ABSTRACT

THE ILLUSION OF SCIENCE: IMAGES OF SCIENCE ON STAGE

by
Preethi Ganapathy

Science has long been regarded as a process of thinking, of pursuing the truth. This quest traditionally has been reserved for an elite group of thinkers, since at least the time of Aristotle, who was considered as the undisputed authority on philosophical truth, including that which we call science. The Scientific Revolution challenged Aristotle's authority and paved the way for the new method of evaluating scientific truths developed by Bacon, Descartes, and Galileo. Science became, over time, a process of inquiry open to all social and economic classes and accessible to all. In the twentieth century, the role of science again became hidden from or remote to public view, either because of innate complexity or the necessity of wartime secrecy.

One forum in which science has been made available to the public is the stage. A few playwrights of the twentieth century have used science in their works. But more often than not, they primarily wrote about the lives of scientists with only the illusion that the plays are about science. Bertolt Brecht's Galileo (1939), Jerome Lawrence and Robert E. Lee's Inherit the Wind (1955) and Peter Parnell's QED (2002) describe, to varying degrees, the lives of scientists, but although scientific concepts are mentioned, these are not fully integrated into the meaning and form of the plays. In Copenhagen (1998), however, Michael Frayn has managed to present the key concepts of twentieth century physics

within the theme and structure of the play. In Copenhagen, finally, we have a play in which science is its subject, not merely an illusion of a subject.

THE ILLUSION OF SCIENCE: IMAGES OF SCIENCE ON STAGE

by
Preethi Ganapathy

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Professional and Technical Communications

Department of Humanities and Social Sciences

May 2003

APPROVAL PAGE

THE ILLUSION OF SCIENCE: IMAGES OF SCIENCE ON STAGE

Preethi Ganapathy

Dr. Robert E. Lynch, Thesis Advisor — Date
Co-Chair, Professor of Humanities and Social Sciences, NJIT

Dr. Norbert Elliot, Committee Member — Date
Co-Chair, Professor of Humanities and Social Sciences, NJIT

Dr. Nancy Coppola, Committee Member — Date
Director MSPTC, Assistant Professor of Humanities and
Social Sciences, NJIT

BIOGRAPHICAL SKETCH

Author: Preethi Ganapathy

Degree: Master of Science

Date: May 2003

Graduate and Undergraduate Education:

- Master of Science in Professional and Technical Communications
  New Jersey Institute of Technology, Newark, New Jersey, 2003

- Bachelor of Science in Physics,
  Ethiraj College for Women, University of Madras, Madras, India, 2000

Major: Professional and Technical Communications

कर्मण्येवाधिकारस्ते मा फलेषु कदाचन ।
मा कर्मफलहेतुर्भूर्मा ते सङ्गोऽस्त्वकर्मणि ॥ ४७ ॥

ज्ञानेन तु तदज्ञानं येषां नाशितमात्मनः ।
तेषामादित्यवज्ज्ञानं प्रकाशयति तत्परम् ॥ १६ ॥

यद्यदाचरति श्रेष्ठस्तत्तदेवेतरो जनः ।
स यत्प्रमाणं कुरुते लोकस्तदनुवर्तते ॥ २१ ॥

To action alone do you have rights and never to its fruits. Let not the fruits of action be your motive, nor let they lead you to inaction (Ch. 2 v. 47).

For those in whom ignorance is destroyed by wisdom, for them wisdom lights up the Self like the sun (Ch. 5 v. 16).

Whatsoever a great man does, the same is done by others as well. Whatever standard he sets, the world follows (Ch. 4 v. 21).

-- Bhagavad Gita

To my Family and Friends

ACKNOWLEDGEMENT

This thesis could not have been written without the inspiration and guidance of Dr. Robert Lynch. I would like to express my deepest gratitude for the long sessions and late nights he spent reviewing and editing each page. My thanks are also due to Dr. Norbert Elliot and Dr. Nancy Coppola who serve as a part of the graduate committee.

I would also like to express my gratitude to Mr. James G. Brown Jr. for proofreading the final document in the midst of his busy schedule. My final thanks goes to my coworkers who so graciously adjusted to my research schedule.

TABLE OF CONTENTS

CHAPTER 1

EVOLUTION OF SCIENCE INQUIRY

Science has not been commonly recognized as potential inspiration for dramatic literature. The inherent gravity of the subject has limited its usefulness for the stage. Because of the complexities of the materials involved in a true scientific story, the popular belief remains that science is beyond understanding and thus, boring. This belief, in general, survives into the 21st century.

What is science? The standard definition of the term has come to be "systematized knowledge derived from observation, study and experimentation . . . of nature and the physical world" ("Science"). This definition has evolved over many centuries. Science originally was about the pursuit of truth, be it philosophical or spiritual. It continues to be a search for truth, though it has come to mean a different kind of truth. More than the mysteries behind nature, science now includes the discovery of new theories consisting largely of abstractions. Science is the venture into frontiers previously explored only in thought. It is the explanation that makes the abstract precise and makes laws applying to a single point relate to a universal truth; it is the medium that gives numbers a material appearance; it is the search for the truth that cannot be seen.

In its early stages, truth was dictated by an elite group of thinkers and was rarely challenged. Aristotle (384-323 BC) developed a method of finding the truth through questions and puzzles. It is human nature to find the world puzzling; the desire to know leads us to pursue an explanation for the puzzles that exist around us. "By posing and answering questions, we do what we can to render the world intelligible to us" (Lear 5). Almost all our beliefs are "stabs at the truth" as they are formed on the basis of interactions with the world (Lear 5). Even though some beliefs may be false, they are worth investigating so that we may secure a clearer grasp of the truth.

Aristotle emphasized that we are not just satisfied with knowing truth but that we also strive for understanding. For instance, we are not satisfied by simply knowing that the Heavens move; we want to know why they move. This determination to gain understanding brings us to a realization of who we are. By coming to understand the world, we "can look to the world to see the structure of [our] souls mapped there" (Lear 8). Aristotle believed that what one comes to understand about nature is divine. He believed that the ability to understand the natural phenomena around us is an innate gift. Thus, the human act of understanding is itself divine.

According to Aristotle, science is one of the modes through which the soul arrives at the truth. Scientific knowledge is based on what exists, on what can be observed through the senses. Anything that cannot be observed cannot be proved to be either existent or non existent. Thus, that which science studies must "exist by an unalterable necessity" (W. Thompson 153). Science is based on induction and deduction: induction gives us a first principle or a "universal" while deduction starts from these universals. What Aristotle means by science here is "a habit of mind with an aptitude for demonstration" (W. Thompson 153). He says a man has scientific knowledge when he is satisfied in his own mind that he has obtained his knowledge as a result of the process of induction and deduction. He must know that the knowledge on which his inductions are based is tangible; otherwise the knowledge he acquires will not be scientific (W. Thompson 154). Scientific knowledge is exact and definite.

Aristotle applied his power of reason to the Universe. His conception of the physical sciences, astronomy in particular, was factually incorrect (Bixby 19). No one, however, dared to challenge him. Even through the Christian Middle Ages his works were taught in schools and his unprovable ideas and mistakes were passed on from generation to generation. "The theories he set forth became part of a Christian dogma, and anyone who dared challenge them was chastised for questioning God" (Bixby 20). Thus the Church never strayed from Aristotle's teachings, and no one dared refute them until the scientific revolution of the 16th century.

In addition to science, Aristotle wrote treatises on logic, metaphysics, philosophy, psychology, ethics, politics and art. He believed that although man was not born with knowledge, he was endowed with the natural curiosity to know; he has the capacity to learn and gain knowledge. Aristotle's works, along with the Bible itself, were regarded as primary authorities and were rarely questioned or debated until Copernicus developed his theory of heliocentrism.

Aristotle's truths derive from the philosophical, and from human thinking, not from laboratory experiment. The authority on spiritual truth was, of course, the Bible. Throughout the Christian West, the word of the Bible was absolute, and no one dared refute it or question what the Bible stated. During the Middle

Ages, the material world was regarded as a storehouse with objects that represented analogies for the incarnation, the crucifixion, the resurrection, and other Christian dogmas. "The habit of searching for allegories had originally been cultivated in the interpretation of the Bible" (Parkes 61). Each passage could be interpreted as having moral, allegorical, literal or mystical significance. In this way, theologians could "dispose of passages in which the literal meaning was embarrassing" (Parkes 61). This habit of searching for hidden meaning was extended to virtually everything. In fact, fantastic animals, such as the unicorn or the phoenix, which find their origins in Egypt and Asia Minor, were believed to be real for thousands of years. They were "constantly cited as exemplifications of theological truths" (Parkes 61). Life was supposed to be directed by religiously sanctioned ethical standards as affirmed in the Bible (Parkes 99). The world was one, created and governed by a God from whom all things began and who determines when all things end. This idea paralleled the Ptolemaic cosmology in which the universe is a finite orderly system with the sun, planets and stars moving around the earth in a series of concentric circles (the theory of geocentrism). Such hypotheses dignified man as the center of the created universe. This model of the cosmology depended on the existence of God, and it was thus impossible not to believe in his existence (Parkes 59-60).

However, at the time of the Renaissance in the 16th and 17^{tth} centuries, a challenge arose against what had been authoritatively accepted among all great thinkers up to that time period. Perhaps the most revolutionary of these "truth defying" concepts was Copernicus' theory of heliocentrism. Copernicus published his theory in De Revolutionibus Orbium Coelestium (On the Revolution of the Heavenly Spheres) in 1543, shortly before his death, and introduced sun-centered astronomy (Meissner 3). "Scholars were willing to accept the new astronomy because it harmonized with their new feelings, not because it was mathematically more convincing" (Parkes 297). The shift of the earth from the center of the universe to the status of an average planet revolving around the sun in concentric circles redefined the view of space to be infinite. Copernicus' theory was by no means perfect. It did not account for the known facts of planetary motion. In addition, Copernicus was asking the people to reject their common sense assumptions that the sun does move across the sky and the earth remains stationary since its motion cannot be felt. "More serious, Copernicus contradicted passages in the Bible, such as the one wherein Joshua commands the sun to stand still" (S. Thompson 190). Thus, followers of Copernicus were in the minority.

Science was entering a revolutionary period. It began taking an approach described by Thomas Kuhn in his book The Structure of Scientific Revolution (1962), as "normal science." Normal science is "research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice" (Kuhn 10). Science, Kuhn says, is a number of assumptions that need to be re-evaluated and reconstructed based on prior assumptions. In the years after Copernicus, we see the scientific pursuit of truth taking on a structured method. Two of the exponents who established the basis of this method were Francis Bacon and Rene Descartes.

Francis Bacon embodied this scientific revolution, believing that the existing methods of formulating a theory were "erroneous and sterile" (S. Thompson 184). He reinforced the notion that scientific developments need to be supported and proven by experiments. He believed that deductive reasoning should be replaced with inductive reasoning, thereby explaining phenomena in a logical, orderly manner. Bacon, in his Novum Organum and other writings, affirmed that science must become independent of religion. By abandoning the medieval belief of a divinely created order, man could become the master of nature (Parkes 467).

Rene Descartes (1590-1650), philosopher and scientist of the 17th century, advanced the idea, now obvious to us, of validating a theory empirically before declaring it a truth. Such an idea made him believe that "physics, astronomy, medicine and all other disciplines which depend on the study of composite things are doubtful; while arithmetic, geometry and other subjects, which deal with the simplest and most general things, regardless of whether they really exist in nature or not, contain something certain and indubitable" (Descartes 15). Descartes published two books in which he outlined the "philosophical basis for constructing his new epistemic system" (Murphy). He believed that reason should be used to go from a general principle to a more specific one. The failure of Aristotle's science in the Dark Ages was mainly due to the lack of methodical presentation. In his Regulae ad directionem ingenii (written in 1619 and published posthumously), Descartes mentions the rules of scientific observation and theory formulation--the scientific method. In Rule 1, Descartes claimed that the sciences are nothing but a collection of human wisdom. This may be a play on the word 'scientia' which covered the meaning of both wisdom and knowledge (Gaukroger 114). He believed all sciences were connected and thus, there was a unity in knowledge. Having established this premise, his Rule 2 states why a method is necessary for scientific inquiries, "holding up the mathematical sciences as models in the virtue of the certainty of their results" (Gaukroger 114). Rules 3 and 4 deal with intuition and deduction, the two operations upon which a method relies. Rules 5, 6 and 7 provide details on how to perform the decided method while Rules 8, 9, 10 and 11 "elaborate on specific points relevant to the following of the proposed method" (Gaukroger 115).

Descartes was a celebrated figure even after his death in 1650. There was no strict Cartesian school after he died, but his name and ideas were brought up in every innovative area. Anyone who was believed to be an innovator was in some way connected to Cartesianism. One of these Cartesians was Sir Isaac Newton. Born in 1642, Newton transformed the world of physics and mathematics, thus furthering science through the scientific method encouraged by Bacon and Descartes. To Father Ignatius Pardies, professor at the College of Claremont in Paris, Newton conveyed his definition of a true scientific method. He wrote in a letter that "the best and safest method of philosophizing seems to be first to inquire diligently into the properties of things, and of establishing these properties by experimentation, and then to proceed more slowly to hypotheses for explanations of them" (Bixby 101). Using his scientific method, Newton made discoveries in the fields of Optics, Mechanics, Astronomy, and Motion; he also developed Calculus.

Newton explained a new scientific philosophy that came to replace the Cartesianism (Weisstein, "Newton"). He presented the scientific method in his book as four rules for scientific reasoning. He proposed that, "(1) we are to admit no more causes of natural things such as are both true and sufficient to explain their appearances, (2) the same natural effects must be assigned to the same causes, (3) qualities of bodies are to be esteemed as universal, and (4) propositions deduced from observation of phenomena should be viewed as accurate until other phenomena contradict them" (Weisstein). By these rules, Newton developed universal laws of nature that explained nearly every natural phenomenon in his day. His method exceeded Aristotle's approach to reasoning. "He refined Galileo's method of analysis creating the compositional method of experimentation still practiced today" (Weisstein).

By the time Newton began making his discoveries, the structure of Aristotle's physics had already been destroyed. Yet, one concept still remained. Aristotle believed that the heavens were perfect, unlike the imperfect earth. Thus, what applies to man on earth cannot apply to the heavens. Newton agreed with this concept and developed his law of universal gravitation based on the relationship between natural motion and gravity. He presented his finding as one of the concepts in his book, <u>Mathematica Principia</u>. "The <u>Principia</u> contains the main body of knowledge that composes the science of mechanics, one of the major divisions of physics" (Bixby 105). Newton's discoveries and developments have allowed us, today, to perform extended space observations.

Newtonian science, thus, became the foundation for modern science. The methods of hypothesis, observation, experimentation and confirmation dealt with facts that were supported by proof. "Modern science at last dealt directly with fact. This is Positivism" (Barzun 509). The champion of positivism was Auguste Comte. He coined the term "sociology," which referred to the science that should complete the total survey of the real world. Positivism found its place among scientists who felt that philosophic support was not necessary for their work. Being a positivist required little effort of thought and offered no occasion for elaborate argument (Barzun 509). Thus, followers of metaphysics could be left to their illusions.

The 20^{th} century perhaps has seen the most revolutionary advancements in science. Within a period of a hundred years, we have flown higher than birds, made earth-shattering explosions and have created instant communications. The scientific community has also incorporated women scientists who have proved their worth by winning such esteemed honors as the Nobel Prize. The latter half of the 20^{th} century has been dubbed the Information Age, the Computer Age, and the Space Age. From home appliances to remote control sensing, the very culture is driven by science. Yet, even with such progress, science still remains a remote subject for people excluded from the community of thinkers who decide the applications of science in new technologies and products. The fact remains that most people today, even educated individuals, are largely unfamiliar with the reasons behind new scientific developments. An excellent example is the human genome project with all its ethical implications.

In addition to industrial and academic research that aims to make our lives more comfortable and knowledgeable, science, in the 20^{th} century, began creeping into imaginative literature. It was a bold challenge that these playwrights and authors took on because, previously, scientific material had been considered unsuitable for the stage. It was considered a boring topic because of its seemingly complex nature. However, a few playwrights have captured the essence of science and shown that it, too, can be a subject that can spark interest, even in the public mind.

CHAPTER 2

SCIENCE: AN ILLUSORY TOPIC FOR STAGE

By the mid 1900s, science was known in the mass media through its famous names like Albert Einstein, Marie Curie, and Richard Feynman. Scientists became icons of the culture, a few became household names, but the science that they actually did remained a mystery to the public. What is known though, is that famous scientists became symbols of achievement to their contemporaries, as well as to the generations that followed them. They have been presented not only as scientists but as special human beings whose stories challenge and inspire us.

As scientists became characters in plays of the 20th century, the audience may have been deceived into thinking that they were learning science from the play. In actuality, most of these plays say little about science itself.

2.1 Galileo

2.1.1 Galileo as a Scientist

Galileo Galilei (1564-1642) is probably the scientist most responsible for bringing the heliocentric view of the solar system to general acceptance. An Italian scientist also known for a variety of inventions that aided research of the natural world, he was a pioneer of the scientific method, which involves a hypothesis and then conducting strict and thorough experimentation to test the likelihood of that idea. His research covered the fields of Mechanics, Astronomy, Optics, Thermometry, and Magnetism. His work in mechanics dealt with the "natural descent of bodies along planes of various inclinations, the formulation of the law which established the relationship between space traversed and time interval in free-fall, the isochronism of the oscillations of pendulums of equal lengths and, of particular importance, the motion of projectiles" (Barattin and Berni). In Optics, he adapted the telescope from Dutch artisans and improved its functionality to view distant objects. He also developed the microscope to view smaller objects. In thermometry, the study of the measurement of heat, he developed the idea for the thermoscope. "This device was used to carry out experiments on the relationship between changes of temperature and variations of the level of the liquid" (Barattin and Berni). In Magnetism, he attempted to increase the strength of loadstones.

Galileo is most widely recognized for his contributions to Astronomy. The telescope he developed allowed him to observe the satellites of Jupiter and Saturn as well as the phases of Venus and sunspots. His observations of the periods and frequencies of appearance of Jupiter's satellites helped him develop a method for determining longitudes at sea (Barattin and Berni). But perhaps his most important, though controversial, contribution to Astronomy was his ardent support of Copernicus' heliocentric cosmography, over a half-century after the posthumous publication of De Revolutionibus (1543). In 1597, Galileo openly expressed his Copernican views for the first time. Jacopo Mazzoni, an old friend, wanted "Galileo's opinion about his new book in which he compared Aristotle and Plato" (Reston 53). Galileo praised the book for its ideas on Greek philosophy but criticized its discrediting of the Copernican theory. Galileo argued that the Copernican theory was more reasonable than the widely accepted assumption of Plato and Aristotle that the Earth was the fixed center of the universe.

Months later, while he continued to hold fast to heliocentrism, Galileo received another book, this one written by a teacher from Graz in Northern Europe: Johannes Kepler's Mysterium Cosmographicum. The book was a mixture of science and mysticism. Kepler claimed that based on his intuitive reasoning, the sun, not the earth, was the center of the universe. Kepler also proposed an arrangement of the celestial system and explained it with the sacred number five: five perfect solids separated by five intervals revolving around the sun. It seemed as if he perceived a connection between the motion of the planets and the gospel of Matthew "which likened the kingdom of heaven to ten virgins, five who were wise, five who were foolish" (Reston 54). Galileo, drawn to anyone who supported the Copernican theory, enthusiastically endorsed Kepler. Kepler encouraged him to publish his works, and suggested that if he could not do so in Catholic Italy, to publish in Protestant Germany. But Galileo did not proceed, as he felt there was little to gain and much to lose by doing so.

Galileo developed the telescope in 1609 when he was 46. He observed our Moon and its mountainous surface, the moons of Jupiter, the phases of Venus and the rings of Saturn (Fowler). He later built a lens that could magnify the sky by a factor of twenty and observed the surface of the moon. He found that the moon, like the surface of the earth, was marked with chains of mountains and valleys (Sobel 31). These discoveries were contrary to the accepted belief that the moon was like a shiny polished mirror. However, "to conceive of the moon not as a polished mirror but as a dry, dirty stone without water or atmosphere would be a shock to all humankind but a sacrilege to the Church" (Reston 93).

Galileo's gaze wandered from the moon to the stars. He noted two different types of stars, those that are fixed and those that move across the sky. These "wandering stars" were the planets Mercury, Venus, Mars, Jupiter and Saturn. Galileo was the first to distinguish these planets further as perfectly round globes and definitely bounded like little moons (Reston 32). He described his discoveries and observations in the Sidereus Nuncius or the Starry Messenger. One night in January of 1610, Galileo observed that Jupiter had three very bright stars near it. The next night, he saw that these bright objects had moved with one eclipsed by the planet. He continued to monitor the movement of these bodies and finally concluded that the three starlets orbited Jupiter much as Venus and Mercury orbited the sun. Thus, "the rotation of the satellites around their mother planet represented the Copernican theory in microcosm" (Reston 98).

Galileo also made observations of Venus. For many months he watched the planet as it waxed and waned. This discovery was more important than the finding of Jupiter's satellites since it proved that Venus was orbiting the Sun and not the earth, as was believed by Aristotle and Ptolemy. This was yet another piece of evidence to support Copernicus' theory.

Galileo also observed the sun and found, to his amazement, that the sun had blemishes, dark spots that seemed to wander the sun much like terrestrial clouds. He determined in 1612 that these dark spots were definitely a manifestation of the sun's atmosphere and were confined only to its tropics. As a result of his Letters on the Sunspots, "Galileo was proclaimed the first discoverer of sunspots" (Reston 130). He was incorrect, however, to have described the spots as atmospheric clouds. Sunspots have now been determined to be caused by varying magnetic fields in the sun. Regardless, to put forth such a theory, that the sun was not clear but spotted, was another rejection of what people had believed for so long. Galileo was challenging the long-accepted Aristotelian theory that the celestial bodies were divine and faultless. "To the closed minded, Galileo was putting forth nothing short of blasphemous witchcraft: upon the divine sun there were massive back blemishes that appeared and dissolved randomly?" (Reston 118)

Galileo's telescope caused a stir among the common folk and the nobility. Many of the latter were pleading for stars to be named after them. Galileo enjoyed this aristocratic courtship and distributed his best telescopes to his best patrons. He recognized that the telescope could have practical uses throughout Europe. He reserved the royal treatment for the Grand Duke Cosimo II of Tuscany whom he would personally show how to manipulate the telescope. Galileo traveled to Pisa to meet Cosimo II. He showed him the stars in the sky through his telescope. At that time, Cosimo II's secretary of state, Belasario Vinta, negotiated a business deal with Galileo, who happily accepted a better salary to devote himself to his work. He was relieved of lecture responsibilities and other public duties and was appointed Mathematician and Philosopher to the Grand Duke of Tuscany. By accepting this position, Galileo upset his friends back in Venice who had worked hard to secure him a place at Padua University (Reston 101-104).

It was at this time that Galileo began openly declaring his evidence affirming heliocentrism. In 1616, the Copernican theory was condemned because it seemed to contradict the Bible. Pope Paul V conveyed this message to Galileo. Galileo was no longer to hold or defend the theory that the earth moved and the sun did not (Fowler). He felt fortunate when, in 1623, Cardinal Maffeo Barberini ascended the Papacy as Urban VIII. Barberini had a keen interest in the arts and science and Galileo welcomed him, feeling that now he could practice his science without hindrance. However, the next decade brought him many enemies, especially among the Jesuits and Dominicans.

When he voiced his heliocentric opinions, Church officials denounced him and told him not to defend the Copernican theory. He and Church scientists quarreled in print on the nature and origin of sunspots and comets. But still, Galileo received permission to continue working on heliocentrism so long as he discussed it on a theoretical basis only. When Galileo published his Dialogue of Two Chief World Systems in 1630 in vernacular Italian, rather than scholarly Latin, he went too far and his ecclesiastical enemies pounced. In the book, he presented both the theories of terracentrism (which was widely accepted at the time) and heliocentrism, but though the arguments advanced in favor of the latter are consistent and compelling, the arguments for an earth-centered universe are made to seem silly (and are presented by a character called Simplicio). In fact, Simplicio offers some of the arguments Galileo had heard from Cardinal Barberini before he became Pope Urban VIII. In 1633 the Inquisition summoned Galileo to Rome, forced him to formally abjure the heliocentric view, and promise never to write in its favor again.

The Church was opposed to Galileo's support of heliocentrism but not only on scientific grounds. According to James Brodrick, the Jesuits in Rome had already been convinced that "Aristotle's views on the unchangeability of the heavens . . . were no longer tenable. The skies were far more complicated than they . . . had suspected but they were not yet ready to go the whole way with Galileo and Copernicus" (64). The Church's opposition had to do as much with theology as science.

In 1615, Galileo had written a letter to the Grand Duchess Christina, mother of Cosimo II, on the merits of heliocentrism to science, including arguments based on theology. The letter was made public almost twenty years later. Though he did his best to reconcile the new scientific views with the Bible, the very fact that Galileo presumed to discuss scriptural texts outraged the clerics. According to Pietro Redondi, the Jesuits had already been plotting to undermine Galileo, not because of his astronomy but because of what they considered his heretical views of the doctrine of Transubstantiation, i.e., the Eucharist (203-26).

In 1633, Galileo was placed under house arrest for the remainder of his life but was allowed to continue working. In 1638, at the age of 74, he published Two New Sciences, a landmark of modern physics. By that time, he had lost most of his vision. He died in 1642.

2.1.2 Galileo as Character in Brecht's Play

Bertolt Brecht's play Galileo begins with Galileo looking for money as a way to fund his astronomy research. Galileo explains to his young assistant and protégé, Andrea Sarti, his discoveries about the universe. He tells the boy that the sun is stationary and that the planets revolve around it. Andrea's mother, obviously annoyed with Galileo for corrupting her son's mind, sternly tells him "not to wheedle free lessons out of Mr. Galilei" (50). Galileo warns Andrea not to talk about their ideas since certain authorities will not like it. Andrea asks, "Why not, if it's the truth?" Galileo responds, "Because we are like the worms who are little and have dim eyes and can hardly see the stars at all, and the new astronomy is a frame work of guesses or very little more-yet" (50). The lack of astronomical evidence prior to Galileo's telescope has caused people to believe only what they could see.

Galileo meets Ludovico Mariseli who wants to become his student and learn science. Ludovico tells Galileo of an interesting tube he has seen with lenses at both ends. The tube magnifies objects five times. Galileo quickly jots down the details that Ludovico has given him and yells to Andrea to buy him two lenses. In the meantime, Curator Priuli comes to tell him Galileo he will not be funded for his research. If Galileo desperately needs money, he will have to go to Florence and request support from the Medicis. However, if he does that, he will be "forbidden to think- in the name of the Inquisition" (53). Priuli urges Galileo to invent something that will be useful for the Venetian Republic. Having conveyed his message, Priuli leaves. Andrea brings Galileo the two lenses and Galileo assembles them and shows Andrea the world magnified.

Galileo presents his new optical tube to the Venetian Senate. Priuli immediately remarks on the military applications of such a device. He also mentions to his friend Sagredo that he has observed the moon and that the moon does not emit its own light. He shows Sagredo the lunar mountains and explains to him how the peaks glisten in the approaching sunlight. Sagredo says, "This gives the lie to all the astronomy that's been taught for the last two thousand years" (59). Priuli comes in then and tells Galileo that his "miraculous optical tube" was already invented in the North and was even then being peddled on the streets. Disillusioned by Galileo's perfidy, he says, symbolically, that Galileo had destroyed his faith in everything. Priuli storms out and Galileo continues to explain the night sky to Sagredo. As he talks about Jupiter and its moons, Sagredo asks him where God features in his scheme of heaven. Galileo replies that God does not feature anywhere and that he believes in the human being. Sagredo reminds Galileo that there are severe penalties for thinking in such a manner. As they continue to look at the night sky, Galileo mentions that he wants to name a star after the Prince of Florence. Sagredo warns Galileo not to go to Florence, that the "monks are in power there" and that Galileo is "traveling the road to disaster" (64-65).

Galileo does not heed Sagredo's advice. He appeals to the Medicis and is given a court position. However, he is mocked for the theories formed through observations from his telescope. He is called an "enemy of mankind" (73). Galileo meets Cardinals Barberini and Bellarmin at a masquerade. The clerics are disguised; Galileo is not. Barbarini talks to him warmly. Barberini tells Bellarmin that he has glanced at some astronomy papers and that "it is harder to get rid of than an itch" (77). Bellarmin, however, is opposed to Galileo's theories of astronomy and says, "we only have to scotch doctrines that contradict Holy Writ" (77). While Bellarmin denounces Galileo's interfering with the Holy Scriptures, Barberini tries to console him and warn him of the consequences of publicizing his beliefs.

That evening, a young monk who supported Galileo's science came to Galileo telling him that he has decided to give up astronomy. The little monk talks about his parents, simple God-fearing people: "They draw the strength...from the little Church and from the Bible texts they hear every Sunday" (83). The little monk asks Galileo a valid question: for these kinds of people who believe that the universe revolves around them and who have all their faith vested in the Holy Scriptures, how would they deal with being told "that they are a lump of stone ceaselessly spinning through empty space around a second-rate star" (83). The little monk fears that such scientific truths would shatter their faith in the Holy Scriptures and that they would feel cheated.

News comes to Galileo that the Holy Father in Rome is on his deathbed. His successor will be Barberini. Galileo is pleased; he no longer has to keep his science to himself since a scientist is going ascend the "chair of Peter" (92). However, he finds it difficult still to convince people of the Copernican cosmography despite the evidence he has obtained through his telescope. First, the general public does not understand Latin. With none of these findings written in the vernacular, there seems to be no way for the public to grasp Galileo's observations and proofs. Second, Galileo's proofs contradict the beliefs that the public have held for the past two thousand years. Galileo's support of such concepts would shake the foundations of the faith in which they had so strongly believed.

In the meantime, Cardinal Barberini, now Pope Urban VIII, argues with the Cardinal Inquisitor regarding Galileo. The Inquisitor tells the Pope that Galileo should be stopped from spreading his science, that he should be arrested. The Pope argues that the "man is the greatest physicist of our time" (109). However, in the end, Pope Urban yields to the Inquisitor's request to arrest Galileo under the condition that he is not tortured, though "he may be shown the instruments" (110). The Inquisitor is satisfied—Signor Galileo is fully capable of understanding how those instruments function.

Galileo is thus arrested and the day comes (22 June 1633) when he is forced to recant his ideas. His pupils ardently believe that he will refuse, that "beaten humanity can lift its head. A man has stood up and said No" (114). The tolling of the bell of Saint Mark's will be the sign that Galileo has recanted. To their disappointment, they hear the bell toll and the town crier reading Galileo's recantation in the face of the Inquisition. Galileo enters the room where his friends and pupils have been waiting. No one greets him or invites him in. Andrea, unable to stand in front of him, is escorted away. As he leaves, he says "Unhappy is the land that breeds no hero"; Galileo retorts, "Unhappy is the land that needs a hero" (115).

Galileo retires to a country house in Florence. He has lost his vision and hence his illegitimate daughter Virginia, a nun, takes care of him. Andrea comes to visit him after years of silence. The meeting seems awkward at first, but then Andrea learns that despite his recantation Galileo has finished his book on Two New Sciences (a book which has since been called the foundation of modern physics). Andrea then reverses his opinion and praises Galileo for recanting, since that decision allowed him another decade of scientific achievement. But Galileo will not accept Andrea's praise; he condemns his own cowardice saying that in 1633 he betrayed a principle more important than his subsequent work could justify.

Brecht had written an early version of Galileo in the early days of World War II. He wrote this play when the theme across Europe was resistance. "The play was about the problem of how to respond to political oppression" (Schapira). Galileo's recantations of his discoveries and his pursuit of those discoveries underground was a "model to encourage the intellectuals trapped in the Third Reich to work underground and fight Nazism" (Schapira). But later on, Brecht revised the play to lighten emphasis on the theme that was conveyed in the original version, that scientific research should take precedence over social responsibility. However, at a time when the Nazis were performing experiments on inmates in the concentration camps and when scientists were tapping into nuclear power, Brecht wanted to stress instead the social responsibilities of science. Hence, in the newer version of the play, he made Galileo recant his ideas out of cowardice despite the hope of his friends and students that he will defy the Church. The newer Galileo thus sells science out to the ruling class instead of establishing science's higher duty to humankind (Schapira). He had betrayed his proletarian instincts.

In his play, Brecht wrote about Galileo, not really about his science, though it sometimes seems difficult to separate the science from the man. Still, there is not a single scientific (or, for that matter, theological) concept developed in Brecht's play. The mathematics and physics of the terracentric and heliocentric arguments are never advanced. Instead, the issue of totalitarian control of thought is repeatedly stressed. Not the scientific impact of Galileo's work, but its social significance concerns Brecht. Though a major figure of the scientific revolution, the character called Galileo in Brecht's play finds himself confronting the need for a political and social revolution, and in that sphere of thought, Galileo, in his recantation, falls short. The audience, meanwhile, is deceived into thinking that they have just seen a play about science.

2.2 Inherit The Wind

2.2.1 The Monkey Trial

In July 1925, the citizens of the town of Dayton, Tennessee, assembled at the courthouse to witness the most publicized trial ever to deal with science education in public schools. The "Monkey Trial," as it was and still is called, was the trial of John Scopes, a high school science teacher. Scopes was arrested for teaching the Darwinian theory of evolution in his high school biology class. The issue here was "a state law banning the teaching of evolution and a Dayton teacher's knowing infringement of that law" (McCabe). The townspeople were predominantly fundamentalist Christians who believed in the literal interpretation of the Bible. They believed that all of creation took place within a week, and that God had created man in a single day; therefore Darwin's view, first published in Origin of Species (1859), that life evolved on earth over the course of millions of years, must be wrong. They supported the 1925 state law that banned the teaching of evolution in public schools (Chadwick 46).

According to Bruce Chadwick, the law was actually challenged by the American Civil Liberties Union (ACLU), which convinced Scopes to claim that he had taught evolution (he actually had not) so that ACLU could make a national test case out of a conflict between science and religion (46). The well known defender of unpopular causes, Clarence Darrow, took on the task of representing Scopes. The prosecution was led by three-time presidential nominee William Jennings Bryan. The clash between these two famous lawyers caused a media field day. "More than 100 reporters jammed courtroom, and WGN radio in

Chicago carried the trial live on its nationwide radio hookup, a first" (Chadwick 46). The trial made front page headlines throughout the country. Foremost among the reporters was H.L Menken of the Baltimore Sun.

The defense set out to achieve the following:

1. It would prove that science and religion occupy two different fields of learning.
2. It would prove that scientists claim that no branch of science can be taught without teaching evolution.
3. It did not intend to prove that humans came from monkeys.

(Hanson 73).

In the courtroom, both lawyers argued in the heat of the Southern summer day. The prosecution simply argued that the state's law banning the teaching of evolution in public schools was legally enacted by the Tennessee legislature. Since the legislature is given the right to make laws and to oversee public schools, the argument went, the law against teaching evolution is constitutional. If the defense had affirmed that Scopes had not taught evolution, the trial would have been over in a day. However, Darrow and the ACLU wanted a victory for academic freedom, on the issue of religion and science in public schools. The national media were mostly supportive of Scopes, while the townsfolk, the judge and jury were clearly pro-prosecution. Most of Darrow's objections were overruled. The judge refused to allow Darrow's scientific experts to take the stand, thus taking away his chance "to let the jury hear the other side of the evolution story" (Chadwick 48). Then, a counter-strategy occurred to Darrow.

Since he could not call experts in science to the stand, he decided to undermine his opposing counsel and call Bryan as an expert on the Bible. To be consistent, the judge should have ruled out biblical experts on the same grounds that he had banned scientific experts, but Bryan, confident in his ability to outwit Darrow, requested permission to testify.

Darrow focused on Bryan's religious beliefs and started asking specific questions about the Bible. He allowed Bryan's confidence to build and then sprung his trap. Darrow asked Bryan if he really believed that Joshua made the sun stand still and whether Bryan understood the effect that such an event would have brought to the planet. Bryan responded that he never looked into the matter. Next, he asked Bryan if Jonah could really have been swallowed by a whale and emerge unhurt. Bryan replied that if God willed it, it could be done. Darrow asked him that if the brothers Cain and Abel were the only children of Adam and Eve, where did Cain find a wife to have children. Bryan answered, "I'll leave the agnostics to hunt for her" (Chadwick 50). As Darrow continued asking probing questions, Bryan started to lose his temper. "The crowd began to grow silent as Darrow continued to pick apart the strict interpretation of the Bible, in the process getting Bryan to give ridiculous answers" (Chadwick 51). The angrier Bryan became, the more rigid his answers. Eventually, the crowd began to laugh at Bryan as Darrow undermined the strict literal interpretation of scripture.

The next day, to prevent Bryan from giving one of his characteristically eloquent speeches to the jury, Darrow changed Scopes' plea to guilty. There was no need for final arguments, and the jury had no choice but to find Scopes guilty. He was fined $100. "The courtroom battle between two famous lawyers...changed forever the roles of religion, science, and education in the United States" (Chadwick 53).

2.2.2 The Monkey Trial on Stage

The Scopes trial was captured not only in the newspapers and magazines at the time, but also in the drama Inherit the Wind, written thirty years after the event by Jerome Lawrence and Robert E. Lee in 1955. In their play, Bertram Cates is the character name for John Scopes, the young teacher imprisoned for teaching Darwin to his high school biology class. Matthew Harrison Brady (William Jennings Bryan), the three-time Democratic presidential candidate, is the prosecutor for the case. A champion of Cates, E. K. Hornbeck (H.L. Menken) of the Baltimore Herald, announces that Cates will have a defender courtesy of his paper: Henry Drummond (Clarence Darrow). Drummond is as unpopular in Tennessee as Brady is admired.

During the trial, Brady confidently argues the primacy of "the Revealed Word." As in the real trial, the judge supports Brady by excluding Drummond's scientific witnesses (who could presumably have brought some real science into the play) ruling that evolution was not on trial. Drummond then puts Brady on the witness stand, as a self-proclaimed and confident expert on Holy Scripture. However, as in the trial itself, Drummond allows Brady himself to undermine the literal acceptance of the Bible and his "understanding of himself as a self anointed prophet" (Inannone). The spectators wind up laughing at Brady.

Though technically losing the case (in fact, the verdict and the fine were thrown out upon appeal), Drummond triumphs along with freedom of thought. When Drummond changes Cates' plea to guilty, Brady tries to protest by beginning an important closing speech. Yet the judge, already embarrassed by the negative publicity, ends the trial.

In Lawrence and Lee's popular play (it was recently revived on Broadway), it's not evolution on trial, as the judge says constantly. The play is about the clash between two powerful personalities, Drummond and Brady. Bertram Cates is a minor character, whose principal interest is his romantic relationship with the daughter of the local minister. He does not seem to have strong feelings about Darwinism or academic freedom. It just happens that the conflict between the two attorneys touches on the roles of science and religion, with religion getting a lot more attention than science in the play. For fundamentalists like Brady and the townspeople, everything in the Bible was accepted literally as it is stated. To refute it or interpret it as merely metaphoric was unthinkable. By accepting what is written literally, Brady chooses not to think independently and presents himself as a closed-minded fanatic. Drummond, on the other hand, represents free thought and respect for individual rights. The fundamentalist view condemns Cates' natural inquiries as blasphemous whereas the intellectuals celebrate any questioning which might lead to an increase in human knowledge.

In this play, Bertram Cates rebels against a fundamentalist law banning the teaching of evolution, but he is hardly presented as a rebellious type. For the audience in the theater, he is a sincere, mild mannered, respectful young man, the kind of suitor we would all wish for our daughter. Inherit the Wind is thus an easy play, one that ignores all the complexities of Darwinian evolutionary theory; one that makes us think we saw a play about science, but which never really does engage a scientific issue; one that promotes exactly the kind of reflexive non-thinking that its hero supposedly denounces.

2.3 QED

2.3.1 Feynman as an Individualist

It may be unreasonable to expect that a play like Inherit the Wind would deal in any substantive way with Darwinian evolution, but when Peter Parnell's play about the life and work of the noted American physicist Richard Feynman opened, audiences might well have anticipated some level of scientific sophistication. It was titled, after all, QED, for quantum electrodynamics, one of the seminal discoveries of twentieth century physics.

If biochemistry can be considered the hot field of the second half of the century, physics reigned supreme in the first half. Names like Einstein, Bohr, Heisenberg, and Oppenheimer, if not household words, were at least familiar to most educated individuals. Their conceptual work in Special Relativity and Quantum Dynamics, developed in 1915 and 1925, took on practical application during World War II with the development of atomic weapons, thus ending the war; but these developments ushered in a period of universal fear of nuclear annihilation which continues to this day.

While still in his mid-twenties, Feynman was recruited to work under J. Robert Oppenheimer on the Manhattan Project at Los Alamos. Heading a team in the theoretical division of the atomic bomb development project, Feynman worked to estimate how much uranium is needed to achieve a critical mass—"the mass of a radioactive material needed to achieve a self-sustaining fission process" ("Critical"). His area of specialization was quantum electrodynamics, "a generalization of quantum mechanics to include special relativity" (Weisstein). The idea is that charged particles (electrons and positrons) interact with each other through the emission and absorption of photons (as mentioned earlier, particles of light). These interactions cause the particles to change their speed and direction of travel when they release or absorb the energy of a photon. "The interaction of two charged particles occurs in a series of processes of increasing complexity...The processes correspond to all the possible ways in which the particles can interact by the exchange of virtual photons, and each of them can be represented graphically by means of the diagrams developed by Feynman" (Schombert).

He also devised procedures to protect the staff from radiation poisoning while working with the uranium. But just as his work at Los Alamos was coming to an end, in July 1945, his young wife Arline, died after a long bout with tuberculosis.

After the war, Feynman became well known as a teacher/researcher, first at Cornell and then at the California Institute of Technology, working in the esoteric area of sub-atomic particles. In 1965, he shared a Nobel Prize with two other physicists, each working independently on quantum electrodynamics. After decades of productive work at CalTech, Feynman contracted cancer of the bone marrow. Though seriously ill, he accepted a position on the Presidential Commission assigned to investigate the cause of the explosion of the Challenger Space Shuttle in January, 1986. Working with characteristic fierce independence and determination, Feynman often offended the Commission chair, former

Secretary of State William J. Rogers. But he defied the NASA bureaucracy and closely questioned the scientists and engineers who came to testify. As attention began to center on the o-rings which were used to seal the solid rocket boosters, Feynman showed how simple the issue really was. At one now-famous session, on live television, he took a piece of the o-ring, compressed it with a simple C-clamp he had just purchased at a local hardware store, dipped the compressed seal into a glass of ice water, lifted it out and showed everyone what had caused the Space Shuttle disaster: "I took this stuff that I got out of your seal and I put it in ice water, and I discovered that when you put some pressure on it for a while and then undo it it doesn't stretch back. It stays the same dimension. In other words, for a few seconds at least and more seconds than that, there is no resilience in this particular material when it is at a temperature of 32 degrees. I believe that has some significance for our problem" (Gleick 423).

The Presidential Commission Report was issued in June 1986. Faced with the threat of a minority report, Chairman Rogers allowed Feynman to write his own appendix containing his "personal observations" on the case, and this addendum has come to be regarded as the most interesting and revelatory part of the entire report. Within two years after his work on the Challenger investigation, in February, 1988, Feynman died.

2.3.2 Feynman as a Character

Peter Parnell's QED tries to capture the personality of this idiosyncratic and captivating personality. As in the other plays we have discussed, the science plays a minor role in the story, even though science was the major feature of Feynman's life and work. We find Feynman in his CalTech office reflecting on his life. But instead of hearing about quantum mechanics, we are told about Feynman's fondness for theater, specifically his role as a tribal chief in the campus production of South Pacific. It seems that Parnell wants to assure his theater audience that the subject of the play will be close to their own interests, that they need not worry that the play will delve deeply into sub-atomic physics, a subject they know little about (Hammerstein more than Einstein).

Although there is one other character, an enthusiastic and bright student, the play is largely a monologue. Feynman is interrupted several times by telephone calls, allowing Parnell to segue into new areas of Feynman's life. One call is from a colleague informing him that their Russian friends are arriving that day. Feynman was enchanted by Tannu Tuva, a tiny country wedged between Russia and Mongolia. The country has been swallowed into the USSR, yet Feynman developed a fascination with the place and its capital city, Kyzyl. He and his friend Ralph Leighton have arranged for an exhibition of Tuvan archeological artifacts, hence the Russians are coming. (In fact, Feynman and Leighton had been petitioning the Soviets for a visa to allow them to visit Tunnu Tava for years; the visa finally arrived, a few months after Feynman's death.)

After theater and archeology, Parnell finally gives us a taste of physics. Feynman explains that light does not travel in straight lines (any more than the story line of the play does). He briefly describes the behavior of atoms, the subject of his life's work. But just as he gets into some complex issues, another phone call interrupts him, his doctor. Feynman tells us about his cancer, his macro-globulinemia, a rare and deadly blood disease.

Feynman reminisces about his job at Los Alamos. He describes how he became proficient in picking locks on the gates of the compound, just to show that the place was not as secure as the army thought. "What I love about locks is, it's a puzzle-one guy tries to make something to keep another guy out. There must be a way to beat it" (Parnell 18). He quickly jumps to his role in the Challenger mission investigation and the famous televised demonstration of how cold affects seals.

If there is a common theme to his rambling stories, it is his fondness for studying and solving puzzles, especially nature's secrets. Feynman says that trying to understand Nature is like "watching a chess game without knowing the rules" (22). Your opponent behaves in most unexpected ways. "Sometime when you're trying to trick Nature into telling you her secrets, she ends up surprising you...and that is most interesting of all!" (24). He explains again the mysteries of light. The photons of light behave like particles, but they also behave like waves, as can be illustrated by light's reflection and transmission through glass. While 96% of the photons pass through glass, thus transmitting light, 4% reflect back, thus giving a reflection. Feynman asks, how does the photon decide which way to go? "Nature permits us to calculate only probabilities..." (23). He finally understood why the photons moved as they did. Each photon was taking every single possible path to get to the eye of the beholder. What we see is the average path taken. Later, Feynman tells us of drawing crude diagrams of these paths for himself, but others started using his diagrams and the science journals had to "print these silly pictures" (36).

When Feynman talks about physics, it seems that Parnell turns over an egg timer. Three minutes of physics, then back to anecdotes about his life, including the story of his first wife and her early death (which is also told in the 1996 film Infinity, which starred Matthew Broderick as Feynman). Though dedicated to the work on the atom bomb project, he would sneak away to Albuquerque to visit her in the sanitarium, where he saw her die. However, he tells us, he did not fully react to her death until months later, when he was walking outside a department store in Oak Ridge, Tennessee, where he was working at the nuclear research center. He saw a dress in the window and immediately thought that Arline would love it. It was only then that he realized that she was dead. Parnell ends this sad story on a lighter note, with Feynman telling us that after her death, he wrote her a letter with the postscript, "Forgive me for not mailing this, but I don't know your new address" (24). He does not tell us about Feynman's two subsequent marriages.

Feynman believed in simplicity. If he could not explain his concepts in everyday words, he probably did not understand them. As Alan Alda put it in the introduction to his play, "he knew more than most of us will ever know, and yet he insisted on speaking our language" (iv). In QED, Feynman speaks in our language. He explains quantum electrodynamics so that even those unacquainted with science can understand it, but not in much detail. Parnell uses Feynman's characteristic fondness for simple language as if to justify his play's avoidance of any of the complex and theoretical issues of sub-atomic particles. Most of all, his Feynman is the scientist portrayed as individualist, full of quirky interests, the kind of man we would love to meet at a cocktail party: a mathematician, a renowned physicist, but also "a revered teacher, a bongo player, an artist, a hilarious raconteur, a safecracker" (iv). Playgoers will likely remember the part about his wife, the part about his reaction to the explosion of the first A-bomb, the part about that funny little place between Russia and Mongolia, the part about his role in South Pacific, his courage when the doctor calls with bad news, his understanding in talking to the pesty student. Even though the title proclaims the subject to be twentieth-century physics, QED is another play about a man who happens to be a scientist rather than a play about science itself.

CHAPTER 3

SCIENCE AND THE STAGE: AN INTEGRATION

The plays that we have seen up to now have not presented the audience with scientific concepts. Rather, they have glorified scientists and in the process presented a few key words relating to these scientists, thereby deceiving the audience into thinking they are experiencing a scientific insight. Michael Frayn's Copenhagen, however, is an exception. Frayn ingeniously interweaves the physics of fission with the events of the play in such a manner that even the most unscientific mind can understand and appreciate the story of the play, while the scientifically-sophisticated mind understands and appreciates its essence.

3.1 Bohr and Heisenberg as Stage Characters

Michael Frayn's play Copenhagen begins in 1941 during World War II. The Nazi regime have recruited German scientists to work on a project to develop a weapon whose power is derived from nuclear fission. Werner Heisenberg is leading a team of German scientists to work on the project aimed at building a Cyclotron (a neutron generator).

At the time, his old mentor, Niels Bohr, resided in Nazi-occupied Denmark with his wife Margarethe. On September 9, 1941, Heisenberg came to Denmark supposedly to attend a conference. He also came for a secret rendezvous with Bohr to discuss certain matters that might have been viewed as treasonous had anyone reported him. Heisenberg and Bohr were in opposite camps as a result of the war. The meeting itself is a matter of historical record, but what exactly was discussed? The subject matter of their extended conversation has been a matter of debate as each scientist subsequently gave varying accounts of the discussion. In fact, both Bohr and Heisenberg years later drafted letters to each other regarding what they "clearly" remembered about the night they met in Copenhagen in 1941.

It is at this point that Michael Frayn allows his imagination to fill in what the principles could not agree on. The central event is, of course, the rendezvous. Frayn makes the subject matter nuclear fission and the atom bomb. They discuss whether experiments should be conducted on extracting energy from the atom and considering the time period, whether it is ethical to create such a weapon. Frayn's objective is to make the audience question each character's motivation.

The audience wonders what exactly Heisenberg was up to when he questions the ethics of building an atomic bomb. Is he at the time involved in a bomb project for the Nazis? Is he trying to find out how far the Allies have come in creating the bomb? Or is he eliciting Bohr's agreement that neither side should proceed on such a project? As created characters, they are ghosts, no longer bound by a regime's rules or prying eyes; they are free to discuss that which was then a treasonous matter. Bohr asks Heisenberg to revisit the day that Heisenberg came to Denmark to meet Bohr.

The first time the ghosts relive the day, they try to enact the events as they had lived them several years earlier. Heisenberg comes to the Bohrs' house in

Denmark and pulls on the calling bell. Bohr opens the door and welcomes his long time friend and colleague. After acknowledging the awkwardness of their being on opposite sides of the war, the two men, along with Bohr's wife, Margarethe, recount stories from their pre-war pasts. When evening comes, Heisenberg suggests that he and Bohr take a walk, just as they had done years before. As Heisenberg remembers it, they take a walk through Faelled Park, as they always had. When they set off on their stroll, Margarethe speaks of the time when Bohr and Heisenberg were as close as father and son. She expected them to stroll for hours talking about physics, but to her surprise they return in ten minutes. Bohr is very angry and informs her that Heisenberg is leaving immediately. The question looms: what exactly did Bohr and Heisenberg discuss that night?

Both Bohr and Heisenberg recount their conversation that night. They begin by reviewing with Margarethe the basis of nuclear fission. When a uranium atom is bombarded with neutrons, it splits and releases energy. This energy is enough, as Bohr says, to move a speck of dust. But in the process of splitting, two or three neutrons are also released, which in turn can cause more splits and more released energy. Thus, a chain reaction is initiated and a vast amount of energy is released, sufficient to move enough specks of dust "to constitute a city and all who live in it" (Frayn 33).

Fortunately, there is a way for this reaction to stop. Uranium consists of two isotopes, U-235 and U-238. Compared to U-238, U-235 is rare, and it is the isotope that exhibits fission when bombarded by fast-moving neutrons. U-238 is nearly impossible to fission, as it tends to absorb neutrons until there are no neutrons left to absorb. U-235 also absorbs neutrons, but only when they are slow moving. In this case, the chain reaction occurs slowly until the uranium nucleus explodes and the reaction is stopped. Thus, to make an explosion, pure U-235 would have to be separated out of natural uranium, which is quite difficult. To isolate just one gram would take nearly 26,000 years.

Margarethe understands this process; they need not explain fission to her. What Margarethe, the scientists, and the historians all want to know and indeed, what the audience wants to know is, what it was that Bohr and Heisenberg discussed during their walk that evening. The ghost Heisenberg says, "I simply asked you if as a physicist one had the moral right to work on the practical exploitation of atomic energy" (36). Bohr immediately jumps to the conclusion that Heisenberg is working on an atomic bomb for Hitler. But Heisenberg now claims that it was not atomic power that he was working on at all, but rather a cyclotron, a reactor to produce power to generate electricity to fuel steamships. In the cyclotron, U-238 is bombarded with fast-moving neutrons until it is transformed to a completely different element: neptunium. Neptunium decays to form another element just as fissile as U-235: plutonium. Plutonium, like uranium, can be split by neutron bombardment. An advantage with plutonium is that fast-moving neutrons as well as slow-moving neutrons can split it. The split, in turn, releases neutrons, which can split more plutonium nuclei, thus initiating a chain reaction ("Physical"). Thus, by building a reactor, the Germans could very well build bombs. This, Bohr fears, is what brought Heisenberg to Copenhagen.

Bohr and Heisenberg decide to revisit the night of their walk so that they can explain to themselves and Margarethe the reason for Heisenberg's visit. They walk again with Heisenberg trying to discuss the problems of developing a reactor. Heisenberg tells Bohr that the development of nuclear weapons would require a great technical effort, so much so that governments will question scientists as to whether weapons can be produced in time for them to be used. Governments (on both sides) will ultimately come to Bohr and Heisenberg to ask their opinion. For this reason Heisenberg has come to visit Bohr. Heisenberg wants to know if an Allied bomb program is underway. If they could collaborate, both scientists might prevent either side from developing an atomic bomb.

However, Bohr does not believe that this was Heisenberg's motive for coming to Copenhagen. He says "So, Heisenberg, why did you come to Copenhagen in 1941? It was right that you told us about all the fears you had. But you didn't really think I'd tell you whether the Americans were working on a bomb" (53). Bohr suggests that they recount the events of that night one more time. So once again Heisenberg recalls walking to the Bohrs' front door and pulling on the calling bell. In the evening when they go for their stroll, we see a father/son, teacher/pupil relationship between the two men. They begin talking of the experiments done with U-235. Bohr asks Heisenberg how much uranium is needed to initiate the reaction. Heisenberg replies that 50 kilograms are needed but claims that he had told Otto Hahn, a renowned chemist of the time, that it required about a ton.

Bohr finally understands the reason for Heisenberg's visit: it was for guidance. Bohr asks Heisenberg if he has thoroughly investigated the amount of uranium needed to start a chain reaction and if he has done the calculations of the diffusion equation. Heisenberg replies that he has not done the calculations, as they are unnecessary. He assumed that no matter what the calculations showed, a greater amount of uranium would be needed to create the atom bomb, and thus, the calculations were not worth doing. Bohr is surprised that Heisenberg has made such an assumption. Heisenberg usually calculated everything. In the past, he performed the mathematics first to nearly every problem he encountered. Heisenberg says to Bohr, "You should have been there to slow me down" (85). Bohr admits if he had been there with Heisenberg, watching over him, as father to son or teacher to pupil, such a piece of information would not have been overlooked. Heisenberg then asks Bohr the same question: Why did Bohr not calculate the amount of uranium needed based on the diffusion equation? Margarethe replies on his behalf saying that Bohr was not intending to build a bomb. Heisenberg replies that he too was not trying to build a bomb and hence did not do the calculations. Bohr requests one final draft version of that evening in Copenhagen.

Hence, again Heisenberg walks to the Bohrs' front door and pulls on the bell. They go through the events of the day, and when evening comes, they take a stroll. Heisenberg presents Bohr with the question, "Does one as a physicist have the moral right to work on the practical exploitation of atomic energy?" (88). Bohr is infuriated upon hearing this question and begins to storm back home.

But then he stops and his spirit contemplates an assumption. Assume he did not walk away but stayed and asked Heisenberg why he is so confident that it will be difficult to build a bomb. What if he had asked Heisenberg at that time if he had performed the calculations of the diffusion equations and found the diffusion in U-235? Heisenberg would then see that the required amount of Uranium is not as much as he thought and that the bomb could have been created for the Nazis. Though Heisenberg demanded to be understood by Bohr that night, perhaps Bohr was right in leaving him misunderstood. The lives of many innocents had been spared. Heisenberg thanks Bohr for leaving him as he did in Copenhagen in 1941.

Bohr tells Heisenberg that, in addition to sparing the lives of several people, he also saved the Bohrs' lives. When the Nazis came to arrest the Jews in 1943 in Denmark, the Bohrs were able to escape along with other Jews to Sweden. A man in the German Embassy, a friend of Heisenberg, Georg Duckwitz, alerted them when the Gestapo was coming. With his help, the Bohrs, along with 8,000 other Jews, were able to cross the waters to neutral Sweden. Bohr traveled from Sweden to Los Alamos and took part in the Allied bomb project to play his "small but helpful part in the deaths of a hundred thousand people" (91).

Heisenberg, on the other hand, stayed in Germany. He returned to Copenhagen to make sure that the Nazis did not take over Bohr's Institute in his absence. In the end, he recounts his struggle to survive the spring of 1945. His family had taken refuge in a village in Bavaria. To see them, he had to travel by bicycle, the only form of transportation available. He traveled by night so that Allied planes that were scouring the land could not spot him. It took him three days to reach Bavaria. On the second night, he had a narrow escape from an Allied sentry. Unable to read his travel papers in the dimmed light, the sentry was about to shoot Heisenberg. In a desperate attempt to save his life, Heisenberg takes out the pack of American cigarettes from his pocket and offers it to the sentry. He describes it as "the most desperate solution to a problem yet" (91). The sentry allows Heisenberg to pass. Heisenberg rides through his ruined homeland to reunite with his family, saved not by his genius but by a pack of cigarettes.

3.2 The Science Behind and Within Copenhagen

Copenhagen is, obviously, set in a specific moment in history. The world's destiny is in a period of uncertainty. Would Hitler win the war or would the Allied forces stop him? Would scientists be complicit in the mass killing of thousands of innocent civilians through the development of the atomic bomb? Before the world wars, in 1905, Albert Einstein had developed his Special Theory of Relativity. As a part of this theory, he developed the equation $E=mc^2$, stating that a large amount of energy (E) can be released from a small amount of matter (m). The atomic bomb implemented this theory.

Einstein was a pacifist. He never intended for his equation to help build a bomb. However, when Hitler came to power, his position changed. Though he still promoted peace, he was not such a complete pacifist as to hope that Hitler could be resisted by non-violent means. In 1939, he wrote a letter to President

Roosevelt urging him to initiate a project to build an atomic bomb. When the uranium atom was split in 1938 in Germany, a group of physicists led by Leo Szilard and Eugene Wigner feared that Germany might already have a bomb project under way. Szilard and Wigner had no influence with any of the world powers, so they took their concerns to Einstein who did have the reputation needed to sway authority. With Einstein's consent, Szilard drafted a letter to President Roosevelt and signed Einstein's name to it. A month before Roosevelt received the letter, Germany invaded Poland. The time was ripe to begin the bomb project. Einstein foresaw the problems that such nuclear weapons would bring. In 1944, he wrote to Bohr: "when the war is over, then there will be in all countries a pursuit of secret war preparations with technological means which will inevitably lead to preventative wars and to destruction even more terrible than the present destruction of life" (Clark 575).

Einstein's letter is credited with the initiation of the Manhattan Project and the creation of the atomic bomb. Nicknamed the "Gadget" during its development and then "Little Boy," the atomic bomb was designed to instill fear in the Germans and then in the Japanese. The Manhattan Project involved some of the most distinguished scientists in Allied and neutral countries: J. Robert Oppenheimer, David Bohm, Leo Szilard, Eugene Wigner, Otto Frisch, Rudolf Peierls, Felix Bloch, Niels Bohr, Emilio Segre, James Franck, Enrico Fermi, Klaus Fuchs and Edward Teller.

The workings of the bomb are based on the theories of quantum mechanics, developed when scientists realized that the physics of Newton, relating to macroscopic objects, could not be applied to the microscopic environment of particles. Newtonian laws allow scientists to calculate positions and velocities for elements of any system at all future times based on the knowledge of their values at one instant. However, as scientists started analyzing the atom in the early 1920s, they realized that Newtonian laws could not be applied to particles in an atom. The laws predicted incorrect outcomes. For example, we know that atoms consist of negatively-charged electrons orbiting around a positively-charged nucleus. According to the laws of Newtonian physics, the electrons should spiral into the nucleus within a fraction of a second. Apparently, this does not happen. Thus, scientists needed another explanation at the point where Newtonian Mechanics failed. This is where quantum mechanics find its place. In quantum mechanics, we speak of mathematical constructs of wave particle dualities. Wave functions give us probabilities of various possible positions and velocities. "So profound is the change, that physicists used the word 'classical' to mean 'before Quantum Mechanics'"(Weinberg 66).

In the early 1920s, when quantum mechanics was in its beginning stages, quantum physicists found themselves in the same position as Newtonian physicists during the early studies of light. In the beginning of the study of optics, scientists understood that light behaved as a wave, especially when exhibiting phenomena like diffraction. They eventually learned that light as a wave caused varying electric and magnetic fields. When quantum mechanics was born, theorists began looking closer at the electron wave. They found that the electron oscillated, creating a wave of a particular frequency depending on its energy level. With this idea in mind, theorists were able to infer a few theories.

Heisenberg had taken a trip to Heligoland to spend some time in solitude and to reflect on the latest theories that have been developed (Weinberg 67). There, he pondered on the problem presented by Niels Bohr years earlier: why do electrons in an atom occupy certain orbits with certain definite energies? Heisenberg decided that he would deal only with the measurable quantities of energy the quantum states and the rate at which an atom may make a transition from one energy level to another by emitting a photon. By understanding how the energy of a particle depends on its position and velocity, Heisenberg was able to calculate the energy of a system in its various quantum states. This is quite similar to the manner in which a planet's energy is calculated based on classical mechanics from the knowledge of its position and velocity. It is perhaps from here that his famous Uncertainty Principle evolved (Weinberg 67).

Max Born had proposed a hypothesis as to what causes an electron wave. He proposed that an electron travels through space as a wave packet—a bundle of electron waves traveling together. When the electron is incident on an atom, the wavelets scatter in different directions. Thus, he concluded that electron waves are not waves of anything but rather tell us that the electron is at or near that location. Some scientists were not satisfied with Born's explanation. This is where Heisenberg introduces his Uncertainty Principle (Weinberg 72). The Uncertainty Principle stated that a particle's position and momentum could not be simultaneously known. The wavelength of light used to measure the particle's position (x) is equal to Planck's constant (h) divided by the photon momentum (p). Mathematically, this is represented by the equation:

$$h / 4\pi\Delta p \geq \Delta x \qquad (3.1)$$

As a result, the uncertainty in a particle's position cannot be greater than Planck's constant divided by the photon's momentum. The most common form of this equation is written as:

$$\Delta x^{*}\Delta p \geq h / 4\pi \qquad (3.2)$$

The variables are as follows:

Δx is the uncertainty of the position measurement

Δp is the uncertainty of the momentum measurement

h is a constant from quantum theory known as Planck's constant, a very tiny number to the magnitude of 10^-32.

π is pi from the geometry of circles.

Bohr's use of this Uncertainty Principle took on a slightly different interpretation. Understanding that the electron can be a particle or a wave, Bohr believed that only one manifestation could be measured. "Bohr's principle of complementarity asserts that there exist complementary properties of the same object of knowledge, one of which if known will exclude the other" (Pagels 94). In an experimental condition, if the position of a particle is what needs to be determined, the wave aspect, or the momentum component, does not exist in that experiment. In a similar manner, when the momentum is measured, the position component does not exist in that experiment. Fred Alan Wolf, theoretical physicist at University of California, offers an excellent example of Bohr's idea of wave particle duality. Consider a camera taking a picture of a speeding bullet. In order to pin point the exact location of the bullet, the camera's shutter speed must be increased. We can increase the speed of the shutter until we get a still picture of the bullet. With the precision in location, we lose the trajectory, the path in which the bullet is traveling. On the other hand, if we want to photograph the path of the bullet, we would have to slow the shutter speed. This will produce a blurred line showing the direction of the bullet. In such a photograph, the position of the bullet cannot be determined. In a similar manner, quantum characteristics cannot be observed simultaneously. Bohr described this relationship as "complementarity" (Wolf 64).

Complementarity can be explained further as follows. Classical mechanics involves an observer-dependent perspective for any situation. Einstein describes covariance, the independence of an action from an observer Bohr says that while quantum mechanics appears to be dependent on the observer's point of view, a higher degree of covariance needs to be considered. This higher degree of covariance is complementarity. While particles may be observed differently from different perspectives (therefore showing dependence on an observer), the basic structure of the periodic table of elements remains unaltered, independent of various calculations and observations (Weinberg 83).

Thus, quantum mechanics is subject to different interpretations. From the collated interpretations by Heisenberg, Bohr and various other scientists came the "Copenhagen Interpretation," which introduced a new age in quantum mechanics, one that led the way to the atomic bomb project.

3.3 20th Century Physics and Frayn's Copenhagen

These two theories (Heisenberg's Uncertainty Principle and Bohr's Complementarity), as well as the concept of fission, are entwined in the dialogue of Frayn's Copenhagen. When Bohr and Heisenberg meet for the first time in years, after they get through an awkward conversation about politics, they recount the stories of their shared past and their work as colleagues on the cutting edge of science. Bohr remembers the time they were in Bayrischzell. He, Heisenberg and physicist Carl von Weizsaecker had to ski down from their hut to get provisions. Bohr talks about Heisenberg's reckless skiing: "At the speed you were going you were up against the uncertainty relationship. If you knew where you were when you were down you didn't know how fast you'd got there. If you knew how fast you'd been going you didn't know you were down" (Frayn 24). Bohr applies Heisenberg's principle to his skiing. Later on, Heisenberg compares their situation to Bohr's complementarity: "Complementarity, once again. I'm your enemy; I'm also your friend. I'm a danger to mankind; I'm also your guest. I'm a particle; I'm also a wave. We have one set of obligations to the world in general, and we have other sets, never to be reconciled, to our fellow-countrymen, to our neighbours, to our friends, to our family, to our children." Throughout the play are similar references to physics, artfully integrated into the story being told.

As the play progresses, Bohr and Heisenberg discuss physics and its role in society. Bohr says to Heisenberg, "You know how strongly I believe that we don't do science for ourselves, that we do it so we can explain to others." Heisenberg continues, "in plain language" (38). Frayn does exactly this in his explanation of fission. Complex processes are clearly described, in plain language, as when Bohr and Heisenberg describe fission, the process of splitting the uranium nucleus and releasing energy. They talk about the initiation of such a chain reaction and the manner in which to "damp" or stop the reaction. Thus, they explain the basic workings of an atomic bomb in terms simple enough for the non-scientific mind to understand.

Heisenberg explains how his uncertainty theory dawned upon him. He tells us how he was walking through Faelled Park in Copenhagen one evening when he imagines what Bohr, who was in Norway at the time, would see. He would see Heisenberg under a street lamp and then he would seem to disappear in darkness, only to reappear at the next lamppost. Heisenberg realized that this is what we see in a cloud chamber – a gas-filled device in which the path of a particle can be detected. The path is "not a continuous track but a series of glimpses—a series of collisions between the passing electron and various atoms of water vapour.... what we see in the cloud chamber are not even the collisions themselves, but the water-droplets that condense around them...there is no track" (66). As they analyze Heisenberg's hypotheses, Bohr introduces the audience to complementarity. When an electron is deflected by a photon of light during observation, the photon also is deflected, thereby affecting what the observer sees. If we know what happens to the photon, we can work out what happens to the electron. To do this, we need to treat the photon of light not just as a particle but also as a wave. Bohr says, "They're either one thing or the other. They can't be both. We have to choose one way of seeing them or the other. But as soon as we do, we can't know everything about them" (69).

Frayn presents these scientists living out their science. One of the quantum mechanical concepts we see in the play, probably the one concept the audience is most familiar with, is Heisenberg's Uncertainty Principle. Uncertainty is woven into play. Throughout the play, we see the characters diving in and out of uncertainty. In the beginning, both Bohr and Margarethe wonder why Heisenberg is coming to visit. Margarethe thinks he is coming to discuss fission, but Bohr thinks that fission is a branch that Heisenberg does not research. When Heisenberg approaches the front door, he is uncertain of how he feels. Once he enters into the Bohr house, he, as well as the Bohrs, are uncertain what to say. The war, placing them on opposite sides, has caused a silent tension between them, making their limited conversation initially awkward. Heisenberg shows uncertainty when trying to discuss with Bohr the ethics of creating an atomic bomb. What exactly is he trying to ask Bohr? What exactly is his reason for coming to Copenhagen?

This feeling of uncertainty is transferred to the audience. At one moment, we feel as if we know exactly why Heisenberg came to see Bohr. In the first draft of the conversation, Heisenberg says that all he asked was "if, as a physicist, one had the moral right to work on the practical exploitation of atomic energy" (36). The audience feels that perhaps Heisenberg is working on creating an atomic bomb and has come to Bohr for technical help. But then, as they discuss the basics of extracting atomic energy and of the cyclotron, Heisenberg actually tries to find out if there is an Allied atomic bomb project. In fact, he believes that Bohr may be involved with it and wants him to discourage any government which seeks his view of the feasibility of atomic weapons. Why? So that the world could be spared the horror of mass destruction? Or so that the Germans alone could monopolize the military uses of atonic energy? The final draft of that evening suggests that Heisenberg simply wanted to voice his thoughts regarding Germany and regarding science to Bohr and to be understood. So, of the three potential motivations offered here, why exactly did Heisenberg come to Copenhagen in 1941? Frayn leaves audience in uncertainty, asking questions, just like Heisenberg, just like Bohr, questions for which there may never be definitive answers.

Using the voices of Bohr and Heisenberg, Frayn presents the intricate concepts of the Uncertainty Principle, Complementarity and fission, all in plain language. In addition to inviting the audience into the world of physics, Frayn gives us a glimpse of the scientists' lives. They lived in a time of uncertainty. With the war that involved most of the world and the Nazi regime in power in much of Europe, people had to wonder what each day would bring. Frayn asks a series of questions in his postscript. If Heisenberg had done the calculations, could the Germans have built the bomb? Thomas Powers, in his book, Heisenberg's War, which was a major influence on Frayn, says that the Germans had a fast start to building the bomb. They had scientists of the first rank, "a huge industrial base, [and] access to materials" (Powers 478). "Germany's failure to build an atomic bomb was not inevitable," he says. If Germany had put in "serious effort," a bomb might have been tested in 1943, well before German industry was destroyed by Allied bombing. There are many possible reasons as to why the scientific events of World War II unfolded as they did. That is also where uncertainty lies. "The effects of real enthusiasm and real determination are incalculable. In the realm of the just possible they are sometimes decisive" (127).

The air of uncertainty also looms around Heisenberg. From the play, we can see parallels between uncertainty and Heisenberg's life. Heisenberg wrote in 1946, "From the very beginning, German physicists had consciously striven to keep control of his project...and had used influence as their experts to direct the work into the channels which have been mapped in the foregoing report" (as quoted by Powers 482). Heisenberg, in his fullest account, tells us why German research never ventured beyond small scale work on an experimental reactor. However, there was much that Heisenberg did not say. His silence left many matters unexplained, which introduces "an element of irreducible uncertainty" (Powers 482). His silence again leaves us to wonder why Heisenberg came to see Bohr. Did he come to find out about an Allied Program? Did he come to consult Bohr on how to build a bomb? Why did he suggest that the building of the bomb would be difficult and too big a project? Why did Heisenberg talk of two tons of U-235? Heisenberg's silence leaves these questions unanswered.

Another point of uncertainty is in the meeting. Why did Heisenberg visit Bohr in the midst of such tensions? What did they discuss? It is believed that Heisenberg gave Bohr a drawing of an experimental heavy water reactor on which he was working. Why he did so is unclear (Cohen 57). The Copenhagen meeting survived longer than either scientist imagined. In 1947, Heisenberg and Bohr met again. When they tried to recount what had happened and what was spoken that fateful night in 1941, they could not agree on what had been said. In fact, in 1957, Bohr wrote and rewrote drafts of a letter (which was never sent) to Heisenberg recalling the 1941 meeting. They finally came to the conclusion that the past was best left undisturbed. Frayn decided otherwise, but captured this uncertainty through his several reenactments of the events of that evening.

Science has been an illusory topic for the stage. While many may think that science is not suitable for entertainment, Frayn proves the opposite with Copenhagen. Certainly, the audience learns about the process and science of fission through this play.

CHAPTER 4

CONCLUSION

Science emerges from curiosity. The human mind yearns to know answers, especially to the question, Why? As scientists, we work to find answers. We search for explanations to realities that are taken for granted and we expound on existing theories to unlock further secrets that the universe holds from us.

Science can be a powerful subject in the literary realm. The challenge for playwrights is to put the intricacies of the subject into, as Heisenberg says in Copenhagen, plain language. Frayn succeeds in this challenge in Copenhagen. He gives the audience an insight into history, into science lesson, and into the lives of two great physicists. In the other plays discussed in this study, science plays a lesser role, since it is the scientist who is under the microscope rather than the science. While we gain insight into the lives of the scientists, we hardly delve into their science. It is here that science becomes an illusion, deceiving the audience into thinking they are learning science.

Science and art have been regarded as opposites. Art has been viewed as the product of creativity and is not reliant upon reason. Science, on the other hand, is the rationality that explains theories that are based on facts: the two cultures. These are notions held by the public, artist, and scientist alike that keep the two disciplines separate. Few have bridged the gap in theatrical representation. Even then, these few have portrayed scientists in dramatic situations not necessarily directly related to their work as scientists. Of the playwrights studied, Frayn has best depicted the intertwining of science and art in a dramatic framework.

It is interesting to note that the root word for theater and theory comes from the Greek "thea" which means "a view." According to science, a theory is connected to observation and vision. In a similar manner, on stage we have a representation of that which we know from elsewhere. Science also uses the theatrical and visual as a part of seminars and demonstrations. "The amalgamation of scientific and artistic activities can thus be seen as an auspicious goal, linking two cultures that, in reality, are not so very far apart" (Frazzetto).

WORKS CITED

Brecht, Bertolt. Galileo. English Adaptation by Charles Laughton. New York: Grove Press, 1966.

Barattin, Luisa and Marco Berni. Galileo Galilei. Institute and Museum of the History of Science of Florence, Italy Website. 5 April 2003. http://galileo.imss.firenze.it/museo/b/egalilg.html

Barzun, Jaques. From Dawn to Decadence. New York: Harper Collins, 2000.

Bixby, William. The Universe of Galileo and Newton. New York: American Heritage, 1964.

Brodrick, James, S.J. Galileo: The Man, His Work, His Misfortunes. London: Catholic Book Club, 1964.

Chadwick, Bruce. Infamous Trials. Philadelphia: Chelsea House, 1997.

Clark, Ronald. Einstein: The Life and Times. New York: World Publishing, 1955.

Cohen, Daniel. The Manhattan Project. Brookfield, CT: Millbrook Press, 1998.

"Critical Mass." Concise Encyclopedia of the Sciences. Ed. John-David Yule. New York: Facts on File, 1978.

Descartes, Rene. Meditations on First Philosophy (1641). Translated by John Cottingham. New York: Cambridge University Press, 1986.

Dietrich, Jane, ed. "The Copenhagen Interpretation: Exploring Science on Stage." E&S Periodicals Website. The California Institute of Technology. 25 March 2003. http://pr.caltech.edu/periodicals/EandS/articles/Copenhagen.pdf

Feynman, Richard P. Surely You're Joking, Mr. Feynman. New York: Norton, 1985.

Fowler, Michael. "Life of Galileo." University of Virginia Physics Department Website. 8 April 2003. http://galileoandeinstein.physics.virginia.edu/lectures/gal_life.htm

Frayn, Michael. Copenhagen. Methuen Drama: London. 1998.

Frazzetto, Giovanni. "Science on the Stage." Embo Reports 3: 2002. www.nature.com/cgi-taf/DynaPage.taf?file=/embor/journal/ v3/n9/full/embor068.html

Gaukroger, Stephen. Descartes: An Intellectual Biography. Oxford: Clarendon Press, 1995.

Gleick, James. Genius: The Life and Science of Richard Feynman. New York: Pantheon Books, 1992.

Hanson, Freya Ottem. The Scopes Monkey Trial. Berkeley Heights, NJ: Enslow Publishers. 2000.

Inannone, Carol. "The Truth about Inherit the Wind." First Things, the Journal of Religion and Public Life. 70 (1997): 28-33. February 20, 2003. http://www.firstthings.com/ftissues/ft9702/iannone.html

Kuhn, Thomas. The Structure of Scientific Revolutions (1962). Chicago: University of Chicago, 1970.

Lawrence, Jerome and Robert E. Lee. Inherit the Wind. New York: Bantam, 1955.

Lear, Jonathan. Aristotle, The Desire to Understand. Cambridge: Cambridge University Press, 1988.

McCabe, Lindsey. "Inherit the Wind." American Studies Program. University of Virginia. April 1996. February 20, 2003 http://xroads.virginia.edu/~UG97/inherit/intro.html

Meissner, Rolf. The Little Book of Planet Earth. New York: Springer Verlag Inc., 2000.

Murphy, B. Kieth. “Rene Descartes.” Fort Valley State University, Department of English and Foreign Languages Website. 1997. http://www.eng.as.fvsu.edu/rene.htm

Pagels, Heinz. The Cosmic Code: Quantum Physics as the Language of Nature. New York: Simon and Schuster, 1982.

Paige-Stone, Lisa. "Galileo Vilifies Limits on Freedom." The Curtain Calls. ModeWeekly.com Website. 2000. February 20, 2003. http://www.modeweekly.com/2000/00.03.16/TheCurtainCalls_00.03.16.htm

Parkes, Henry Bamford. The Divine Order. New York: Alfred A. Knopf, 1968.

Parnell, Peter. QED: A Play. Introduction by Alan Alda. New York: Applause Theater & Cinema Books, 2000.

“Physical, Nuclear and Chemical Properties of Plutonium.” Institute for Energy and Environmental Research Website. 1997. March 23, 2003. http://www.ieer.org/fctsheet/pu-props.html

Powers, Thomas. Heisenberg's War. New York: Alfred A. Knopf, 1993.

Redondi, Pietro. Galileo Heretic. Trans. Raymond Rosenthal. Princeton: Princeton University Press, 1987.

Reston, James Jr. Galileo. New York: Harper Collins, 1994.

Schapira, Agustine. Review of The Life of Galileo. 7 April 2003. http://kdl.cs.umass.edu/people/schapira/blog/archives/000008.html

“Science.” Webster's New World Dictionary. 2nd College Edition. New York: Simon and Schuster, 1980.

Schombert, James. Quantum Electrodynamics. 31 January 2003. http://zebu.uoregon.edu/~js/glossary/quantum_electrodynamics.html

Sobel, Dava. Galileo's Daughter. New York: Walker, 1999.

Thompson, Stephen P. The Renaissance. San Diego: Greenhaven Press, 2000.

Thompson, Stephen P. The Renaissance. San Diego: Greenhaven Press, 2000.

Thompson, William Irwin. At the Edge of History. New York: Harper & Row, 1971.

Weinberg, Steven. Dreams of a Final Theory. New York: Pantheon Books, 1992.

Weisstein, Eric W. "Newton, Isaac." Wolfram Research Website. 31 January 2003. http://scienceworld.wolfram.com/biography/Newton.html

Weisstein, Eric W. "Quantum Electrodynamics." Wolfram Research Website. 31 January 2003. http://scienceworld.wolfram.com/physics/QuantumElectrodynamics.html

Wolf, Fred Alan. Parallel Universes. New York: Simon and Schuster, 1988.