all other planets. So, before completely accepting Kepler's and Newton's ideas, astronomers felt they had to find a way to use Newton's equations to calculate the total gravity acting on, and exerted by, each planet at every point in its orbit. Only then would they be able to calculate the predicted position of each planet at every point in time and compare their predictions to observed positions. If their calculations matched the planets' real orbits, this would prove Kepler's and Newton's theories correct.

The first step in this complicated process was taken by a wealthy "amateur" English scientist named ***Henry Cavendish*** in 1794. Cavendish did an experiment with two lead balls separated by a known distance the analysis of which allowed him to calculate the value of the constant for gravity in all Newtonian equations in which two or more bodies act on each other.

But the planets presented a much more difficult problem than two stationary balls acting on each other in a closed system. To understand the difficulty of this task, let's take the Earth as an example. First, since the Earth (like all planets) has an elliptical orbit, the distance between the sun and the Earth is always changing, as is the sun's gravitational pull on the Earth. And second, since each planet orbits at a different distance from the sun and takes a different amount of time to complete one orbit, the distance between the Earth and each other planet is constantly changing, as is the gravitational effect of ***each*** planet on the Earth. In fact, there are times when the collective effect of all the other planets pulls the Earth in one direction or another, and others when their gravitational pulls nearly cancel each other out. In other words, there are a befuddling and ever-changing array of gravitational effects acting on the Earth as it orbits the sun.

Nevertheless, when astronomers did their calculations, they discovered that calculus and the Laws of Gravity could be used to: 1) calculate all the gravitational effects on the known planets, 2) predict where each should be and how much it should "wobble" because of the gravitational pulls of other planets during its orbit, and 3) compare these predictions to their telescopic observations of the planets. Remarkably, at least within the accuracy of measurement possible at that time, the observed orbits of all the known planets matched those predicted by Kepler's and Newton's theories.

To many astronomers, this was the most profound proof possible of both Newton's ideas about gravity ***and*** Kepler's about the solar system yet. However, in 1781, an English astronomer named ***William Herschel*** found a new planet near the edge of the solar system that he named ***Uranus***. When its orbit was analyzed, Uranus had wobbles that could not be explained by the gravity exerted on Uranus by the sun and the other known planets. But by this time, ***faith in Newton's model was so strong astronomers speculated there must be an unknown planet on the outskirts of the solar system causing these "extra" wobbles***. In fact, scientists were so confident that they used Newton's laws, Kepler's model, and the wobbles of Uranus to predict the size (mass) and orbit of the as-yet unknown planet.

Scientists were unable to test this prediction until the 1840's, when the invention of more powerful telescopes allowed them to make a meaningful search for their "missing" planet. However, noone was surprised when scientists discovered ***Neptune in 1846***. Nor were they shocked that its size and orbit perfectly matched their predictions. To many scientists, this discovery ***offered another important proof of Newton's model and, not insignificantly, of the validity of the modern scientific method that had guided science since the mid-1600's.***

Between 1778 and 1808, Herschel also studied the stars, in part to see if Newton's model applied to the entire Universe. As part of this effort, he studied 2,500 ***nebulae*** (clouds of stars, each with millions of stars). Then, he found ***binary stars*** (two stars that orbit each other), whose behavior Herschel said was due to their exerting almost equal gravitational pulls on each other. But ***most importantly, he found the background drift of the stars in relation to the Earth that Copernicus had looked for*** 250 years earlier. However, in a clear demonstration of the progress that had been made in the intervening years, Herschel correctly interpretted this to mean that, since stars exert gravitational pulls on each other, all of them are moving. Thus, while the sun is at the center of our solar system, it is not at the center of the Universe. In fact, there is no permanent or absolute center of the Universe. Given the range of work Herschel did, many modern astronomers still consider him the greatest astronomical observer of all time.

After Herschel's discoveries, other astronomers turned their attention to the stars, using even more powerful telescopes to: 1) identify individual stars, 2) show that groups of stars are organized into ***galaxies***, and 3) measure the distances to some stars or galaxies. In all this work, astronomers found no evidence that violated Newton's Laws of Gravity, while finding much that supported it. In fact, as astronomers had hoped, they were able to demonstrate that while Newton's model had been created to explain "events" ***within*** the solar system, it actually applied to the whole Universe.

In more general terms, by 1850 work done by astronomers demonstrated Newton's model could explain existing observations and predict new ones, like the existence of a new planet, the orbit of a comet, or the existence of binary stars. It also appeared to be equally useful within the solar system and beyond. In other words, astronomers both tested Newton's model ***and*** proved it was useful to those who wanted to do new scientific work.

<u>The Evidence from Physics and Chemistry</u>

After 1704, physicists concentrated on light, vacuums, heat, magnetism, and electricity. All these fields of study eventually had an effect on Newton's model. So let's begin with electricity.

In 1785, a French physicist named ***Charles Coulomb*** did experiments on two objects that are separated from each other and which have different amounts of electrical energy, to see how they affect each other. Coulomb's experiments showed that the strength of an object's ***electrical potential***, that is its ability to electrify a second object, ***varies inversely with the square of the distance between the two objects, the exact relationship Newton had found for gravity*** 98 years earlier. Thus, Coulomb's equations appeared to confirm that unrelated forces could be unified under a few simple or identical equations, and that work on one phenomenon could confirm the truth of work in another. After all, scientists reasoned, what were the chances separate experiments on gravity and electricity would give the same incorrect equations? (NOTE: While it is outside our story, it was during this period that Ben Franklin did his experiments on electricity and lightning, thereby becoming the first American to make a significant contribution to modern physics.)

After Coulomb's work, others continued to study electricity in other contexts. As a result of all this work, between 1824 and 1827 a German named ***George Ohm*** proposed a theory for ***electrical currents*** in a wire that stated: 1) a metal wire is made up of small particles, each of which has an electrical potential, and 2) a current occurs when an electrical potential is passed from one particle to the next, a process driven by the tendency of adjacent particles to seek equal electrical potentials in order to lower the overall energy level of the entire system. In fact, an electrical current is the consequence of this "local" process repeating itself over and over again down the length of a wire. Ohm also suggested that similar mechanical descriptions might apply to other electrical phenomena, such as the transfer of electrical potential from an electrified metal ball to another metal ball, or from one battery terminal to the other.

Other physicists studied heat, a phenomenon that was still a mystery. In fact, until the 1700's, some scientists believed all gases, liquids, and solids have a fluid in them that carries heat. So, hotter objects contain more "heat fluid" than cold ones. But others argued matter is made up of constantly vibrating particles. Thus, when an object's particles vibrate more, it becomes hotter, and when they vibrate less, it becomes colder.

For many years, scientists lacked the experimental means to prove either theory correct. Then, in 1824, a French physicist named ***Sadi Carnot*** showed the heat generated by friction between two objects and the heat inside an object can move or rotate another object, such as the shaft of a machine. Hence, both kinds of ***heat can be transformed into motion***. Since it was already known that friction is caused by the back-and-forth motion of objects when they come in contact with each other (a kind of vibration of large bodies), Carnot suggested the internal heat of an object is due to a similar mechanical process among its tiny particles (see the discussion on Dalton, below). Over the next 20 years, Carnot's work guided experiments that demonstrated when heat in an object does work by moving or rotating a second object, some of the heat in the first object is "used up." Moreover, this work offered ***the first scientific explanation of the energy transformations that occur in a steam engine***.

Finally, in 1850, a German physicist named ***Rudolf Clausius*** examined all known observations and ideas about heat and created the ***Laws of Thermodynamics***, which stated: 1) heat is present in all matter, be it solid, liquid, or gas, 2) heat is caused by the internal motion of a substance's particles, 3) the energy of this internal motion can be transferred to a second object, either to make its particles increase their motion, thereby increasing its thermal energy, or to move or rotate an entire object, thereby increasing its angular or linear momentum, and 4) in both cases, the total energy of the first object decreases, while that of the second object increases. However, since the temperature of an object depends on many factors, only one of which is thermal energy, a decrease in an object's heat energy is not always accompanied by a decrease in temperature.

This reasoning allowed Clausius to focus on thermal energy, not temperature, and to produce equations that stated that the ***total energy from heat and motion (altogether, mechanical energy)*** of any set of objects and the space around them remains constant, a concept called the ***Law of Conservation of Energy***. This Law established ***a framework that allowed scientists to think of all forms of energy as related phenomena following similar mechanical laws***. Thus, just as Newton's Laws of Gravity had unified observations from astronomy and mechanics, Clausius' Law of the Conservation of Energy ***unified the concept of energy*** under a single Newtonian explanation. Moreover, by 1850, scientists noted that Clausius' description of the transfer of heat from one object to another was analogous to Ohm's of electrical potential in a wire, a comparison that once again demonstrated Newton's model fit a wide range of phenomena and, perhaps, all of nature.

Turning to chemistry, in ***1808*** an English chemist named ***John Dalton*** published a book in which he argued that the Earth's atmosphere is a mixture of gases, each of which is made up of its own kind of ***atoms***, which Dalton pictured as solid little balls.

Dalton then stated the atoms of one gas, such as oxygen, have a different mass and size than atoms of other gases, like nitrogen. In fact, the atoms of some materials "like" to join together to form stable molecules, while other atoms, or relatively stable combinations of atoms, resist forming new molecules.

Many of Dalton's ideas later proved to be incorrect. But we must remember that the pictures of electricity and heat that were emerging in this period required a matter that would be made up of particles that could vibrate, accumulate electrical potential, and pass electrical potential to other particles. So, Dalton's theory was a necessary first step in the difficult task of picturing these particles and learning about their behavior. In fact, despite its shortcomings, many scientists immediately recognized the importance of Dalton's concept and started working to refine it. ***As a result, in the 1880's, physicists began to create a model of the atom that was made up of sub-atomic particles, some of which carry electrical charges.*** Moreover, the arrangement, number, and behavior of these sub-atomic "charged" particles determine each element's electrical and chemical behavior. (NOTE: Dalton did not know his idea had been proposed 2,200 years earlier by Democritos and Leucippos. However, he did recognize the connection between his ideas and Francis Bacon's earlier speculations about matter.)

While some scientists used Dalton's atomic model to examine heat and electricity, others tried to apply it to ***chemical reactions***. The most important work in this area involved experiments on ***electrical batteries*** that could generate and store electrical energy. By the late-1800's, these experiments proved that the atoms in a battery's metal strips (electrodes) and liquid (electrolyte) undergo chemical changes that cause opposite electrical charges to concentrate on the two electrodes, thereby creating an electrical potential between them. In fact, the electrolyte's molecules act as the medium in which this entire interaction takes place. Thus, ***chemical energy***, or at least the kind generated in a battery, is like an electrical current in a wire or the transfer of electrical potential from one ball to another. But, since it had already been demonstrated that these kinds of electrical energy are similar to other forms of energy, such as gravity, motion and heat, chemical energy, like others that had already been studied, "fit" Newton's mechanical model.

In the early-1800's, scientists became so sure of Newton's model they finally abandoned their mystical ideas and fully embraced the notion of a mechanical Universe. In fact, most scientists believed new experiments would soon uncover all the laws of nature, perhaps in the next few decades. This faith was also based on the sheer number of scientific breakthroughs in the preceeding 100 years and the resultant confidence scientists' (and other Europeans') came to feel about the modern scientific method, with its alternating use of experimentation, math, and theory-making. Without that confidence, European science would never have made the progress it did in the 1700's and 1800's. Nor, ironically, would scientists have discovered the evidence that ultimately led them to question Newton's picture of the Universe. (NOTE: Not coincidentally, it was during this period that scientists freed themselves from the Biblical idea that the Earth and Universe had been created 6,000 years earlier. This new perspective was pioneered by the Scottish geologist Charles Lyell in 1830. Lyell's work layed the groundwork for Charles Darwin and others, who could now think about natural processes that might take thousands or millions of years. In some ways, this new "time-line" was as culturally epoch-making as any insight by a physicist or astronomer.)

A Model is Changed:

Faraday and the Electro-Magnetic Evidence

Studies into electricity and magnetism between 1820 and 1825 by ***Hans Christian Oerstad*** in Denmark and ***Andre Marie Ampere*** in France showed that a wire with an electrical current in it could cause a nearby magnet to swing away or toward the wire. Then, in the 1830's, experiments by the English physicist ***Michael Faraday*** showed that: 1) a spinning magnet generates a flow of electricity in a coil of wire around it, 2) passing an electrical current down a wire wrapped around a bar of iron turns that bar into a magnet, and 3) passing an electrical current down a wire coiled around, but not touching, a magnet makes it spin. Aside from the insights this work provided to those studying electricity, Faraday's first experiments showed that ***electricity, magnetism, and motion are related forms of energy that can be transformed into each other*** as part of a single energy system, an idea that later led to the development of ***electro-magnetic motors*** in the Second Industrial Revolution.

In 1838, Faraday published a preliminary paper in which he suggested that one possible explanation for his results was that an electrical current in a wire creates ***lines of electrical force*** in the space around the wire, while a magnet creates ***lines of magnetic force*** in the ***space*** around the magnet. Hence, each creates a disturbance in space that ***contains*** the electrical or magnetic energy that acts on a nearby wire or magnet. In papers and speeches given over the next few years, Faraday further stated his lines of force form distinct mathematical patterns in space, which he called ***electrical and magnetic fields***.

Faraday's skill as a public lecturer made him a celebrated popularizer of science in Great Britain. He even gave children's lectures at the Royal Academy of Science on general topics, like the history and meaning of modern science. To some historians, Faraday's lectures mark the high point of science's mass appeal, and of scientists communicating their discoveries to a broad audience. Despite his celebrity status, however, Faraday recognized that he still could not explain ***how*** a magnetic field rearranges the atoms in a wire or coil to cause an electrical current to flow in it. Or, how an electrical field affects a nearby piece of iron or magnet. Nevertheless, he understand his explanation implied ***space*** is an ***active player*** in interactions between electricity and magnetism, and in their ability to do work. After all, by 1840, it seemed obvious to Faraday that when a magnet and wire that are not touching excite each other, they are really acting on the "local" space between them. Then, this disturbed space acts locally on the space around it, and so on, until the affected area of space becomes very large.

In other words, once an area of space has been disturbed, the energy represented by a field (or by several overlapping fields in the same space) can be transferred instantly to any object entering that field. So, while it may take some finite, if very small, amount of time for a magnetic or electrical field to form in space, ***once a field has been established, it takes no time for one object to affect another, even if they are very far away from each other***. Most intriguingly, this idea suggested an explanation for why gravity seems to act instantly at a distance. For, if magnetic or electrical fields "permanently" exist in space, perhaps gravity fields do as well. Nevertheless, these ideas still contradicted Newton's assertion that space plays no part in gravity, or in any other interaction involving force. In fact, according to Newton, space is just an ether-filled, non-active feature of the Universe.

Kelvin and Maxwell: Interpretting the Evidence

The full significance of Faraday's ideas was not immediately apparent to scientists. But many realized they could not separate Newton's depiction of space from other aspects of his model without dismantling its basic principles. In any case, by 1840, experimental evidence and new theories on motion, electricity, heat, and other forms of energy had all "confirmed" Newton's picture of gravity, as had a great deal of astronomical evidence. Therefore, it seemed unlikely Newton's depiction of space could be wrong. Moreover, forgetting Huygens, in all forms studied so far, energy seemed to be due to properties of matter, not a quality of space. In any case, Faraday was still unable to create equations for his energy fields that would force other scientists to re-examine their most fundamental beliefs. (NOTE: Clausius began his groundbreaking Newtonian work on electricity 10 years after Faraday suggested space might behave in distinctly non-Newtonian ways.)

Faraday was stuck. Then, around 1850, a young Scottish mathematician and physicist named ***William Thompson***, who was later knighted ***Lord Kelvin***, wrote Faraday to suggest his electrical and magnetic fields might be the result of ***radiation***, and that the equations Faraday needed might be found in the math already developed to describe light waves. In fact, experiments that were still ongoing in this period by the French physicist ***Augustin-Jean Fresnel*** and others on light had finally demonstrated that it is a transverse wave (like water molecules moving up and down in the same place while the energy associated with that motion travels forward). Aside from re-awakening the study of waves, Fernel's experiments answered one of the great mysteries about light by provided the first plausable explanation of how two light waves could interfere with each other in the same space, thereby creating alternating dark and light bands. According to Fernel, a dark band simply represents a transverse trough from one wave overlaying a transverse crest from another.

To fully understand Kelvin's suggestion and Fresnel's work, we must remember Huygens' description of light, which stated it is a ***wave*** travelling through space. Hence, despite occasional collisions with bits of matter, light waves travel great distances over time without any matter or area of space moving. Instead, it is ***the effect of the disturbance*** that spreads. By the 1850's, physicists had begun calling the creation and movement of these kinds of waves ***radiation***. So, Kelvin was suggesting electrical and magnetic forces might follow the rules governing the radiation of light waves. In fact, Kelvin suggested Faraday should do experiments that would probe the connections among magnetism, electricity, and light. (NOTE: Modern physicists assume photons have no mass. So, even from this perspective, no matter is transferred from one place to another as light moves.)

Aside from demonstrating a remarkable supportiveness for the work of a fellow-scientist, Kelvin's suggestions imply his own work on an absolute-zero temperature scale, energy transfers and conservation, and entropy (the tendency of order to break down in nature) had already created doubts in his mind about Newton's ideas about matter, energy, and space. In any case, after considering Kelvin's suggestion, Faraday carried out a series of experiments that showed a light wave moving through space creates ***a light field that distorts electrical or magnetic fields that are in or enter the space occupied by that light field***, while electrical and magnetic fields bend light waves passing through them. More importantly, Faraday's measurements of the strengths of electrical, magnetic, and light fields at different points in space suggested all three form identical geometric patterns.

Faraday was able to represent all this on graphs. But he was still unable to find a simple set of equations that could unite his results under a single model. Nevertheless, he remained convinced his ***Field Theory*** would eventually be found to apply to all forms of energy, and that scientists would some day prove space is an active player in transfers of energy, while mass and distance (the key elements in Newton's equations) would be shown to play derivative roles in the interactions involving energy and matter. (NOTE: These ideas were later proven correct. Scientists now know gravity-waves emitted by particles in the nucleus of an atom disturb space in such a way that gravitational fields exist around all bits of matter, and over mathematically infinite distances and periods of time. In fact, like electrical and magnetic fields, gravitational fields affect the path taken by light as it travels through space.)

The triumph of Faraday's ideas occurred in ***1873***, when an English physicist (and protege of Kelvin's) named ***James Clerk Maxwell*** produced ***four simple equations for magnetic, electrical, and light fields*** that matched the photographs he produced of the way fields interact with each other. Maxwell's equations proved: 1) light, magnetism, and electricity are all forms of radiation, 2) since radiation occurs through an active change in space, space is a crucial player in energy transfers and as important as matter and energy in the make-up of the Universe, and 3) questions about energy that are impossible to answer with Newton's model can be explained by picturing them as radiation. Thus, ***Field Theory is a more basic picture of energy, matter, and the Universe than Newton's Mechanical Theory***.

Maxwell understood all this. So he predicted electricity and magnetism give off radiation-waves, not unlike light waves. In fact, according to Maxwell, there should be a wide range of ***electro-magnetic waves*** across a broad spectrum of wave-lengths, all of which move at the speed of light. In ***1888***, a German physicist named ***Heinrich Hertz*** found Maxwell's electro-magnetic radiation waves, and called them ***radio waves***. And their speed was exactly what Maxwell predicted: the speed of light. With this experimental proof in hand, a new era in physics began.

<u>Summary:</u>

<u>Part I: Of Methods and Relativism</u>

The death of Galileo and birth of Newton made 1642 a seminal year in the history of science. But 1642 is also a convenient marker for the moment scientists' rejected the Greco-Christian model of nature and felt free to do so. Nevertheless, many of the breakthroughs that made this epoch-making shift possible occurred before 1642, including the outlining of the Grosseteste-Galileo method that guided all science from 1642 to 1873 and which has continued to guide most science, but not all physics, since 1873.

But using the Grosseteste-Galileo method did more than lead scientists to reject Greco-Christian ideas. It changed the kinds of models scientists proposed, ***and*** the way they used them. After all, Greek, Moslem, and European scientists before Galileo made models as plausable, often speculative, explanations of the observations they made. Hence, a model could be considered "true" until a scientist made observations that violated it. Then, and only then, would scientists re-examine that model. However, after 1642, scientists came to see models as valid *only* if they stood up to experimental and observational tests. Thus, ***a model had to suggest ways to do new science or make predictions scientists could (eventually) test***. A model that did not meet these criteria might appear to be true, or be fun to think about, but it was not a scientific model.

By the 1880's, many scientists understood that one consequence of this new way of thinking is that ***all scientific theories are only temporarily true***, at least according to the old meaning of truth. In fact, to many scientists, it seemed obvious the invention of new mathematics and doing future experiments would ***always*** prove their models were imperfect or entirely wrong. Thus, one of the main tasks of science would henceforth be critically analyzing accepted theories and looking for new ones, especially when a new model appeared to explain known experiments and observations better than an old one *or* when it suggested a richer mix of new experiments. In other words, scientists could no longer assume, as they had when the wobbles of Uranus led to a search for Neptune, that a model is so perfect there must be something wrong with an observation or experiment that fails to fit it. For, while future evidence might prove the correctness of a theory, as radio waves did for Maxwell's equations, it was just as likely it might prove an existing theory wrong.

This way of using models and scientific evidence amounted to a new definition of truth, called ***Relativism***. By the 1890's, the acceptance of Relativism created as great a philosophical and scientific revolution as the one begun by Copernicus and others in the 1500's and early-1600's, or the one begun by Newton and others in the late-1600's and early-1700's. (NOTE: Relativism should not be confused with Relativity, a term Einstein used to describe two theories, one that deals with the relationship between mass and energy, and another that deals with the relationship between motion and an observer of that motion.)

Part II: The Universe According to Maxwell, and Beyond

Much as Newton's ideas caused scientists to ask new questions about nature, or old ones from a new perspective, Maxwell's equations forced them to re-examine concepts like mass, distance (or, space), waves, fields, energy, and time. But what about the evidence that had proven Newton's model correct? Surely, Neptune exists, as do binary stars, the wobbles in the planetary orbits, the Laws of Thermodynamics, and a host of other phenomena that fit Newton's model. With all this experimental proof, how could Newton's model be "wrong?"

To answer this question, we must remember that when Newton's model replaced the Greco-Christian one, scientists ***had*** to reject the earlier one because it was incompatable with Newton's. Once it was accepted, Newton's model helped scientists develop a much better understanding of nature in general and key concepts like motion, mass, energy, and the mechanical processes that involve the application of forces on matter. However, Newton's model did not address several questions inherent in these seemingly simple concepts, such as "what is force?" Or, "what is energy?" But Field Theory does. It says energy is radiation, and force is the interaction between matter and radiation fields.

To be fair, Field Theory raised as many questions as it answered. For, physicists soon realized they had to ask: what is radiation? What is matter's underlying relationship to energy? And, ultimately, what is the character of a Universe that manifests itself through such phenomena as matter, energy, time, or space? While the Socratic nature of these questions brings us, in a sense, full circle, the raising of these questions and the partial answers to them that have been found so far have created a new perspective that ***is*** modern physics.

Nevertheless, in practical terms, modern physicists have found that ***Newton's model*** perfectly describes experiments in which large masses move at relatively slow speeds in comparison to the speed of light. In these cases, the effects of radiation do not greatly alter the measured values of energy, force, or matter in Newtonian equations. Moreover, this ***special case of slow speed and large object*** fits all moving objects humans can perceive directly with their senses, be they stars, planets, comets, cars, feathers, balls, people, arrows, planes, or horses.

This was a great relief. The modern scientific method that had guided experiments since 1642, as well as the results of those experiments, were still valid. However, Maxwell (and soon others) predicted that whenever scientists developed the equipment and instruments needed to produce and observe high-energy phenomena or to do experiments involving very small objects moving at very high speeds, such as those within an atom, they would discover radiation has profound effects on energy phenomena and measurements. In that situation, according to Maxwell, Newtonian equations would break down completely, while Field Theory predictions would match experimental results.

But this would have to wait. For, in 1873, it was still impossible to do such experiments. So, the only "proof" Maxwell could offer for his equations was the way they matched the results of previous experiments, his photographs and drawings, and his ***predictions about indirect consequences*** of fields. Having to wait to confirm the Field Theory until Hertz' 1888 discovery of radio waves or until the early-1900's, when the first sub-atomic experiments were done, however, created an understanding among physicists that their focus on phenomena operating at sub-atomic or galactic ***scales*** of space and time would make it inevitable that ***thought-experiments and indirect evidence would often be the only tools available to physicists*** as they pursued their future work of theory-making, experimentation, further theory-making, and so on.

By 1890, scientists understood Field Theory would eventually be proven ***imperfect and incomplete***. Thus, unlike in the 1830's, when Faraday first suggested flaws in Newton's model of nature, they were not surprised when work in the 1890's and the first two decades of the 1900's led to the creation of new models of the atom and its parts by scientists like Ernest Rutherford and Niels Bohr, Albert Einstein's Theories of Relativity, or an entirely new picture of nature called ***Quantum Mechanics*** by Max Planck and others. Nor are present-day physicists surprised that these breakthroughs have led to further refinements of these ideas, and to a new set of questions, many of which remain unanswered. (NOTE: Kelvin, the great facilitator of science for much of the 1800's, lived until 1905. But he never accepted the validity of Einstein's or Planck's pioneering work, which appeared in 1895.)

At present, all physicists can say with any certainty is that Quantum Mechanics and more recent models, like (Super)String Theory and Chaos Theory, grow stranger, more mysterious, and more beautiful with each new discovery. And, that these theories have so far failed to provide a ***unified theory*** of time-space and energy-matter that makes sense out of the forces that act within the nucleus of an atom or across the vast reaches of time-space. Nor do they offer an adequate explanation of how the Universe came into existence, how it works, or even what it is. As such, the work of the last 120 years has dashed the Newtonian hope that physics would soon (or perhaps, ever) solve all of nature's mysteries. Instead, that hope has been replaced by a different kind of excitement: the appreciation of how great and elusive a puzzle awaits the continuing efforts of science.

This should not be taken as an indictment of Field Theory, its role in the evolution of physics from Newtonian to Quantum Mechanics, or of modern physics in general. In modern terms, Field Theory was a "good" model. And it was "true." After all, like any scientific truth, it offered a deeper and more unified understanding of nature than the one it replaced ***and*** contributed to the creation of the even deeper and more unified ideas that later subsumed Field Theory within their mathematics. Someday, of course, historians will say the same thing about the Theories of Relativity, Quantum Mechanics, or any other model the human mind proves capable of creating.

CHAPTER ELEVEN

HISTORY, PHYSICS, AND VISIONS OF MODERNITY

We have come a long way from 9,000 BC to 1873. Our path has gone through Mesopotamia, Egypt, Ionia, Athens, Alexandria, the rest of the Greek world, Persia, Baghdad, Cairo, Italy, Iberia, and the rest of Western Europe. Along the way, we have taken side trips to India and China. In all these places, science's goal has been the same: to discover new ideas about nature *and* new methods for developing those ideas and studying nature itself. Every civilization has accomplished this task by building on its own intellectual accomplishments and borrowing ideas from other civilizations. At times progress has been slow. In some places, and at some times, it stopped altogether, or appeared to go backwards. But seen as a world-wide process, scientific progress continued to be made.

Between 1540 and 1873, Europe played the largest role in the development of modern physics. But we must remember that in the beginning science was an Asian and African invention, and in the 5,000 years humans have created scientific pictures of nature, Europeans and their colonial offshoots have only led the way for the last 450 years. In fact, if we were to continue our story past 1873, it would take us to the United States, Canada, Japan, South America, Australia, China, India, Israel, and Eastern and Western Europe. For, since 1873, Western-style scientists of every race, creed, and religion, in every continent and nearly every country in the world, have made contributions to "Western," or "European," science.

Europe as the Home of Science: A Comparison with China

But why was Europe the place where the latest developments in physics and astronomy began? After all, the Chinese, Indians, and Moslems were far more scientifically advanced than Europeans in 1150, when Europe's current scientific tradition began, and remained so until 1500, when Europe first emerged as a world-wide power. These civilizations also had access to, or created, many of the ideas Europe used to produce its Scientific Revolution. In fact, Europe's Scientific Revolution depended on Babylonian and Egyptian arithmetic and habits-of-mind; Phoenician alphabet-based writing; Greek philosophy, rhetoric, and geometry; Hindi numbers; Arabic algorithms, algebra, trigonometry, and scientific equipment; Chinese paper, printing, magnetic compasses, and mechanical clocks; and earlier European, including Greek, work on the scientific method and standardized measurements, all of which pre-dated the rise of European science and power.

Nevertheless, we cannot deny what did happen. After 1450, Europe became the home of a great scientific tradition while

Moslem, Chinese, and Indian science declined. Why did this happen? Chapter 5 has already dealt with the Moslem case. But we may be able to get at the larger question of the rise of European science by examining several key differences between China and Europe. Let's begin with a brief history of China.

The concept of a Chinese empire dates from the Xia and Shang cultures that formed along the Huang Ho (Yellow River) between 2,100 and 1,200 BC, and the Zhou (Chou) Dynasty that conquered the Shang about 1,000 BC. However, the "heartland" of China was not unified until the first Qin (Chin) emperor did so in 221 BC. Over the next 450 years, Qin and then Han rulers expanded China's empire until it included almost all the land that makes up China today. Amazingly, the cultural forms that were established by AD 200 shaped a long line of dynasties that ruled China until 1911, when the first Western-style government was formed to rule China. Some China experts even argue the People's Republic of China, which has ruled China since 1949, is a modern variation of China's traditional empire.

During this period of over 3,600 years, there were times when China's empire was fractured into warlord states, split into two or more states or empires, or conquered by outsiders. But the ideal of a stable and centralized political, social, and cultural authority remained intact, giving China a love of order and long periods of peace, good government, and great artistic, economic and technological accomplishment.

These accomplishments might not have been possible if the Han Dynasty had not established an Imperial Academy in 124 BC that taught prospective bureaucrats (mandarins) the arts of government, as well as Confucian and Daoist ideals. For, the educational system that grew out of these Han innovations was so successful and long-lived that by 1000, when China had a population of 110 million and hundreds of major cities (several of which rivalled Baghdad and Byzantium, the largest Western cities of that time), China's schools trained 200,000 mandarin examination candidates. More importantly, China's government had become so effective that by 1000 it was possible to rule China with only 35,000 mandarins, roughly the same number who had run the earlier, smaller, and less complex Han Empire.

But the period that began in 1000 also saw a succession of Inner Asian nomadic tribes, including the Qidans (Liao Empire), Ruzhens (Jin Dynasty), and Mongols (Yuan Dynasty), conquer parts or all of China, while China's "native" Song (Sung) Dynasty, which in its last guise only ruled southern China, was reduced to paying tribute to northern warrior tribes to keep them from invading China. Thus, while China's cultural traditions gave it a refined social and governmental system in times of peace and prosperity, those same cultural forms also rendered China incapable of sustaining its own indigenous military and political leadership in times of rebellion or external threat.

As a result, while later versions of China's Imperial State relied on Neo-Confucian concepts of family, state bureaucracy, and social order, political and military leadership was more often than not provided by Mongols and Manchurians, who together ruled China for 344 of the next 622 years. (NOTE: As noted in Chapter 2, there is a striking similarity between this situation and that of ancient Egypt. In each case, insularity and a feeling of cultural superiority bred both cultural permanence and military vulnerability. Moreover, repeated conquests by outsiders finally undermined both cultures.)

Given the conservatism inherent in China's Imperial system and the mandarins who staffed it, it is not surprising that for much of its history, Chinese rulers tried to control all potentially revolutionary ideas, including scientific ones. So, as in Hellenistic Greek culture, the ***purpose*** of studying nature remained finding solutions to practical problems and creating mechanical inventions. Moreover, without an interest in abstract models, no civilization, however "advanced," could create the kind of science that developed in Europe after 1450.

Nevertheless, we must not overstate this distinction. For, there were many similarities between early Chinese mathematical and scientific work and that done by Greek, Arabic, and early European thinkers. The Chinese developed a base-10 number system, excellent algorithms, the world's first decimal fractions, a form of geometry and algebra, and number puzzles that included the magic square, a geometric pattern of numbers with special additive properties. At least by AD 80, and perhaps as early as 600 BC (it is hard to know because in 219 BC the founding emperor of the Qin Dynasty mounted a Reign of Terror in which thousands of books were burned and many were intellectuals killed, leaving later Chinese scholars to try to reconstruct much of China's early intellectual history), Chinese mathematicians suggested the numbers in magic squares represent the structure of the Universe, an idea not unlike ones put forward by Pythagoras. Meanwhile, other early Chinese scientists, not unlike Aristotle and Ptolemy, suggested the Earth is a sphere at the center of the Universe and that all other heavenly bodies orbit the Earth in circular paths.

Chinese astronomers also produced the ancient world's best catalogue of astronomical observations, which they used in ways that were sometimes similar to Western ones. To cite just a few examples: 1) in 350 BC, Shih Shen and Kan Te used the astronomical data they collected to improve China's calendar, as did Chang Heng around 100. 2) In 20 BC, Liu Hsiang correctly suggested solar eclipses are caused by the moon moving between the Earth and sun, while in 100 Wang Ch'ung said lunar eclipses are caused by the Earth moving between the sun and moon, which keeps the sunlight reflected off the moon from reaching the Earth. 3) At the Imperial Observatory at Kaifeng in 1088, Su Seng designed and built the world's most precise armillary sphere (it was almost identical to the one Brahe later used), which he adjusted and aligned using the world's first automatic clockwork mechanism. And, 4) after 2,000 years of observing the heavens, by 1400, Chinese astronomers had described and distinguished a large number of "unusual" celestial phenomena, including sunspots, novas, and supernovas.

Remarkably, Wang's explanation of lunar eclipses included a plea to abandon "false notions" like the belief that they are caused by spirits or by an Emperor losing his right to rule (his ***Mandate of Heaven***). Nevertheless, the idea that the Heavens determine the fate of the Emperor or that the Emperor's behavior influences celestial events remained a part of a Daoist-Confucian belief that everything in nature, including the Earth, Heaven, plants, animals, the Chinese State, and individual humans, are connected through arcane spiritual resonances and sympathies. (NOTE: The similarity between Wang's understanding of light and reflection and that of later Western scientists is striking. However, Wang did say an Emperor losing his Mandate of Heaven causes famines and other Earth-bound catastrophes. So, like Newton, he was selective in his anti-spiritualism stance.)

The above examples demonstrate Chinese scientists ***were*** capable of thinking abstractly ***and*** of considering ideas similar to those that formed the foundation of Western science. However, China never developed a robust tradition of finding abstract explanations for nature's processes. It may therefore be most apt to say China had scientific figures as remarkable as Oresme, Stevins, Galileo, Kepler, Descartes, and Newton, but Chinese culture carried on as if their ideas made no difference. Thus, even in periods when China made great technological and scientific advances, the most prominent of which were the Tang and Song Dynasties (altogether, AD 618-1279) in which China gave the world mechanical clocks, magnetic compasses, gun powder, many important scientific instruments, and the printing press, China devoted more time and talent to the creation of the literature and rituals associated with ancester worship, magic, alchemy, and astrology than it did to scientific ideas.

While the wisdom embedded in China's "occult" traditions demonstrates the intellectual and literary subtlety of Chinese culture, it also reflects an Animistic view of the Universe that limited the development of scientific explanations, if only by offering Chinese thinkers the illusion they already had workable explanations for natural phenomena. Moreover, China's belief in ancestor worship and astrology remained deeply entwined in its

Imperial system of government. After all, the authority of China's political system rested on astrological charts and signs that could only be made and interpreted by Imperial astrologers.

Herein lay a great problem for science, and astronomy in particular. The need to protect the Imperial government and their own special place in it compelled Chinese mandarins to guard celestial knowledge as a state secret. In fact, while China was a large and complex "country" in which some people were always doing forbidden things, this self-protective and secretive attitude kept independent ***and*** court astronomers from accumulating and sharing enough astronomy observations or thoughts about such observations to make natural models of the heavens.

In comparison, European astrology slowly evolved from its Babylonian roots into a private belief that the Latin Church, and then all Western Christian Churches, tried to eradicate (with little success at the personal level, even among scientists like Kepler and Newton) on the grounds it was pagan, and therefore anti-Christian. So, astrology played no significant role in European politics. Thus, despite resistance between 1200 and 1642 from Christian religious leaders for other doctrinal reasons, European astronomers were eventually able to: 1) study earlier Babylonian, Egyptian, Greek, and Arabic observations, 2) make original observations of their own, 3) share their work with each other, and 4) use their collective data to construct religiously and politically independent pictures of the Universe that became part of a tradition in which scientists could re-examine astronomical observations ***and*** the models that explained them.

The examples given above illustrate the kinds of cultural biases and choices that kept China from developing a modern scientific tradition ***before*** Europe. But in the 1200's, China's elite began to promote a New-Classical Confucianism, a nostalgia for "pure" Chinese ideals, that fostered negative attitudes toward all foreign civilizations and ideas. Strangely, this officially-promoted isolationism reached a climax just after the Southern Song Dynasty was overthrown in 1279 and Ghengis Khan's grandson, Kublai Khan, established the Mongol-ruled Yuan Dynasty. For, while Yuan emperors promoted foreigners to high positions in the Imperial government and put Turks, Ruzhens, Chinese Moslems, and even Arabs in control of much of China's trade by land or sea, they also tried to legitimize their rule by embracing the supposedly superior and universal Chinese culture. In fact, much Yuan policy over the next 89 years was designed to further one goal, winning over the naturally conservative Chinese mandarins through whom they were forced to rule.

When the Mongols were overthrew in 1368, China's last native dynasty was established. But the first emperors of the Ming

Dynasty entrenched the most conservative aspects of Mongol rule by: 1) re-writing China's history to emphasize its superiority (for example, Chinese emperors ever having paid tribute to other peoples was forgotten), 2) minimizing China's contacts with the outside world, and 3) stifling ***any*** innovations, indigenous or imported, that might undermine traditional beliefs. In fact, in an echo of early Chinese history, the start of the Ming Empire was marked by a seven year Reign of Terror in which at least 100,000 people were executed, many simply for being teachers or intellectuals who were assumed to have cooperated with the Mongols in order to get or maintain their advantaged positions.

In other words, China entered a period of foreign control and stagnation ***before*** Europeans reached China. Thus, while it is seldom recognized today by Chinese or Westerners historians, China's ***internal*** decline in the years before 1600 had as great an impact on China's future relationship with Europe as any European actions or attitudes after contact was established.

Despite this decline, when Europeans first reached China, they were fascinated by its wealth and customs. Thus, while Europeans tried to convert the Chinese to Christianity and expand trade with it in ways that were grossly unfair, Europe also underwent a "China craze" in which intellectuals and wealthy consumers became enamored with China's intellectual and artistic traditions. Hence, many European governments sent ambassadors to China and made a great show of honoring Chinese emperors and their court officials, something the Chinese never reciprocated. In fact, during this period, if ironically given our current stereotypes about the "mystical East" and "Western know-how," many Europeans felt China had a far more orderly, rational, and practical society than Europe. In short, the Western ambivalence about "Easternness" has its roots in the 1600's.

Thus, while Chinese leaders had always thought ***science was too socially and politically important to be left to private individuals or the possibility of revolutionary discoveries***, it was during the Ming period that European science and technology began to pass China's, even in areas in which China had excelled, such as calendar-making, astronomy, weaponry, and transportation. The following three examples highlight several possible reasons for this shift.

1) In the 1620's, a Jesuit missionary named Father Ricci gave a telescope like Galileo's to Chinese Imperial astronomers, while other missionaries translated Euclid's <u>Elements</u> into Chinese, Korean, and Japanese. But in China, Imperial officials feared Western math and astronomy might fall into "the wrong hands." So court astronomers and astrologers were the only ones allowed to use European telescopes and mathematics. As a result,

these "tools" failed to help China catch up to Europe in these fields. Above all, this demonstrates that ***any tool is only as important or good as the way it is used, something that is determined by the culture of those who possess it***. (NOTE: The telescope and Euclidean geometry did not become important technologies for China until the mid-1900's. From the European point of view, it is also ironic Father Ricci was championing Galileo's discoveries and "modern" scientific ideas in China at the very same time those ideas were being attacked by the Vatican and Ricci's own Jesuit Order.)

2) The printing press was invented in China around 800, and arrived in Europe in the 1300's. However, it was not until the 1450's that Europeans printed books (again, demonstrating how cultural bias affects usage of a technology). So, the Chinese had more than a 600 year head start in printing. Why, then, did not printing stimulate a Chinese intellectual revolution like the one that followed its introduction in Europe? The answer to this question lies in the conservatism of China's political and social systems, as outlined above, and in the usage and structure of China's written language. So let's briefly examine the latter in relation to printing.

In ***pictographic*** written languages, like that used in China and several other East Asian cultures, each word is represented by a separate ***character*** (albeit sometimes made up of "radicals," sub-units that can be used in many characters). Thus, when a Chinese printer named Pi Sheng improved the printing press in 1045 by making clay blocks (the world's first "moveable type"), each of which contained a single character, Chinese printers found it difficult to make, organize, store, and retrieve the thousands of blocks they needed. But when Johannes Gutenberg made pieces of wood for each letter in the Latin ***alphabet*** and then placed those letters on a press in different combinations in 1454, ***moveable type*** made the printing of European books much easier and more efficient. It is also worth noting in this context that Chinese grammar and the nature of Chinese characters made it much more difficult to express complex abstract ideas or rhetorical arguments than did Latin or other Western written languages. Without these kinds of arguments, it would have been impossible for any society to develop the ideas and reasoning that animated Western science.

Thus, the difference between China's and Europe's response to moveable type printing did ***not*** reflect a difference in the inventiveness of the two societies, or their relative readiness to consider new technologies. Instead, Chinese writing simply made moveable type less useful, leaving Chinese printers to continue carving full-page wooden blocks, a slow and artistic process that was wonderful for making beautiful illustrations but limiting when it came to printing books with a lot of text. As a result, while there were periods of intense debate and great inventiveness in China after 800, especially during the Tang and Song Dynasties, printing never was as central to the robustness of China's intellectual life as it later became in Europe. (NOTE: As with most generalizations about China, there are exceptions to this one. As the head astronomer at the Royal Observatory in Kaifeng in 1088, Su Seng had over 1,000 copies of his star-chart printed so other astronomers could have access to it, which made printing an important tool for those who might use Su's data to arrive at their own scientific understandings of the heavens.)

China's failure to use printing as a tool for change also reflected the great difficulty of learning to read and write Chinese, which kept China's literacy rate low and gave China's elite a powerful tool for maintaining *their* control over Chinese society. Moreover, since almost all education took place in government-sponsored schools that emphasized traditional beliefs, knowledge, and values like discipline and obedience, most of China's literate class remained uninterested in creating, printing, *or* reading books with revolutionary ideas. Without books filled with scientific information and ideas (again, a kind of tool in themselves) and an audience willing to read such books, modern science could not develop in China.

Not surprisingly, the cultural factors and language patterns cited above doomed the effort Catholic missionaries made to (re)introduce European moveable-type printing into China in the 1600's. In fact, Chinese printers simply ignored the possibility of printing books filled with new ideas, including foreign ones. As a result, it was not until the mid-1800's that Chinese intellectuals responded to the decay of China's political and social systems by opening themselves up to Western ideas, while the full power of printing was not felt until 1911, when China's Imperial system collapsed completely. (NOTE: Recently, computer-based photographic technologies have made it easier to print character-based languages. And a larger percentage of China's population has become literate, mostly due to a program begun in 1951 by the People's Republic of China that utilized a Romanized [alphabet-based] version of China's written language. However, when European moveable type was first introduced into East Asia, the only country that introduced an alphabet form of its own language to utilize this Western innovation was Korea.)

3) As we saw in Chapter 7, Chinese explorers could have sailed around the world by 1405, and possibly much earlier. But exploration was only used to verify China's superiority or satisfy an occasional curiosity about the rest of the world. Thus, when Zheng He's remarkable voyages of exploration ended, China failed to launch further voyages that might have led to a full understanding of the world or to Chinese domination of distant colonies. In retrospect, it is particularly ironic in this context that when Chinese inventions were passed on to Moslems, and through them to Europeans, those inventions greatly

contributed to Europe's ability to build world-wide colonial empires, and to its "discovery" and undermining of China.

European "Virtues" and the Birth of Modern Science

The above examples explain why China did *not* become the home of modern science. But we must still ask the companion question of why Europe did. For, the real mystery in our story is that *any* civilization created the scientific ideas Europeans did.

Above all, Europe became the home of modern science because it offered the "right" blend of scientific tools and political, religious, and cultural beliefs. First, contact with Moslems gave Europe access to Arabic science, better mathematics, some Asian inventions, and a rich tradition of Babylonian, Egyptian, and Greek ideas. Second, the collapse of the Holy Roman Empire and the development of competing countries shattered any unified political authority, while the Reformation had the same effect on religion. Third, the printing of books began just as national vernaculars were developing and the pool of literate readers and authors was growing and beginning to include people who were less bound to institutions like royal governments or the Latin Church that might want to discourage new ideas. And fourth, universities and government-sponsored observatories and scientific societies gave European scientists institutions in which they could do and share their work without surrendering their independence.

Aside from contributing to the onset of the Renaissance and its accomplishments, these changes helped create an urge to find sea routes to China, India, Japan, and the Spice Islands, which accidentally led to Europeans "discovering" the world. These discoveries, along with the growth of Europe's population, the cities, and the middle class, stimulated Europe's Mercantile economy and the generation of the "extra" wealth needed to support science. As all these changes took root, Europeans also came to see ***science and technology*** as a way to generate further wealth and "improve" life. In fact, the cultural value placed on science encouraged Europe's secular authorities to give ***individual*** scientists the freedom they needed to make and interpret their own observations. Moreover, we must remember that secular authorities were only able to grant scientists this freedom because of a growing separation of religious and secular institutions that depended on the development of Western Europe's secular monarchies, the collapse of its religious unity during the Reformation, and the emergence of nationalism.

It is easy to forget that this kind of ***intellectual freedom has been very rare in human societies***. It existed for some free males in city-states and colonies in Hellenic and Hellenistic Greek society. Then it existed for a select class of males in the Arabic (and then, Moslem) culture, India, China, and a few other Medieval Asian societies. And finally, after 1200, it developed in Western Europe, again, initially, only for certain males. In fact, despite the honoring of Classical Greek and Roman authorities during the Renaissance, its greatest long-term contribution to European culture was its enhancement of the idea that an individual could both think for himself and question authority (the two essential elements of intellectual freedom).

One of the key moments in this evolution toward a more open and pluralistic society was Galileo's confrontation with the Catholic Church. For, despite the Church's success in punishing Galileo, the ideas he championed continued to gain influence. As a result, the next generation of scientists did not have to worry about religious authorities, or even about the conflicts between their work and their own private religious beliefs. In fact, by the late-1600's, the Age of Exploration, Renaissance, Reformation, and Constitutional Monarchy had all conspired, in many cases unintentionally, to create an ideological climate that ***valued freedom of thought and the individual.***

By 1700, these values, along with the already entrenched traditions of European science and changing technological and economic conditions in Europe, caused an explosion of scientific work, including Newton's articulation of a new picture of the Universe. And lastly, these scientific successes, along with ideas about "truth" and scientific methods proposed by Galileo and Descartes, convinced scientists ***they*** had to tolerate and consider each other's pictures of the Universe. Thus, ***the doing of science created and sustained the values needed by a modern scientific effort and culture.***

As the Chinese and Arabic examples demonstrate, however, tolerance within the scientific community alone would never have been enough. ***Europe's political and legal systems had to provide protection for these values, at least for scientists.*** Otherwise, scientists would have become fearful of doing modern science and progress would have stopped. But this did not happen. Instead, science became an integral part of Western civilization ***and*** a key to its ability to maximize its wealth and power in the world, all of which increased support for further scientific efforts.

Physics and Western Culture: An Interdependency

One of the sciences that developed in Europe's climate of relative intellectual tolerance was modern ***physics***, which aimed to discover the physical laws of nature. That was its goal, nothing more. But European physics was not created in a vacuum. It was greatly influenced by the culture around it, while shaping that culture's further development. Hence, as one of the main themes of this book, it is only fitting as we near the end of our story to take a deeper look at this mutual relationship.

We have already seen how European developments indirectly made science possible. But European events also affected physics ***directly***, by influencing the scientists themselves and the kind of work they chose to do. Thus, without realizing it, physical scientists in each period of European history did work that helped solve the economic, political, and social problems that were most pressing in Europe.

When Europeans wanted to explore the world, it was important to discover better ways to measure time and a ship's position on the surface of the Earth. So physical scientists like Copernicus, Kepler, Galileo, and Newton made many of their most important discoveries in astronomy, which was particularly useful in solving these problems. Similarly, when the machines of the Industrial Revolutions needed new sources of power, physicists turned their attention to energy. And, since Western societies are still great consumers of energy, physicists continue to make their most important discoveries in this field and the allied study of sub-atomic matter. To date, this work has greatly increased the power available from mechanical, chemical, electro-magnetic, and atomic (fission) energy. In the foreseeable future, it appears physicists will continue looking for ways to unlock the huge potential of lasers and nuclear fussion, the latter being the energy-source of the stars.

It may seem physicists picked, or continue to pick, these subjects for their own reasons or because earlier scientific discoveries inevitably led them to these subjects. But scientific discoveries often point in more than one direction. So, the direction a generation of scientists ***actually*** takes is greatly influenced by the society around them. In other words, cultures shape their scientists in ways that make it difficult for them to make truly free or individual choices in these matters.

This is why scientists ignored Gilbert's work until they began re-examining electro-magnetism in the 1820's. Or, why the same thing happened to Huygen's ideas about light, waves, and radiation. In both cases, the quality (or, any lack thereof) of these scientists' work had nothing to do with their being ignored, ***or*** with their later rediscovery. Moreover, on a much grander scale, the same could be said of the Greek Atomists or many Arabic scientists. (NOTE: In a striking example of humility, intellectual honesty, and historical awareness, Lord Kelvin had Carnot's work on heat translated into and published in English, and Gilbert's on magnetism reprinted, so he could publicly acknowledge their influence on him and the new picture of the Universe that was emerging in the mid to late-1800's.)

Given this interdependence, it is impossible to understand the development of European physics without understanding its history. But it is equally impossible to understand Europe's history over the last 450 years without understanding its physics, which, as much as politics, war, the arts, religion, philosophy, or the movement of peoples into Europe from Asia and Africa, within Europe, or from Europe to other parts of the world, has shaped European society. This is most obvious in the effect physics has had on the technologies it has produced or helped explain. After all, they have remade the material culture of Western societies, while increasing their wealth, military might, and power over non-Western societies. In fact, radio and televison; telephones; electro-magnetic motors; space satellites and exploration; nuclear weapons, power plants, and medicine; lasers for weapons, medicine, and entertainment; and computers are just a few of the products made possible by the physics of the last 125 years.

Many Western people understand this. But few understand that when they use these products they are indirectly "using" Western scientific methods and values. For, it is these beliefs, such as the need to dominate nature, devotion to change as a positive and inevitable part of life, a secular and natural view of the Universe, and Relativism's celebration of the elusiveness of absolute truths that have made modern science and its products possible.

More subtly, the ideas created by astronomers and physicists have had many direct and indirect effects on non-scientists and their ideas. To cite just one example, ideas about motion, energy, matter, forces, the structure of the Universe, and the scientific method helped shape political thought and the Age of Enlightenment. In one particularly striking example, Newton presented a first-edition copy of The Principia with his hand-written notes in the margins to Locke in 1687, ***a year before England's Glorious Revolution***, and suggested to Locke that its contents might be relevant to political philosophy. Moreover, it is easy to forget that Locke's epoch-making Two Treatises... on human rights and the underpinnings of governmental legitimacy was published only three years after Newton's on calculus and gravity. Or, that Newton's greatest book was published just as William of Orange was being appointed Great Britain's King, and Britain's Civil War was reaching its climax.

Therefore, while it is seldom noted by historians, Newton's ideas deeply affected British, American, and French politics. In fact, the French Enlightenment's blind faith in an idealized scientific methods and insights was a major contributor to the extremism and brutality of the French Revolution, and to the rise of Napolean. However, the Age of Enlightenment, the French Revolution and the Napoleanic Era also had other more positive and lasting effects. Chief among these were the evolution of a belief in rational thought as a problem solving tool (as expressed in the ensuing Age of Reason), the creation of a more universal and secular justification for the rights of the individual, and the rise of modern nationalism.

So, as Western historians trace the history of nationalism, human rights, or the Age of Reason, they are, in part, tracing science's effects on non-scientific processes. In fact, the ***chain of cause and effect*** (a Newtonian idea that has also greatly affected our sense of historical process) that led to our most cherished political and social ideals includes the science done between 1540 and 1750, especially by Copernicus, Brahe, Kepler, Galileo, Descartes, and Newton.

The Whole Ball of Wax: Science, Culture, and Philosophy

This important two-way connection is seldom mentioned in accounts of this period, or in histories dealing with politics, the arts, or, strangely, science itself. This is partly due to a cultural bias that developed as a result of Descartes and Galileo defining the scientific method in a way that was meant to ensure scientists could distinguish scientific conclusions from mere speculations about nature. Although these methods have been incredibly useful for science, which is no small matter, they have also transformed science into a ***unique*** endeavor with its own "specialized" (and, to many non-scientists, arcane) procedures, language, and behaviors.

This is particularly ironic given Galileo's and Descartes' educations, which stressed religious studies, rhetoric, the arts, and music (at the time, considered one of the sciences) as much as what we would consider math and science. Or, given both men's broadly varied lives, including Galileo's upbringing as the son of a leading musical figure who was at the center of an important Renaissance artistic circle. Moreover, while we often assume scientists have ***always*** been alienated from their societies, we must remember it was not until the late-1800's that science was isolated it from other aspects and endeavors of Western culture.

Before this cultural shift, many scientists were accorded great fame and respect as "mainstream" figures. To cite only a few examples, after finishing his distinguished career in science, Carnot briefly became the President of France. Newton was knighted and became one of the best known individuals of his day. And, Faraday and Kelvin played significant non-scientific roles in British public life and became "household names," even among those who had little interest in science. (NOTE: Einstein represents a different case that, ironically, proves the same point. Since his fame arose after the isolation of science, it was based on his supposedly being an eccentric, counter-cultural, genius-figure whose "otherworldly" absent-mindedness and ideas were beyond a normal person's understanding. Given his seemingly pleasant personality and manner, not to mention his soulful eyes as an old man, these traits made him a mass cultural icon.)

Unfortunately, the isolation of modern science has made it easier for Western individuals to reject the insights gained from science in the last 450 years. In fact, it is not uncommon to hear well-educated people dismiss science as a "cold" and hostile activity that has little impact on *their* culture, except in negative or material ways. Or, to hear such people contrast their own beliefs to what they, often incorrectly, interpret to be modern scientific beliefs. Or lastly, to hear contemporary historians, artists, musicians, writers, poets, and entertainers express the opinion that science has little to do with the work they do or the developments they study.

Nothing could be further from the truth. After all, to follow one causal train, breakthroughs in astronomy were crucial to Europe's launching of its Age of Exploration, which led to the rise of some nations, such as Portugal and Spain, and then Holland, Great Britain, and France, and the decline of others. Later scientific discoveries helped launch the Industrial Revolutions and Britain's emergence as a super-power, which ensured British political ideals would have a remarkably broad influence on the future of other countries. Still later, other scientific breakthroughs facilitated the rise of Germany and made the natural resources available in North America more valuable, which made it possible for the United States to become a world-class economic and political power with a large population.

As importantly, scientific discoveries and their industrial and technological offspring led to the emergence of urban life, with all its advantages and disadvantages, as the central reality of Western societies and the context for Western artists, including those who championed or romanticized "natural" settings and anti-urban and anti-science/technology values. In fact, these science-induced processes and events, and many others we have not mentioned, helped shape all the social, economic, artistic, and political institutions of Western societies.

In a broader sense, scientific breakthroughs and the cultural changes to which they have contributed have caused a restructuring of all Western social institutions. As a result, traditional ideas about the relationship between husband and wife, the definition and upbringing of children, and the values that justify and sustain these customs had to change, as did Europe's class structure. Ultimately, these changes allowed merchants, manufacturers, factory workers, and government workers to become more powerful; while monarchs, nobles, and religious leaders became less so. Moreover, while science may not deserve all the credit (or blame) for these changes, none of them would have been possible, or necessary, without science.

Perhaps most importantly, however, ***modern physics*** and ***mathematics*** have become ***the fundamental source of philosophical ideas in Western culture***. Thus, in the last 150 years, probability theory, statistics-based mathematics, non-Euclidian geometry, new models of sub-atomic realms of matter, energy, and time-space, as expressed in the Field Theory, the Theories of Relativity, Quantum Mechanics, and the ideas currently being explored in Chaos and (Super)String Theory, have forced physicists and those who understand their work to re-examine the issues raised (often in purely literary terms) by the Western philosophical tradition, and to revisit the most ancient intellectual questions of all: 1) How should we define knowledge? 2) Does the observer of an event alter that event by studying it, thereby limiting the accuracy and value of experiments? 3) What is the relationship between the structure of the Universe (in modern terms, the nature of its dimensions) and the events and processes that occur within that structure, such as energy-mass interactions? And, 4) what are the limits and potentials of our ability to know about nature, or anything else for that matter?

The answers modern physics has given to these ***metaphysical questions*** are at the heart of our current Western philosophical understanding of the Universe and of our place in it. Moreover, it is worth emphasizing once again that that understanding is at the heart of all Western endeavors, including those in the arts and the humanities.

The "Layering" of Western Civilization: An Endnote

In 1687, Newton laid the foundation for a model of the Universe based on the assumption all entities and processes in nature are connected to each other in ***cause-and-effect mechanical relationships*** that are discoverable by humans. As this model was further developed and verified by physicists, it gave rise to an explosion of work in the other hard sciences: chemistry, biology, and geology. In the last 150 years, Newtonian ideas have also been applied to the ***social sciences*** (anthropology, sociology, psychology, history, and economics) that examine human behaviors and relationships. Then, by 1900, ***these*** ideas re-shaped the everyday thoughts of all Westerners, whether they know it or not. Thus, even today, the three most influential Western thinkers are Newton (in physics), Charles Darwin (in biology), and Sigmund Freud (in psychology), men who did their work from the late-1600's to 1900.

It does not matter that most people have never read these men's works or considered the substance of their thoughts. Nor that their ideas have been modified and improved upon by more recent work in their respective fields. All that matters, in a broad cultural sense, is that their ideas of a mechanical Universe, evolution and natural selection, and psychological complexity and meaning are now unthinkingly applied by people whenever they attempt to solve a problem. Thus, most Western people rely on notions like "one thing causes another," "life is a competition in which the fittest survive or prosper," "nothing stays the same," and "there are deeper meanings and motivations to a person's behavior than he or she understands."

In 1873, Maxwell created the Field Theory, which laid the foundation for a new understanding of the Universe. However, Maxwell's ideas, and those of physicists who followed him, did not change most people's ideas about how one event is connected to another. So, while the year 1873 marks the dawn of a new era in physics, it does not mark the beginning of a new view of reality by most Western people. In fact, this discontinuity between the habits-of-mind of most Westerners and science's metaphysical understanding has created a rather strange, and strained, situation in all contemporary societies. So, let's end by briefly looking at those strains and their consequences.

Many modern people believe in magic, ghosts, astrology, miracles, superstitions, and God as the direct cause of all that happens in nature. Perhaps without realizing it, these people believe in a pre-1642 European description of nature. There is also a minority within Western societies who claim to have rejected European technology and religion in favor of the spiritual traditions of Asian, African, or Amerindian cultures, or of New Age beliefs. In fact, some people have noted the superficial similarity between some Eastern, especially Buddhist, thinking and modern physics ideas. However, modern physics ideas are products of a method and a set of underlying beliefs that make those ideas fundamentally different from Buddhist ones. In any case, the beliefs, methods, and traditions of science ensure that our current physics ideas will never be "canonized" as a body of mysterious insights and fixed "truths."

Paradoxically, many in this group also believe science should find absolute truths. Hence, whenever scientific opinions change, they assume science has "tricked" or failed them. Or just as often, they fail to adjust their thinking, on the mistaken and opposite assumption scientific answers should be permanently true because they are "scientific." Thus, many modern people adhere to a belief in infallible answers, a position that is greatly at odds with modern science, which makes no such claims for itself. In fact, ***modern theoretical science is based on the assumption that re-examination is at the heart of scientific inquiry and methodology, and its greatest strength***. In fact, whether others understand it or not, scientists only claim to have found a way to improve our view of nature. Accordingly, ***observations, theories, and technologies are merely temporary, imperfect, and peripheral by-products of the scientific process.***

Most maddeningly to many non-scientists, this belief is simply based on the fact scientists have found this the most productive way for them to ***do*** science. Indeed, modern physicists admit, with some glee and frustration, that humans will never find answers to all their questions. Rather, they will discover new questions to ask, new mysteries to probe, and new ways to describe the things they discover. In fact, to most physicists, it is exactly this ***uncertainty*** that offers the greatest excitement and justification for the modern scientific method and its values. (NOTE: "Uncertainty" also has a technical meaning for physicists. In the early-1900's, Werner Heisenberg, a German mathematician and colleague of Max Planck in Berlin, created ***the Uncertainty Principle***, a mathematical expression that is factored into all Quantum Mechanics equations dealing with high-speed, high-energy "events," such as those that occur in sub-atomic particle experiments. At a metaphysical level, Heisenberg's Uncertainty Principle represents the unpredictability of results in experiments or of cause-and-effect relationships in nature.)

At the same time, many educated people in Western societies have come to believe that nature is best described by the insights of Newtonian scientists who did their work in the 1700's and 1800's, based on Galileo's inductive, empirical, scientific method. This point of view has been very resistant to change for four reasons. First, few people understand post-1873 physics or its experiments. Thus, most fail to see how these experiments or ideas overturn Newton's view of the Universe. Second, the math used by modern physicists, while elegant to them, has made it impossible for most people to appreciate the evidence that demonstrates Newtonian Mechanics do not accurately describe the Universe. Third, most people fail to appreciate that while everyday experiences and common sense tell them the world is governed by Newtonian rules, those experiences are not relevant to high-velocity or high-energy interactions, very small amounts of mass, or extremely large or small scales of time-space. And lastly, it is not clear to most people how the overturning of Newton's view of the Universe, at any scale or for any reason, is relevant to their daily lives or beliefs.

People with these attitudes often feel they are modern, a stance they believe they demonstrate by having an "open mind" about new scientific discoveries, even when this openness is accompanied by a gleeful admission that they have no personal understanding of mathematical or scientific ideas and no intention of attempting to acquire one.

Nevertheless, there is a small group of people who do understand ***some*** post-1873 physics concepts and are learning to apply them to other realms of thought. This group is mostly made up of physicists, mathematicians, and other scientists. However, as physicists become more adept at explaining the consequences of their ideas (to the extent ***they*** understand them), a larger number of people is beginning to grasp how important those ideas are and how they change one's thinking about everything. Thus, with great excitement and hesitation, some people are beginning to apply post-1873 physics ideas to history, art, literature, medicine, economics, music, and a raft of other human endeavors.

Describing contemporary society in this way may seem like little more than an attempt to congratulate those who embrace post-1873 scientific ideas. But, it is important to recognize that each group described here represents a different period in Western civilization's philosophical and cultural history. For historians, this recognition broadens one's understanding of the role the past still plays in shaping the modern world ***and*** makes history a more important tool for describing and explaining the beliefs and actions of contemporary people. That said, in reality, many people embrace beliefs from two, or even all three, of these groups. In that sense, the above analysis is grossly over-simplified. But this also means it can be used as a framework for analyzing the inconsistencies and complexities ***within*** individuals.

As importantly, this framework can be applied to non-Western societies. For, each contemporary society contains people who represent each period in ***that*** society's development to its current form. Moreover, the heritage of ***all*** non-Western cultures now includes Western ideas, arts, and styles; while Western civilization has absorbed many non-Western ideas, customs, and objects into its heritage and culture. Thus, at least in the context of this discussion, the only difference between Western and non-Western societies is that in non-Western ones there are fewer people with post-1642 or post-1873 Western ideas about "how the world works." In fact, it is important to recognize that there are people in non-Western societies who fall into each of the groups defined above for Western societies. Some believe in pre-Newtonian ideas from either their own traditions or Western philosophy and religion. Others believe in Newtonian descriptions of how the world works. And lastly, a few believe in ideas created since Maxwell's work in 1873.

This illustrates an important point that is often misunderstood. ***Western societies and their populations are less modern than we think, while non-Western societies include some people who are modern, even in a Western sense***. Given the role Western culture plays in today's global economy and the complexity of all contemporary cultures, this should not be as surprising as it seems to many observers. In fact, one of the most destructive aspects of Western analyses of non-Western cultures, including those done by people who think they are defenders of "non-Westernness," is the idea that those cultures have, or ever had, an unchanging character that could be starkly distinguished from "outside" influences, or contrasted to Western notions of change as a virtuous end in itself. In fact, when it comes to Western notions about non-Western societies, the only difference between Euro-centrics and Euro-bashers is often whether the stereotype of non-Western cultures they share proves non-Westerners are "bad" or "good."

These judgments aside, it may seem that the simultaneous existence of multiple belief systems creates a diversity that strengthens Western societies (almost uniquely, if imperfectly). In a sense, this is true. People who live in today's Western societies are fortunate to enjoy the freedom to believe what they want while benefitting from the richness of living in diverse societies ***and*** the material advantages science and economic expansion have brought. However, as the world becomes more competitive and dependent on science and technology, we may not find it so easy to maintain these advantages. In fact, ***any*** society's ability to do so may soon depend on it producing a greater number of people who understand and know how to apply modern scientific concepts, if only because future cultures will have to make many decisions about what science should or should not be allowed to do, and about how best to use the knowledge and technologies science produces. Moreover, if current trends continue, it appears these decisions will have to be made during a period in which an increasing number of people will be ignorant of the issues they are judging.

Nevertheless, scientists should never be asked to make these decisions for us, or to singlehandedly sustain our physical culture to the benefit of all its members. Nor should we assume ***we*** will continue supporting scientists' freedom to do their work or make such decisions. Nor finally, would it be good thing to allow scientists to make these decisions, even if it were possible. For, in that case, the majority of people would have to live with decisions made by others, while scientists would be doomed to an even greater isolation, based on a perception of them and their work as "evil." In fact, such a solution would undermine all Western traditions of political democracy that have evolved in the 800 years since the Magna Carta. In practical terms, this would also make it increasingly difficult to maintain the material ***and*** cultural richness that Western societies have enjoyed in the recent past, and that most non-Western societies are currently striving to achieve for themselves.

Thus, while in some ways we may cherish non-modern, non-Western, and non-technological ideas and values (three different things), one point should be clear. Our culture will not last long if we insist on maintaining a negative attitude toward science and scientists. Or, if the majority of people within our society ignores or does not understand the science and technology that has made our culture possible, sustains it today, and will shape it in the future.

This problem cannot be left to future generations. After all, most of today's children, who will become adults in the first half of the 21st Century, are still not being taught physics ideas from the beginning of the 20th Century. Nor are they learning about the philosophical and other consequences of these ideas, except from the ecology movement, which often justifies its positions by stating more generally anti-scientific and anti-technological opinions.

This book has tried to address this problem by emphasizing: 1) the processes and events that have shaped the present world and made modern physics possible, 2) those earlier scientific ideas that are the roots of modern physical science, and 3) the importance of science to every facet of a society in which it happens and to all societies that later use the knowledge it creates. Hopefully, this book has also put the doing of physical science into a context that is fair to the contributions of other civilizations *and* more inclusive of science in the humanist traditions of Western civilization (and vice versa).

It is also worth noting in this context that the writing of this book involved habits-of-mind that came from Hellenic Greek concepts about rhetoric and logic, a deep interest in our culture's past, and Newtonian concepts about cause-and-effect. Thus, if nothing else, this book demonstrates that an interest in modern ideas does not have to preclude the valuing or using of the rich heritage past thinkers have left us. In fact, to cite the argument raised in the text about the introduction of Field Theory, we do not have to throw out all old insights in order to embrace new ones.

In the end, this book is meant to be an introduction to modern physics that will prepare readers to better understand the ideas of post-1873 physics, while encouraging them to want to learn more about those ideas. However, those subjects fall beyond the scope of this book. So, we must end for now by simply saying that more than 125 years after Maxwell created his equations for electro-magnetism, and roughly 90 to 100 years after the creation of Quantum Mechanics, the Theories of Relativity, and the Uncertainty Principle, it is time for us to understand our place, both in the Universe and in the culture that has nurtured and supported us. Armed with this knowledge, we may at last enter into our own time and prepare ourselves to contribute to the making of our own future.

THE END

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NOTE: Other than primary sources, which are not listed here, several authors were particularly important in shaping this text: 1) Ronan, for his information on physics and its connections to other sciences, 2) Kuhn, for his conceptual model of scientific periods and change, 3) Sarton, for his call to unite science and the humanities in our culture, 4) Krauss and Heisenberg, for their suggestive brief introductory chapters on the Greeks, 5) Ross, for his detailed treatment of early Chinese science and technology, 6) Joseph, for his cross-cultural information on and approach to mathematics, and 7) Fairbank, for his wealth of information on Chinese history.

Given the text's closing plea for the reader to investigate modern physics ideas, I have also included a number of sources that deal with post-1873 physics. My favorites are those by Planck, Heisenberg, Jeans, Hoffman, and Einstein. The first two, in particular, demonstrate a remarkable passion, clarity of expression, breadth of knowledge, and humanism that bespeak the attitudes of true "Renaissance men." Non-scientists would do well to emulate their example.