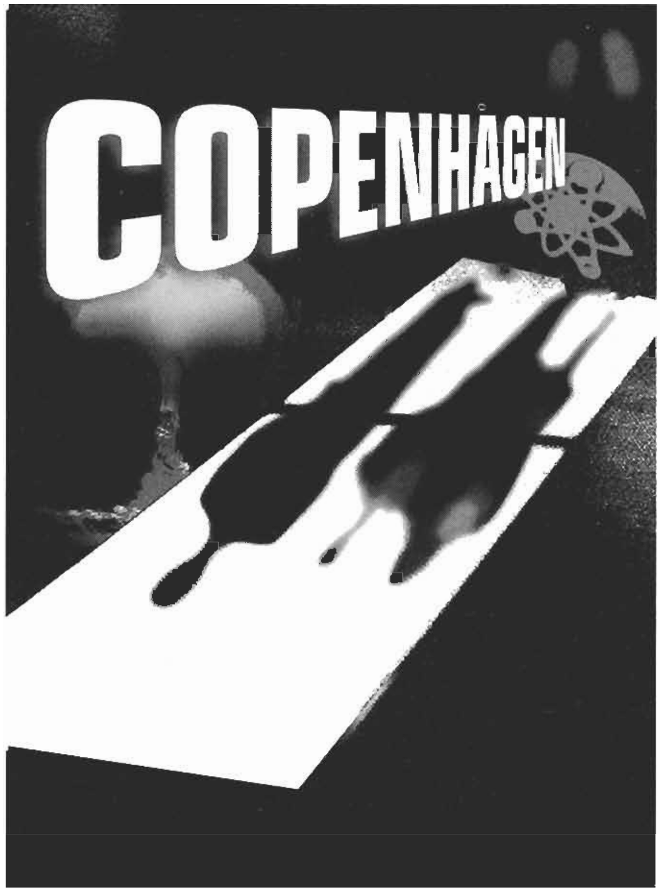
STUDY GUIDE

THE REPERTORY THEATRE OF ST. LOUIS



BY MICHAEL FRAYN

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MAJOR SPONSOR: MARY RANKEN JORDAN AND ETTIE A. JORDAN CHARITABLE FOUNDATION
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WHO'S WHO

NIELS BOHR (1885–1962)

Bohr's early work in physics was on the classical theory of metals. After failing to interest J.J. Thomson in Cambridge in it, he moved to the Manchester laboratory of Ernest Rutherford, with whom he formed a life-long friendship. Bohr eagerly took up Rutherford's nuclear model of the atom and recognized its far-reaching implications. In particular, he explained many properties of radioactive transformations and recognized the existence of what later became known as isotopes. He became convinced that classical electrodynamics was fundamentally limited in the atomic domain and had no doubt that this limitation would be governed by Planck's quantum of action. His formula relating the range of penetration of ionizing particles in a medium to their velocity has, in its essentials, survived modern quantum mechanics.

In 1913, almost immediately upon his appointment as an assistant at the University of Copenhagen, Niels Bohr published his most important and daring contribution, the old quantum theory. This was the finding that the Rydberg formula for the frequencies of series of spectral lines could be explained only if the emission of light by an atom occurred as single quanta involving Planck's constant. Thus, while the stationary states of atomic systems could be explained by classical mechanics, the transition from one state to another was a non-classical process.

Bohr at once recognized that the quantal behavior of a system had to go over to the corresponding classical behavior for motions involving large quanta. This insight was later dubbed the Correspondence Principle. (It has only recently been challenged.) Bohr's atomic theory inaugnrated what arguably were to become the two most adventurous and fruitful decades in the history of science: the invention and perfection of quantum mechanics and its successful application to the solution of numerous problems in physics, chemistry and even biology.

After two years the Danes moved to offer Bohr a professorship and three years later, thanks to the intervention of friends who donated the land, they were persuaded to build Bohr a laboratory. This was the famous Institute for Theoretical Physics, of which he was the director for the rest of his life. Most of the world's great theoretical physicists spent periods of their lives at Bohr's Institute. The first to join Bohr in 1916 and to remain for ten years was H.A. Kramers; others who came during the early years included Georg von Hevesy, Oskar Klein, Wolfgang Pauli, and Werner Heisenberg.

Bohr did not rest on his laurels. In 1924, with Kramers and J.C. Slater, he published "The Quantum Theory of Radiation," a renunciation of the classical from of causality in favor of a statistical description. And even though it was Heisenberg who in 1927 discovered the indeterminacy relations (also known as the Uncertainty Principle), it was Bohr who formulated their epistemological foundations in terms of the role of an observer and the complementarity, i.e. the inevitability of mutually exclusive descriptions of quantum phenomena.

By the 1930s, with atomic and solid state physics well understood through quantum mechanics, the main interest had shifted, in Copenhagen as elsewhere, to the rapidly expanding field of nuclear physics. In particular, an explanation had to be found why nuclei were so readily able to capture neutrons for a sequence of resonance energies. Bohr accomplished this in 1936 by imagining, classically, the nucleus as an assembly of nucleons (protons and neutrous) held together by short-range forces, and thus, in effect, behaving like the assembly of molecules forming a drop of liquid, a model which had been put forward earlier by George Gamow. The most important application of this theory was the interpretation of nuclear fission, which Bohr and John A. Wheeler published in 1939, immediately upon the discovery of the fission phenomenon.

This happened while Bohr held a visiting appointment at Princeton University. In 1943, in the face of the Nazi occupation of Denmark, he was able to flee to Sweden. From there he was transported to England, where he was suddenly faced, to his surprise, with the advanced stage of a project—the building of an atomic bomb—that he had deemed beyond the realm of technical accomplishment. Although as "Mr. Baker" he made some contributions to the development of the bomb at Los Alamos, his preoccupation for the rest of his life was to make statesmen and the public aware of the political and human implications of this new weapon and of the urgency of reaching a universal agreement never to use it.

MARGRETHE BOHR (1890–1984)

Margrethe Nørlund met Niels Bohr in 1909 through her brothers Niels Erik and Poul, who were friends of Bohr. They were engaged in 1910 and married in 1912 in a brief, civil ceremony. She was an indispensable companion to Niels. In the early years of their marriage, she acted as his secretary-assistant, taking down drafts of his papers from dictation. (Niels reports that on one occasion, in 1912, "I went to the country with my wife and we wrote a very long paper on these things [probably an attempt to complete his work on alpha particles]."After November 1916, when their first son, Christian Alfred , was born—who, in 1934, tragically drowned while sailing with his father—Margrethe's help in taking dictation understandably waned. Throughout their lives together Niels used her as a sounding board for ideas.

All the many friends and associates who have written about their stays at the Bohrs' home agree on Margrethe's extraordinary contributions as a hostess and participant in the conversations. She was very much in her element after the Bohrs moved into the sumptuous "Residence of Honor" in the Carlsberg breweries in 1932. Abraham Pais reports in his biography, *Niels Bohr's Times, in Physics, Philosophy, and Polity*, that at the many receptions "whether for the staff and visitors from Bohr's institute, or for Queen Elizabeth and Prince Philip of England, or other high dignitaries, ...[she officiated] with great charm and dignity. She had the particular talent of knowing the names and some personal circumstances of all her guests. She came to be known as Dronning (Queen) Margrethe, with affectionate respect by some, with envy by others."

Shortly after Niels Bohr's death, the mathematician and longtime family friend Richard Courant, in explaining Niels's success, wrote: "...It was not luck, rather deep insight, which led him to find in young years his wife, who, as we all know, had such a decisive role in making his whole scientific and personal activity possible and harmonious." And their son, Hans, wrote of his parents' lives together: "...My mother was the natural and indispensable center. Father knew how much mother meant to him and never missed an opportunity to show his gratitude and love...Her opinions were his guidelines in daily affairs."

WERNER HEISENBERG (1901–1976)

Heisenberg displayed an early talent for mathematics, and he entered the University of Munich intending to become a mathematician. However he soon came under tutelage of the renowned physics professor Arnold Sommerfeld and received his doctorate from him in 1923. Subsequently Heisenberg studied and collaborated with Max Born in Göttingen and with Niels Bohr in Copenhagen (succeeding H.A. Kramers there as Bohr's assistant in 1926). Later he also made the acquaintance of and worked with, among other physicists, Wolfgang Pauli, Enrico Fermi and P.M.A. Dirac. In 1926, at the age of twenty-five, he was called to the University of Leipzig as Germany's youngest full professor.

Heisenberg is popularly best known for his Uncertainty Principle (variously called by him Ungenauigkeit [inexactness] or Unschärfe [lack of sharpness] Relation, but later changed to Unbestimmtheit [intederminateness or even indeterminability]). Simultaneous precise measurements of canonically conjugate properties, such as the position and momentum, or energy and location in time, of a particle are in principle (and in experimental fact) not possible; the product of their lack of precision is at least as big as Planck's constant. In 1927, based largely on this insight and Bohr's recognition of complementarity, Heisenberg, Bohr, and Born presented the Copenhagen Interpretation of quantum mechanics.

With Carl Friederich von Weizsäcker and others, Heisenberg also explored the philosophical interpretations of quantum mechanics, sounding the death knell of strict determinism, claiming the weakening of causality and investigating the applications of neo-Kantian notions. With Bohr he pushed the Copenhagen interpretation into chemistry and biology and even into social phenomena. With physicists such as Felix Bloch, Rudolf Peierls and Edward Teller he applied quantum mechanics to the solution of many problems, such as the helium atom and ferromagnetic materials. After 1927, drawing on the work of Dirac, Pascual Jordan, Oskar Klein, and others, Heisenberg's major scientific concern became the unification of quantum mechanics and relativity theory. Soon after the discovery of the neutron in 1932, Heisenberg developed a neutron-proton model of the nucleus by introducing the concepts of the nuclear exchange force and of isotopic spin. In 1936, Heisenberg discovered a mathematical minimum length which, he believed, marked the frontier of a new, wholly revolutionary physics.

During the entire course of his life, Heisenberg was a patriotic German. In 1919 he supported the resistance against a Bolshevik-oriented take-over in Bavaria and in defense of the elected social-democratic government.As a boy-scouts leader he strove for the renewal of German life through the direct experience of nature and the beauties of Romantic poetry, music, and thought. In the early years of the Nazi regime, he and other theoretical physicists came under attack as "white Jews," but by the outbreak of the Second World War, he and the regime had made sufficient peace with each other for Heisenberg to remain in Germany and to be put in charge of the German nuclear reactor program.

In the last, chaotic days of the War, the ALSOS mission, scientifically led by the Dutch-born refugee physicist Samuel Goudsmit, captured Heisenberg and nine other German scientists. They were interned at Farm Hall, a country estate near Cambridge, England, for six months. After their repatriation Heisenberg set out to revitalize German science and to resume relations with scientists, many his former friends and colleagues, in other countries. He reestablished and headed the Kaiser Wilhelm Institute, renamed the Max Planck Institute, in Göttingen, became the President of the German Research Council and headed the German delegation at the founding of the European research center for nuclear (high energy) physics, CERN, in Geneva. In spite of the demands of his political involvements, he continued to be active in physics and to pursue his search for a consistent quantum field theory until his death.

This material is adapted from Biographies of Persons in Copenhagen, *compiled by Harry Lustig.*

WORDS TO THE WISE

German occupation—In May of 1939, Denmark signed a ten-year non-aggression pact with Germany and in April 1940 was invaded and occupied by German troops.

Uncertainty principle—Formulated by Heisenberg in 1927, this scientific principle states that it is impossible to know at once both precisely where a particle, such as an electron, is and how quickly it is moving.

Tisvilde—Heisenberg and other assistants often joined Bohr and his family here at their summer home.

Quanta—In 1900, researcher Max Planck discovered that energy can only be released or absorbed by matter in the form of this very small unit.

Quantum theory—This theory uses the quantum as the basis for describing all relationships among subatomic particles.

Matter—In the scientific sense, matter is anything that has weight and occupies space.

Energy—Scientifically, energy is the ability of matter to perform work as either a result of its motion or its position.

Quantum mechanics—This mathematical theory developed out of a need to explain processes at the atomic level that did not follow the laws of classical or Newtonian physics.

Max Born—A German-British physicist, Born is known for his major contributions to quantum theory and in 1954, won the Nobel Prize in physics.

Pascual Jordan—A German theoretical physicist, Jordan worked with Max Born and Heisenberg to polish Heisenberg's mathematics in what would become qnantum mechanics.

Göttingen—Home to the Max Planck Institute, this central German city is known for attracting some of the world's finest mathematicians and physicists.

Complementarity—This principle of physics, developed by Bohr, states that the behavior of an electron can be understood completely only by descriptions in both wave and particle form.

Carl von Weizsäcker—This physicist was an original member of the Uranium Club, the secret German state run program to research the military possibilities of uranium fission. Weizsäcker was detained at Farm Hall with Heisenberg.

SS—An abbreviation for Schutzstaffel, this elite army force served as Hitler's personal guard as well as policing the occupied countries.

John the Baptist—In using this analogy, Heisenberg says that Weizsäcker has announced his arrival in the same way that John the Baptist announced Christ and his teachings.

Stefan Rozental—A Jewish-Polish physicist, Rozental was a longtime assistant to Bohr and studied under Heisenberg.

Christian Møller—A Danish mathematical physicist, Møller worked primarily in Copenhagen and is best known for his contributions to relativity.

Samuel Goudsmit—Dutch-born, Goudsmit became a naturalized American citizen and worked in the U.S. with George Uhlenbeck to show that electrons have magnetic properties.

Theoretical physics—Theoretical physics varies from experimental physics in that it relies on mathematical models and abstractions rather than concrete trials.

Fission—Fission is the splitting of the nucleus of an atom that results in the release of a large amount of energy.

Wolfgang Pauli—Pauli was an Austrian-American physicist and is best known for his exclusion principle which says that no two electrons can occupy a quantum state at the same time in an atom.

Otto Frisch—In 1939, Frisch, with his aunt, Austrian physicist Lise Meitner, explained the process of fission.

Arnold Sommerfeld—Sommerfeld, a Jewish-Prussian theoretical physicist, taught Heisenberg before Bohr did and is recognized for his work in developing quantum theory.

Von Laue—A German physicist, von Laue earned a Nobel prize in 1914 and in 1942, resigned his professorship at the University of Berlin in protest of the Nazi regime.

Karl Wirtz—A member of the Uranium Club, Wirtz studied under Heisenberg and was instrumental in bringing his former teacher into this research project.

Paul Harteck—An Austrian physical chemist, Hartneck worked on construction of the German nuclear reactor during World War II.

Otto Hahn—Hahn was a German radiochemist whose work led to the discovery of uranium fission.

Enrico Fermi—An Italian physicist, Fermi was a key member of the U.S. Manhattan Project and research at Los Alamos, developing a controlled, self-sustaining nuclear chain reaction.

Uranium—After Hahn and Fritz Strassmann announced fission in 1939, this radioactive metallic element became the focus of military research.

Barium and Krypton—When a uranium atom is split, it forms these two lighter elements.

John Wheeler—An American physicist, Wheeler led the U.S. team working to create the first hydrogen bomb.

Cyclotron—This particle accelerator makes possible the separation of uranium 235 from natural uranium.

James Chadwick—An English physicist, Chadwick headed the British atomic bomb effort and invited Bohr to come to England in 1943.

J. Robert Oppenheimer—Leader of the Manhattan Project, Oppenheimer achieved the first nuclear explosion.

Schrödinger's cat—Austrian physicist Erwin Schrödinger, a pioneer in quantum mechanics, proposed an experiment to highlight the insufficiency of theories on sub-atomic particle behavior. His proposition involved placing a cat, a vial of poisonous gas and a radioactive mineral in a sealed box, assuming that given enough time, the mineral will decay and release the gas, killing the cat. Of course the experiment was never performed, but Schrödinger's argument is that it is impossible to know if the cat is alive or dead until one opens the box, so according to the theory the cat must be simultaneously alive and dead.

Hendrik Casimir—This Dutch physicist studied under Bohr in Copenhagen.

George Gamow—A Russian-American physicist, Gamow was the first to propose the liquid drop model of the nucleus and was one of the originators of the big bang theory.

Reactor—According to Heisenberg, this device that allows the controlled release of nuclear energy was the sole goal of the German nuclear project.

Plutonium—Chemically similar to uranium, this radioactive metallic element can be used to produce atomic energy.

Farm Hall—This British manor served as a detention point for 10 German physicists for a 6-month period just prior to and following the bombing of Hiroshima and Nagasaki. Not knowing the full extent of the German nuclear project, Allied forces felt it best to keep these men isolated from Russian and French intelligence.

Hiroshima—The first of two Japanese targets for atomic bombs, Hiroshima was bombed on August 6, 1945, killing an estimated 140,000 people.

Nagasaki—Following the August 9, 1945 bombing of this Japanese city, Japan surrendered, ending World War II.

Albert Speer—A Nazi-German, Speer served as Hitler's Minister of Armaments and Munitions.

Cadmium—Because this element easily absorbs neutrons, it is used to make control rods for nuclear reactors.

Heavy water—Heavy water is chemically the same as regular (light) water, but with the two hydrogen atoms (as in H_2O) replaced with deuterium atoms. Deuterium is an isotope of hydrogen and has one extra neutron. It is this extra neutron that makes heavy water "heavy." Used in a nuclear reactor, heavy water transfers heat and slows emitted neutrons, increasing the fission reaction rate.

Critical mass—This term refers to the minimum quantity of uranium or other fissionable material required for a chain reaction to occur.

Copenhagen Interpretation—This represents the first major attempt to understand the atomic world in terms of quantum mechanics and is a term applied to Bohr's and Heisenberg's joint (if not completely unified) explanation of atomic behavior.

Matrix mechanics—This was Heisenberg's original approach to quantum theory, one which Bohr did not completely support.

Wave mechanics—De Broglie introduced this approach to quantum mechanics with the idea that all particles have wave aspects.

Cloud chamber—First developed in 1911 for experiments on the formation of rainclouds, the cloud chamber was used to track the path of atomic particles.

Peregrinations—When likening a walk around town to the Uncertainty Principle, Bohr uses this term to refer to Heisenberg's hypothetical walks.

235—This is a shortened term for enriched uranium^{235}, needed for an atomic bomb.

The Road to the BOMB

ELECTRONS
1895 Thomson discovers the electron, the extremely light, negatively charged particles orbiting inside the atom which give it its chemical properties.

QUANTUM THEORY
1900 Planck discovers that heat energy is not continuously variable, as classical physics assumes. There is a smallest common coin in the currency, the quantum, and all transactions are in multiples of it.

PHOTONS
1905 Einstein realizes that light, too, has to be understood not only as waves but as quantum particles, later known as photons.

THE NUCLEUS
1910 Rutherford shows that the electrons orbit around a tiny nucleus, in which almost the entire mass of the atom is concentrated.

THE QUANTUM ATOM
1913 Bohr realizes that quantum theory applies to matter itself. The orbits of the electrons about the nucleus are limited to a number of separate whole number possibilities, so that the atom can exist only in a number of distinct and definite states. (The incomplete so-called 'old quantum theory'.)

THE BOMB
1945 The bomb is successfully tested in July, and on August 6, 1945 is used on Hiroshima.

THE REACTOR
1942 Fermi in Chicago achieves the first self-sustaining chain reaction in a prototype reactor.

THE MANHATTAN PROJECT
1942 The Allied atomic bomb program begins.

THE CRITICAL MASS
1940 Frisch and Peierls in Birmingham calculate, wrongly but encouragingly, the minimum amount of U^{235} needed to sustain an effective chain reaction.

THE NEUTRONS MULTIPLY
1939 Bohr and Wheeler at Princeton realize that fission also produces free neutrons. These neutrons are moving too fast to fission other nuclei in U^{238}, the isotope which makes up 99% of natural uranium, and will fission only the nuclei of the U^{235} isotope, which constitutes less than 1% of it.

THE CHAIN REACTION
1939 Joliot in Paris and Fermi in New York demonstrate the release of two or more free neutrons with each fission, which proves the possibility of a chain reaction in pure U^{235}.

THE WAR
1939 The Second World War begins, and Germany at once commences research into the military possibilities of fission.

GERMANY DEFEATED
1945 The Allied advance into Germany halts the atomic program there.

QUANTUM MECHANICS
.5 Heisenberg abandons on orbits as unobservable, nds instead a mathematical lation in terms of matrices what can be observed—ffects they produce upon the absorption and emission of light.

UNCERTAINTY
1927 Heisenberg demonstrates that all statements about the movement of a particle are governed by the uncertainty relationship: the more accurately you know its position, the less accurately you know its velocity, and vice versa.

MATTER AS WAVES
1924 De Broglie in Paris suggests that, just as radiation can be treated as particles, so the particles of matter can be treated as a wave formation.

THE COPENHAGEN INTERPRETATION
1928 Bohr relates Heisenberg's particle theory and Schrödinger's wave theory by the complementarity principle, according to which the behavior of an electron can be understood completely only by descriptions in both wave and particle form. Uncertainty plus complementarity become established as the pillars of the Copenhagen (or 'orthodox') interpretation of quantum mechanics.

THE WAVE EQUATION
1926 Schrödinger finds the mathematical equation for the wave interpretation, and proves that wave and matrix mechanics are mathematically equivalent.

INTO THE NUCLEUS
1932 Heisenberg opens the new era of nuclear physics by using neutron theory to apply quantum mechanics to the structure of the nucleus.

NEUTRONS
1932 Chadwick discovers the neutron—a particle which can be used to explore the nucleus because it carries no electrical charge, and can penetrate it undeflected.

TRANSMUTATION
1934 Fermi in Rome bombards uranium with neutrons and produces a radio-active substance which he cannot identify.

IDENTIFICATION
1939 Hahn and Strassmann in Berlin identify the substance produced by Fermi's bombardment as barium, which has only about half the atomic weight of uranium.

FISSION
1939 Lise Meitner and Frisch in Sweden apply Bohr's liquid drop model to the uranium nucleus, and realize that it has turned into barium under bombardment by splitting into two, with the release of huge quantities of energy.

THE LIQUID DROP
1937 Bohr explains the properties of the nucleus by analogy with a drop of liquid.

"About 40 seconds after the explosion the air blast reached me. I tried to estimate its strength by dropping from about six feet small pieces of paper before, during, and after the passage of the blast wave.... The shift was about 2 1/2 meters, which, at the time, I estimated to correspond to the blast that would be produced by ten thousand tons of T.N.T."

—Enrico Fermi's eyewitness account of the first test of an atomic bomb at Los Alamos, N.M. on July 16, 1945. He was located 20 miles from the blast.

BIO & BEYOND

Michael Frayn has said that his plays are about "the way we impose our ideas on the world around us." In *Copenhagen*, he has constructed a drama around two men whose ideas shaped the way a century of people see the world. That Frayn has crafted a thoughtful, complicated play that takes on big issues is no surprise. The surprise of *Copenhagen*, is that it is such a serious work from the man best known in the U.S. for his farce, *Noises Off*.

Michael Frayn was born in London on September 8, 1933. Early on he found joy in the attention he could draw to himself by mocking his elementary school teachers. By the time he made it to Cambridge between 1954 and 1957, he had become completely enamored of the stylish and witty sophistication of the place. He enjoyed that it was a privileged arena and he describes the brand of comedy he developed there as "whimsical, carefully artless, sub-Thurber cartoons."

From Cambridge, Frayn fell into newspapers, working as a reporter and then as a columnist first for *The Guardian* and later for *The Observer* at a time when writers might be sent on virtually any assignment. Frayn made his mark as a columnist of humorous essays often steeped in the politics and philosophy that would later fill his plays. He has published five books of columns from *The Guardian* and *Observer*, including *The Day of the Dog* (1962), *The Book of Fub* (1963) and *Speak After the Beep* (1995).

In the 1960s he successfully launched a new career as a novelist. Still writing in a satirical vein, *The Tin Men* (1963) deals with computers taking over the drudgery of human existence, *A Very Private Life* (1968) predicts a future in which people have turned ridiculously in on themselves, and *The Trick of It* (1990) follows a young academic as he becomes involved with a famous author and tries fruitlessly to become a writer himself. Never one to take on light material, Frayn's comedy has deepened and become darker, while maintaining a playful approach to his serious subjects. His most recent novels include *Headlong* (1999) and *Spies* (2002).

He began writing seriously for the stage in 1970 with *The Two of Us*, a series of four short plays linked by a pair of actors that portrayed two different characters in each play. Mostly, Frayn's drama has focused on the distorted worlds of niche industries, from the newspaper-cutting library of *Alphabetical Order* (1975), and the sales business of *Make and Break* to the theater itself in *Noises Off*. He has also departed from farce onstage in plays like *Benefactors* (1984), about the deterioration of a marriage in the 1960s, and in his well-received translations and adaptations of the work of Anton Chekhov.

WHAT'S THE STORY?

***Copenhagen* is** a hypothetical after-death meeting of real-life figures, physicists Niels Bohr and Werner Heisenberg, as well as Bohr's wife, Margrethe, in an attempt to puzzle out the events of an evening they spent together in September 1941. At that time, Heisenberg was leading the German initiative to investigate the feasibility of an atomic bomb, and Bohr was a half-Jewish Dane living in his German-occupied homeland.

The play begins with a recreation of the 1941 meeting. Each of the characters is uncomfortable with the politics of the meeting and careful with every word, as Bohr's home has surely been bugged by the Nazis. Bohr is convinced that there is no future in looking for a military use for fission, while Heisenberg has come bearing the disturbing news that that's exactly the project he is saddled with advancing in Germany—information which is clearly treason.

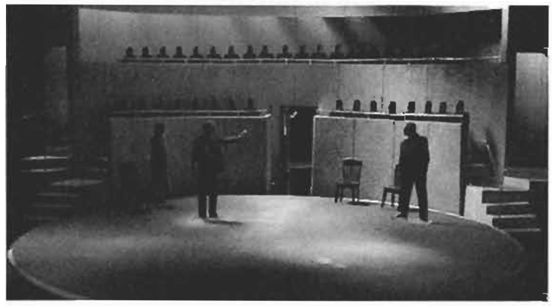
Bohr tries to get out of Heisenberg the reason for his visit. Heisenberg tries to feel out Bohr's knowledge of Allied nuclear research, but Bohr claims ignorance. Heisenberg suggests that Bohr may find a friendly reception with the Cultural Division of the German Foreign Office in Denmark, but Bohr is appalled at the suggestion that he come to amiable terms with his oppressors.

Just as Heisenberg's commitment to his German homeland is about to forbid any real communication with Bohr, the two fall into a memory of their first meeting and begin to rhapsodize about their long hours and fierce debates over the nature of the atom in the 1920s. Bohr reminds Heisenberg that he has a tendency to speed through the details of his science, and Heisenberg chides Bohr for plodding along and picking up all of the stray bits and pieces.

In multiple replayings of that now distant evening, the characters vainly search for a definitive answer to the huge question, "Why?" Eventually, they realize just how unsolvable the puzzle of human motivation is—that their own lives and intentions operate under Heisenberg's Uncertainty Principle. In their efforts to ferret out the truth, to observe and track intention, they impact and possibly alter the same truth, leaving them in a perpetual state of questioning.

These materials are adapted from StageNotes, *published by Camp Broadway, 2000.*

SHOP TALK



Students attending The Rep's production of *Copenhagen* will have a unique opportunity to gain a new perspective on the stage. Approximately 30 audience members will be seated onstage for this innovative drama. In collaboration with director Steven Woolf, scenic designer Todd Rosenthal has created a set which incorporates a second "mini-audience" into the design. While exciting for patrons, the choice plays an integral part in the storytelling process as well. As the three characters, Bohr, Margrethe and Heisenberg attempt to determine what happened on that night in 1941, they replay events over and over in their own minds and each asserts his or her own interpretation of the evening. In doing this, they illustrate two of the major components of the Copenhagen Interpretation: complementarity and the Uncertainty Principle. Complementarity, first proposed by Bohr, states that an electron can only be understood completely by descriptions in both wave and particle form—in layman's terms—more than one perspective is essential in order to know the whole truth. Heisenberg's Uncertainty Principle further complicates the search for truth by stating that it is impossible to know both the location and the velocity of a particle because the process used to determine either one of these inevitably affects the accuracy of the measure. In other words, the act of observation is inherently flawed.

The three characters can never really determine what happened in 1941 because they are viewing it—so they keep viewing it to see if their perception will ever be changed. Woolf explains it this way:

> *This idea of multiple paths is one of the central metaphors of the show and is one of the reasons for playing it in the "round." The audience in the main house is an observer of the story, as is the audience onstage. But the audiences are also observing themselves—across the set—as they judge what is going on in the story of the play. Everyone is observing and everyone is measuring and yet, according to Heisenberg, the measurement will never be fully correct because you cannot accurately measure what you are observing. It's why the three characters can't easily solve what happened at their meeting. They all were there, but remember it differently leading to differing interpretations. The other view the set brings to this production is the idea of an atom surrounding its nucleus and the three elements of the nucleus—proton, neutron, electron—circling each other, colliding on occasion, triggering reactions.*

Margrethe, Bohr and Heisenberg personify these elements inside the "cloud chamber" of the set, reflecting their ideas and perceptions off of one another—but never being able to determine what really happened.

Read more about it

We encourage you to examine these topics in-depth by exploring the following books, websites and videos.

Hitler's Uranium Club: The Secret Recordings at Farm Hall by Jeremy Bernstein. Spring Verlag, 1995.

The Philosophical Writings of Niels Bohr by Niels Bohr. Oxbow Press, 1987.

Uncertainty: The Life and Science of Werner Heisenberg by David C. Cassidy. WH Freedman & Co., 1993.

The Copenhagen Papers: An Intrigue by Michael Frayn and David Burke. Metropolitan Books, 2001.

Now It Can Be Told by Leslie R. Groves. Da Capo, 1962.

Critical Assembly: A Technical History of Los Alamos During the Oppenheimer Years, 1943–1945 by Lillian Haddeson. Cambridge University, 1993.

Brighter than a Thousand Suns: A Personal History of the Atomic Scientists by Robert Jungk; translated by James Cleugh. Harcourt Brace, 1970.

The Second World War by John Keegan. Penguin, USA, 1990.

Niels Bohr's Philosophy of Physics by Dugald Murdoch. Cambridge University, 1989.

Why the Allies Won by Richard Overy. W.W. Norton & Co., 1997.

Niels Bohr's Times: In Physics, Philosophy and Polity by Abraham Pais. Oxford University Press, 1993.

Heisenberg's War: The Secret History of the German Bomb by Thomas Powers. Da Capo, 2000.

The Making of the Atomic Bomb by Richard Rhodes. Touchstone Books, 1995.

The Niels Bohr Archives—www.nbo.nbi.dk

World War II: In Color, released by Goldhill Home Media, 1998.

J. Robert Oppenheimer, released by A & E Entertainment, 1998.

WW II: Special Edition, released by Madacy Entertainment, 1998.

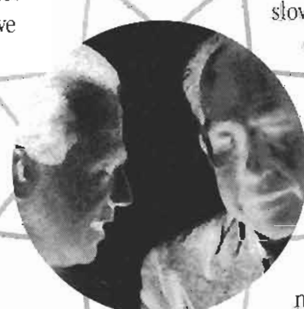
Weapons of War—The Atomic Bomb, released by Best Film & Video, 1993.

These questions and activities are designed to help students anticipate the performance and then to build on their impressions and interpretations after attending the theatre. The activities and questions are divided into "**Before the Performance**" and "**After the Performance**" categories. While most of the exercises provide specific instructions, please feel free to adapt these activities to accommodate your own teaching strategies and curricular needs. To assist you in incorporating these materials into your existing curriculum, we have provided the numbers of some of the corresponding Missouri Knowledge Standards and Illinois Learning Standards.

Communication Arts

Before the Performance

1 We've all heard the old saying, "There are two sides to every story." In reality, there are usually many more. The relationship among how we, as individuals, remember events; how another person who was part of the same event recalls it and what actually transpired is always interesting. Perform an experiment to illustrate for yourself how this process works. Choose 2 friends from your class and plan to spend at least 2 hours with each other. How you spend your time together is completely up to your group. You may study after school, go to the mall, share a meal, or if you have multiple classes together, you may designate that as your "group time." When the two hours have passed, write a detailed description of what happened. Include conversation, actions and events as well as the attitudes of your fellow group members. Write your accounts individually, not as a group. Then share your versions of events with each other. What are the similarities and differences? What do you think accounts for the variations? As a group, try to write a single description that you can all accept as accurate. (MO: CA1, CA4, CA6, SS6 IL: 1, 3, 4, 5)



After the Performance

2 *Copenhagen* is a challenging play in that it is driven by description of people and places and retelling of information, rather than by action or plot. In order for this kind of work to be effective, the playwright must employ a variety of rhetorical, or stylistic devices to maintain the dramatic stakes and the audience's interest. In the excerpt below, Michael Frayn uses an extended scientific metaphor to illuminate the interaction among the three characters. Based on this dialogue, analyze the complex relationship shared by Bohr, Heisenberg and Margrethe.

Heisenberg: Listen! Copenhagen is an atom. Margrethe is its nucleus. About right, the scale? Ten thousand to one?

Bohr: Yes, yes.

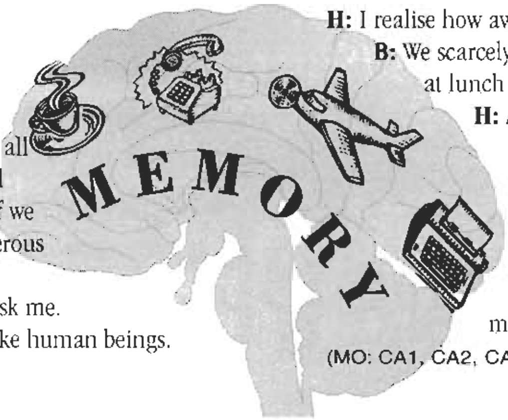
H: Now, Bohr's an electron. He's wandering about the city somewhere in the darkness, no one knows where. He's here, he's there, he's everywhere and nowhere. Up in Faelled Park, down at Carlsberg. Passing City Hall, out by the harbour. I'm a photon. A quantum of light. I'm dispatched into the darkness to find Bohr. And I succeed, because I manage to collide with him.... But what's happened? Look—he's been slowed down, he's been deflected! He's no longer doing exactly what he was so maddeningly doing when I walked into him!

B: But, Heisenberg, Heisenberg! You also have been deflected! If people can see what's happened to you, to their piece of light, then they can work out what must have happened to me! The trouble is knowing what's happened to you! Because to understand how people see you we have to treat you not just as a particle, but as a wave. (MO: CA1, CA2, CA4, CA5, CA7 IL: 1, 2, 3, 4, 5)

3 Along with metaphor, vivid description is an essential writing tool that Frayn wields in *Copenhagen*. The detailed sensory descriptions that his characters provide give the audience the sense that each accounting of events is "the real" one. Note the sights and sounds in the following excerpt:

Heisenberg: I crunch over the familiar gravel to the Bohrs' front door, and tug at the familiar bell-pull. Fear, yes. And another sensation, that's become painfully familiar over the past year. A mixture of self-importance and sheer helpless absurdity—that of all the 2,000 million people in this world, I'm the one who's been charged with this impossible responsibility....The heavy door swings open.

Bohr: My dear Heisenberg!
H: My dear Bohr!
B: Come in, come in...
Margrethe: And of course as soon as they catch sight of each other all their caution disappears. The old flames leap up from the ashes. If we can just negotiate all the treacherous little opening civilities...
H: I'm so touched you felt able to ask me.
B: We must try to go on behaving like human beings.
H: I realise how awkward it is.
B: We scarcely had a chance to do more than shake hands at lunch the other day.
H: And Margrethe I haven't seen....
B: Since you were here four years ago.
M: Niels is right. You look older.



Think of an event from your past. List words or phrases that describe your memory of that time. Then form your list into a memoir of what happened that day. (MO: CA1, CA2, CA4, CA5, CA7 IL: 1, 2, 3, 4, 5)

Fine Arts

Before the Performance

1 Because two of the three characters in *Copenhagen* are scientists, there are a number of references to atomic physics in the play. While it is not necessary to understand all of these processes to enjoy the play, it is helpful to have some perspective on the miniscule nature of the particles involved. Playwright Tom Stoppard describes the atom this way in his play, *Hapgood*:

> *...when things get very small they get truly crazy, and you don't know how small things can be, you think you know but you don't know. I could put an atom into your hand for every second since the world began and you would have to squint to see the dot of atoms in your palm. So now make a fist, if your fist is as big as the nucleus of one atom then the atom is as big as St. Paul's, and if it happens to be a hydrogen atom then it has a single electron flitting about like a moth in the empty cathedral, now by the dome, now by the altar...Every atom is a cathedral.*

Based on this analogy, create a visual representation of the atom. You may use sculpture, drawing, painting, collage or any other artistic medium to convey this concept. Present your artwork to your class. (MO: FA1, FA2, FA3, FA4, FA5, CA1, CA3 IL: 1, 2, 5, 25, 26, 27)

2 Think about a friend or relative that you have not seen for a long time. Consider why you haven't seen him or her and why you might want to make contact now. Imagine that you are going to call that person or visit his or her house. Write a monologue in which you describe the moments before you dial the phone or knock on the front door. Describe what you are thinking and feeling. Then follow the monolgue with the first few minutes of conversation that you imagine having after you reach the person. (MO: FA1, FA2, FA3, CA1, CA4 IL: 1, 2, 3, 4, 5, 25, 26)

After the Performance

3 Michael Blakemore, who directed *Copenhagen* in both London and New York, describes his blocking of the play as being like the movement of particles within an atom. Read the script excerpt below as if you are the director. At this point, Margrethe is no longer able to contain her feelings about Heisenberg. Determine which character you believe to be the "nucleus" of the atom. About whom does the action revolve? Using this model of the actors as particles within an atom, select three classmates to play these roles and block, or stage, the action of the scene. Remember that movement should be motivated by emotion, not vice-versa. Rehearse your cast and present the scene for the class. How do your choices compare to those made by Steven Woolf in The Rep's presentation of the same scene? What differences in interpretation of the characters' thoughts are demonstrated through their blocking?

Margrethe: No, I've kept my thoughts to myself for all these years. I'm sorry, but really....On your hands and knees? It's my dear, good, kind husband who's on his hands and knees! Literally. Crawling down to the beach in the darkness in 1943, fleeing like a thief in the night from his own homeland to escape being murdered. The protection of the German Embassy that you boasted about didn't last for long. We were incorporated into the Reich.
Heisenberg: I warned you in 1941. You wouldn't listen. At least Bohr got across to Sweden.
M: And even as the fishing-boat was taking him across the Sound two freighters were arriving in the harbour to ship the entire Jewish population of Denmark eastwards. That great darkness inside the human soul was flooding out to engulf us all.
H: I did try to warn you.
M: Yes, and where are you? Shut away in a cave like a savage, trying to conjure an evil spirit out of a hole in the ground. That's what it came down to in the end, all that shining

springtime in the 1920s, that's what it produced—a more efficient machine for killing people.

Bohr: It breaks my heart every time I think of it.

H: It broke all onr hearts.

M: And this wonderful machine may yet kill every man, woman, and child in the world. And if we really are the centre of the universe, if we really are all that's keeping it in being, what will be left?

B: Darkness. Total and final darkness.

(MO: FA1, FA2, FA3, FA4, FA5, CA1, CA2, CA5 IL: 1, 2, 4, 5, 25, 26, 27)

Social Studies

Before the Performance

1 Do yon think that scientific experimentation should be monitored for its ethical intentions and potential outcomes? Is it possible both to control scientific experimentation and encourage technological advancement? Debate this issue in groups of no more than five. (MO: SS2, SS3, SS6, CA1, CA6 IL: 1, 4, 5, 16, 18)

2 The U.S. did not launch a program for the development of nuclear arms until 1942, giving Germany a more than 2-year research lead; yet, when Hiroshima was bombed in 1945, Germany was no where near producing an atomic bomb. Historians cite numerous reasons for this failure, but four of the most prominent are: 1) Heisenberg's miscalculation of critical mass; 2) lack of funding; 3) Hitler's support of V-2 rockets; 4) the shortage of theoretical physicists in Germany. Find three research partners, with each of you selecting one of these four areas to study. Together, form a theory explaining why the German nuclear program failed. (MO: SS1, SS2, SS6, SS7, CA1, CA3, CA4, CA6 IL: 1, 2, 3, 4, 5, 16, 18)

After the Performance

3 In both the play and in life, Heisenberg suggested that he intentionally thwarted the German nuclear program by requesting less money from the government than was needed for the project. Based on his, Margrethe's and Bohr's accounts of events in the play, do you accept this explanation or not? To what extent, if any, does a scientist's (or any citizen's) duty to his or her country override personal moral and ethical accountability for actions? Debate these questions in your discussion group. (MO: SS2, SS3, SS6, CA1, CA3, CA5, CA6 IL: 1, 2, 4, 5, 16, 18)

4 Bohr and Heisenberg struggle with their perceptions of each other. They are at once fiercely loyal and distrustful of one another, as the following scene illustrates:

Heisenberg: Now we're all dead and gone, yes, and there are only two things the world remembers about me. One is the uncertainty principle, and the other is my mysterious visit to Niels Bohr in Copenhagen in 1941.

Margrethe: I never entirely liked him, you know. Perhaps I can say that to you now.

Bohr: Yes, you did. When he was first here in the twenties? Of course you did. On the beach at Tisvilde with us and the boys? He was one of the family.

M: Something alien about him, even then.

B: So quick and eager.

M: Too quick. Too eager.

B: Those bright watchful eyes.

M: Too bright. Too watchful.

B: Well, he was a very great physicist. I never changed my mind about that.

M: They were all good, all the people who came to Copenhagen to work with you. You had most of the great pioneers in atomic theory here at one time or another.

B: And the more I look back on it, the more I think Heisenberg was the greatest of them all.

H: So what was Bohr? He was the first of us all, the father of us all. Modern atomic physics began when Bohr realised that quantum theory applied to matter as well as to energy. 1913. Everything we did was based on that great insight of his.

B: When you think that he first came here as my assistant in 1924.

H: I'd only just finished my doctorate, and Bohr was the most famous atomic physicist in the world.

Imagine that you have been asked to write eulogies for these two men. Based on the portraits they paint of one another here and the historical information provided in "Who's Who," compose final remarks on the lives of these figures. (MO: SS2, SS6, SS7, CA1, CA3, CA4, CA5 IL: 1, 2, 3, 4, 5, 16, 18)