Outreach Info-Packet for Copenhagen

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Supported in part by NSF CAREER Award DMR #0748856

The Play

COPENHAGEN originally opened in London at the Cottesloe Theatre, Royal National Theatre on May 28, 1998. It was directed by Michaek Blakemore. It opened on Broadway in New York at the Royal Theatre on April 11, 2000.
It won the 2000 Tony Award for Best Broadway Play, the Outer Circle Critics Award for Outstanding Broadway Play, and the New York Drama Critic's Award for Best Foreign Play. It has had numerous successful productions around the world.

The Playwright

Michael Frayn

Playwright, novelist and translator Michael Frayn was born in London in 1933. After two years National Service, during which he learned Russian, he read Philosophy at Emmanuel College, Cambridge, and his fascination for the subject has informed his writing ever since.

On leaving Cambridge, he worked as a reporter and columnist for The Guardian and The Observer, publishing several award winning novels. His latest novel, Spies (2002), is a story of childhood set in England during the Second World War. He has also authored dozens of plays, including His plays include Clouds (1976), Noises Off (1982) and Democracy (2003). He has also translated a number of works from Russian, including plays by Chekhov and Tolstoy. He also wrote the screenplay for the film Clockwise (1986), a comedy starring John Cleese.

His latest book is a work of non-fiction, The Human Touch: Our Part in the Creation of the Universe (2006).

The Characters

Niels Bohr was born in Copenhagen on October 7th, 1885, growing up in a warm and intellectual family atmosphere. He studied at the University of Copenhagen, and in 1911 received his doctorate with a thesis on the electron theory of metals. After a short stay in the Cavendish laboratory in Cambridge under J.J. Thomson, he moved to Manchester in 1912 to work on atomic structure in E. Rutherford's group, incorporating quantum theory ideas.

Returning to Copenhagen, in the summer of 1912 he married Margrethe Nørlund with whom he had six children. Bohr held a lectureship in physics at Copenhagen University (1913-1914) and at Victoria University in Manchester (1914-1916). In 1916 he was appointed Professor of Theoretical Physics at the University of Copenhagen. Between 1920 and 1930, Bohr's Institute of Theoretical Physics became the foremost research centre for atomic theory and quantum mechanics. During this period Niels Bohr and Werner Heisenberg carried out a very fruitful collaboration, which produced what was called the Copenhagen Interpretation of quantum theory. Bohr received the Nobel Prize for Physics in 1922, in recognition for his work on the atomic structure. Since 1930, Bohr's work in Copenhagen was oriented to the understanding of the atomic nuclei, playing a central role in the description of the nuclear fission discovered in 1939. This year, he was elected President of the Royal Danish Academy, a position he occupied until the end of his life.

During the first years of the Second World War, with Denmark occupied by Germany, Bohr stayed in Copenhagen fighting to preserve the activities at his institute. However, in 1942, shortly before he was to be arrested, he escaped with his family to Sweden and then flew to England. He spent the last years of the war in USA, where he participated in the Manhattan project, the American effort to produce an atomic bomb. However, deeply worried by the use of atomic energy for weapons development, he tried to persuade the international community about the needs of free exchange of people and information as a way to control nuclear weapons. In 1955 Bohr organized the first Atoms for Peace Conference, and contributed to the creation of the European Council for Nuclear Research (CERN).
Niels Bohr summarized his principal scientific contributions in three books, The Theory of Spectra and Atomic Constitution (1922), Atomic Theory and the Description of Nature (1934), and The Unity of Knowledge (1955).

Niels Bohr has had a profound influence on many generations of physicists, who were attracted to his scientific knowledge, as well as his kind personality. Margrethe, Bohr's wife, was an ideal companion, supporting Bohr throughout his career and life. Niels Bohr died in Copenhagen on November 18th 1962.

Margrethe Bohr (maiden name, Nørlund) was born on March 7th, 1890, the daughter of a pharmacist in the small Danish town of Slagelse, some 50 miles south-west of Copenhagen. She was studying French for a private teacher's certificate when in 1910 she met the brothers Niels and Harald Bohr, friends of her own brothers. Niels hired her to type up his work, and a year later they were engaged. On 1st August 1912 they were married in a brief civil ceremony.

They had six children, all sons, two of whom – Christian the eldest and Harald the youngest – died young. Christian was 19 when he was thrown overboard in a storm during a sailing excursion with his father, and drowned. Harald was incapacitated by a disease (possibly meningitis), spent his life in institutions and died aged about 10. Margrethe served for years as her husband's assistant, taking dictation and typing the numerous drafts of the scientific papers he was in the habit of producing. She was more than just his assistant, however, she

was also a sounding board for many of his scientific ideas.

She was a gracious hostess, whether providing plates of sandwiches to sustain Niels and his students and colleagues as they discussed and argued late into the night, or entertaining visiting scientists and Heads of State at their 'Residence of Honour' on the Carlsberg Brewery estate. Always courteous, she was nonetheless cooler about Heisenberg than her husband, and openly angry about the 1941 visit, remarking after Bohr's death, "No matter what anyone says, that was a hostile visit."

In 1943 the family escaped to Sweden where Margrethe stayed for the remainder of the war, while her husband continued to England and later, with their son Aage, to the USA. After Niels Bohr's death, a friend of the family spoke about Margrethe and Niels' marriage: "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."

In 1984, thirty-one years after the death of her beloved Niels, Margrethe Bohr passed away at the age of 95. She is buried with her husband in Copenhagen.

Werner Heisenberg was born on December 5th, 1901, in Würzburg, Germany, and grew up in Munich. In 1920 he began to study theoretical physics under Sommerfeld at the University of Munich. During the winter of 1922-1923 he went to Göttingen to study atomic theory under Max Born. In 1923, he presented his doctoral dissertation at the University of Munich on turbulence in fluid streams. Afterwards, between September 1924 and May 1925, he worked with Niels Bohr at the Institute for Theoretical Physics in Copenhagen.

Back in Göttingen, Heisenberg developed the concept of matrix mechanics, the first version of quantum mechanics, which he published

in 1925. In May 1926, he was appointed lecturer in Theoretical Physics in Copenhagen, and in 1927 Professor of Theoretical Physics at the University of Leipzig. In 1927 he published his Uncertainty Principle, and in 1928 The Physical Principles of Quantum Theory. In 1932 he wrote a seminal paper elaborating the modern picture of the atom, which paved the way to apply quantum theory to the atomic nucleus. For his contribution to the creation of quantum mechanics, he received the Nobel Prize for Physics in 1932.

In 1937 Heisenberg married Elisabeth Schumacher, with whom he had seven children. Forced by the Nazi laws into retirement, Sommerfeld appointed Heisenberg to fill his chair at the University of Munich. However, the Nazis blocked this appointment as Heisenberg was looked down upon for teaching relativity and quantum theory, considered “Jewish physics.” During the Second World War, Heisenberg lead the German nuclear research project (Uranverein). For that reason, in 1941 he left his family and his chair at the University of Leipzig to be director of the Kaiser Wilhelm Institute for Physics in Berlin. At the close of the war Heisenberg and other German nuclear scientists were arrested by advanced Allies forces and interned at Farm Hall, England. After returning to Germany in 1946 he was appointed director of the Max Planck Institute for Physics and Astrophysics in Göttingen. In 1958 the Max Planck Institute moved to Munich where he continued until 1970, when he resigned from his director position. Heisenberg became President of the Alexander von Humboldt Foundation in 1953.

Music was one of his great passions, and he was considered an excellent pianist. Heisenberg was also very interested in philosophy, especially in its relation with physics. His main philosophical writings are condensed in two books Physics and Philosophy (1962) and Physics and Beyond (1971).

After the war, Heisenberg actively promoted the peaceful use of nuclear energy, and supported in 1954 the creation of the European Council for Nuclear Research (CERN).

Heisenberg and Bohr

(Right) Facsimile of a page from a letter that Niels Bohr wrote to Werner Heisenberg (transcribed by Margrethe in her handwriting) about Heisenberg's visit in 1941. Note the many deletions and corrections. The letter was never sent.

(Courtesy of the Niels Bohr Archive, Copenhagen)

Translation of the Letter from Bohr to Heisenberg

Dear Heisenberg,

In recent years... I am frequently asked about the background and purpose of the visit by you and Weizsäcker to Copenhagen in 1941. It is very difficult for me to give an answer because, as you know from our conversations in Tisvilde, both shortly after the war and during you and your family´s summer stay in Liseleje, (I) got a completely different impression of the visit than the one you have described in Jungk´s book. I remember quite definitely the course of these conversations, during which I naturally took a very cautious position, when you informed me that it was your conviction that the war, if it lasted sufficiently long, would be decided with atomic weapons, and (I did) not sense even the slightest hint that you and your friends were making efforts in another direction. At that time I was completely cut off from any connection with England and the U.S.A. and... before I escaped from Denmark, had no idea of the great efforts that had been started there.

It is obvious that during the course of the war such a wise person as yourself must gradually lose faith in a German victory and end with the conviction of defeat, and I can therefore understand that perhaps at the end you may no longer have recalled what you had thought and what you had said during the first years of the war. But I cannot imagine that, during a meeting so boldly arranged as that in 1941, you should have forgotten what arrangements had been made in this regard with the German government authorities, and it is on that point that all the interest of other governments focuses. I therefore very much hope that, by telling me a little about this, you can contribute to the clarification of what is a most awkward matter for us all.

draft of letter from Niels Bohr to Werner Heisenberg,
handwritten by Margrethe Bohr
(unsigned -- letter never sent)

Important People mentioned in the Play

Robert Oppenheimer - Known as the father of the atomic bomb, Oppenheimer was the director of the Manhattan Project - the American WWII effort to develop nuclear weapons.

Carl von Wiezsacker - A German physicist and philosopher, he worked on Heisenberg's nuclear research team. His father was a German diplomat and friend of Niels Bohr. He specialized in binding energy in atomic nuclei and the nuclear processes in stars.

Kurt Diebner - A Nazi party member, he became the director of the German nuclear energy project and led an atomic research effort within Germany which competed with Heisenberg's.

Albert Einstein- A German Physicist and Nobel Prize winner (1921) known best for his theory of relativity. Though he was not a participant in the American bomb effort called the Manhattan Project, it was his letter to President Roosevelt which got the project started.

Wolfgang Pauli - An Austrian physicist and university classmate of Heisenberg in Munich - he was noted for his work in spin theory and for the discovery of the exclusion principle.

Max Born- A German physicist and mentor to Heisenberg who was instrumental in developing quantum mechanics. He won the Nobel prize in 1954.

Otto Frisch - A Jewish - Austrian physicist who designed the first theoretical detonator for the atomic bomb.

Lise Meitner - Jewish Austrian physicist who studied nuclear physics and radio activity. She was a part of the team that discovered nuclear fission, the splitting of atoms.

Otto Hahn - German chemist who won the Nobel Prize in 1944 for discovering nuclear fission. He is called the "father of nuclear

chemistry."

John Wheeler - An American physicist who worked with Einstein and Bohr. He's known for coining the terms "black hole" and "wormhole."

Enrico Fermi - An Italian physicist who worked on the development of the first nuclear reactor at the University of Chicago. In 1938 he won the Nobel prize in Physics for his work on induced radioactivity.

The Physics

Quantum mechanics:

Quantum mechanics explains the behavior of matter and energy on subatomic scales, where our intuitive picture for the behavior of everyday objects breaks down.

The Copenhagen Interpretation:

The Copenhagen interpretation was the first attempt to understand the world of atoms as represented by quantum mechanics. The founding fathers included the Danish physicist Niels Bohr and the German Physicist Werner Heisenberg. Other physicists made important contributions to the overall understanding of the atomic world, but since Heisenberg worked with Bohr at his institute in Copenhagen when these discoveries were made, the name associated with this modern understanding of atomic physics is called the “Copenhagen interpretation.”

Wave Function:

The wave function describes the possible positions of a particle. If the wave function is large at one position, it is likely to find the particle there. If the wave function is small, it is unlikely.

Schroedinger's cat:

“Schroedinger's cat” is not about a real cat, but rather a thought experiment which Erwin Schroedinger asked himself. He wanted to know if large objects, such as a cat, could behave in the strange way that small particles do. If a cat obeyed the laws of quantum mechanics,

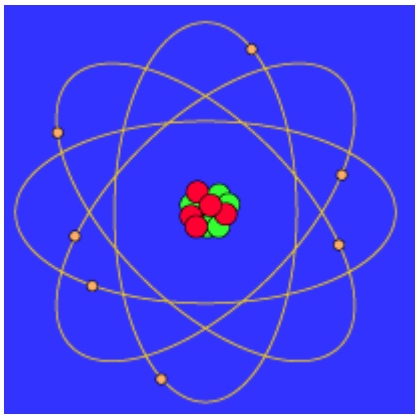
he could be 50% alive and 50% dead at the same time. The results of his thought experiment revealed that, in the world of subatomic particles, very strange things can happen that completely defy our intuition on macroscopic scales.

Uncertainty principle:

The uncertainty principle, developed by Werner Heisenberg, states that if we measure the location of a particle, we cannot be certain about its velocity. Conversely, if we measure the velocity of a particle to highest accuracy, we cannot be certain of its position.

Bohr model of the atom:

The Bohr Model is similar to the "planetary model" of the atom. In the Bohr Model, the neutrons and protons (symbolized by red and green balls) occupy a dense central region called the nucleus, and the electrons orbit the nucleus much like planets orbiting the Sun. In Bohr's model, however, the electrons are only allowed to orbit at fixed distances, an exception to the rules of physics that people believed until then, and one of the first hints of the strangeness of quantum mechanics.



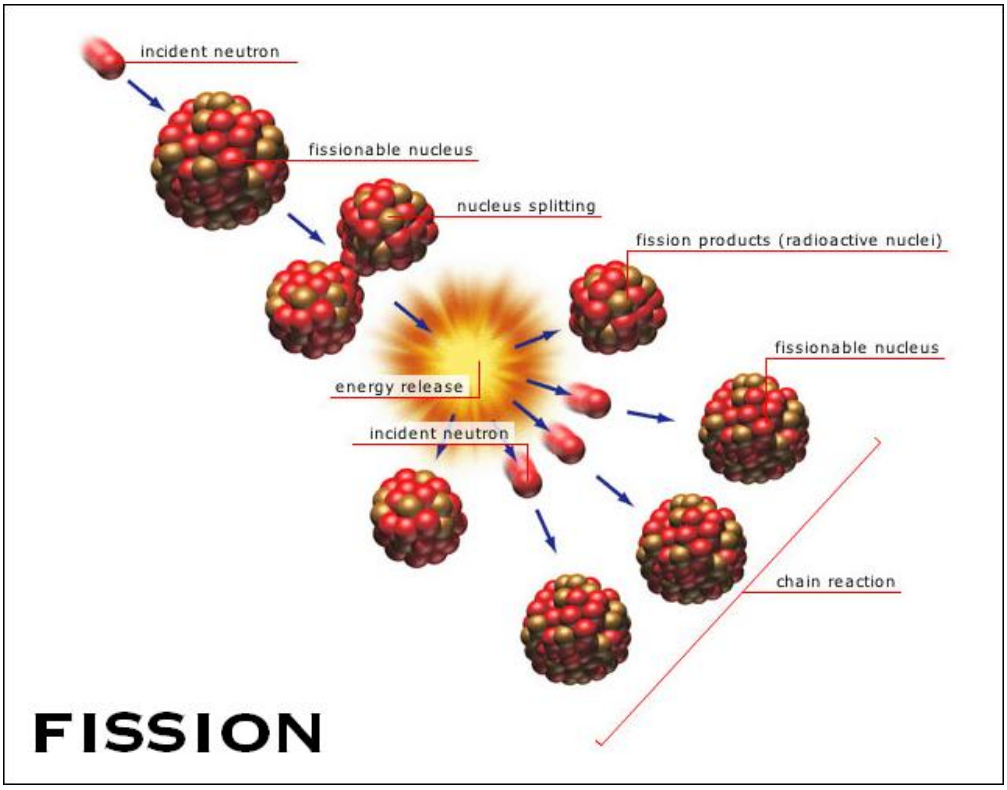
Nucleus:

At the center of the atom is an extremely small nucleus made of protons (positively charged particles) and neutrons (neutral uncharged particles). In orbit around this is a swarm of negatively charged electrons. The number of electrons equals the number of protons, so the total atom is uncharged. Standard chemistry involves the rearranging of electrons and electrical bonds between atoms, but the atoms themselves do not change. In nuclear reactions, by contrast, atoms CAN change from one element into another, or one atom can split into several different elements when its nucleus breaks apart.

Nuclear fission:

The process of splitting the nucleus of an atom into smaller parts. In

fission, one atom from one element is transformed to two atoms of two lighter elements. When this happens, large amounts of energy are released in the form of radiation and kinetic energy. Nuclear fission produces energy for nuclear power and nuclear weapons.



Chain Reaction

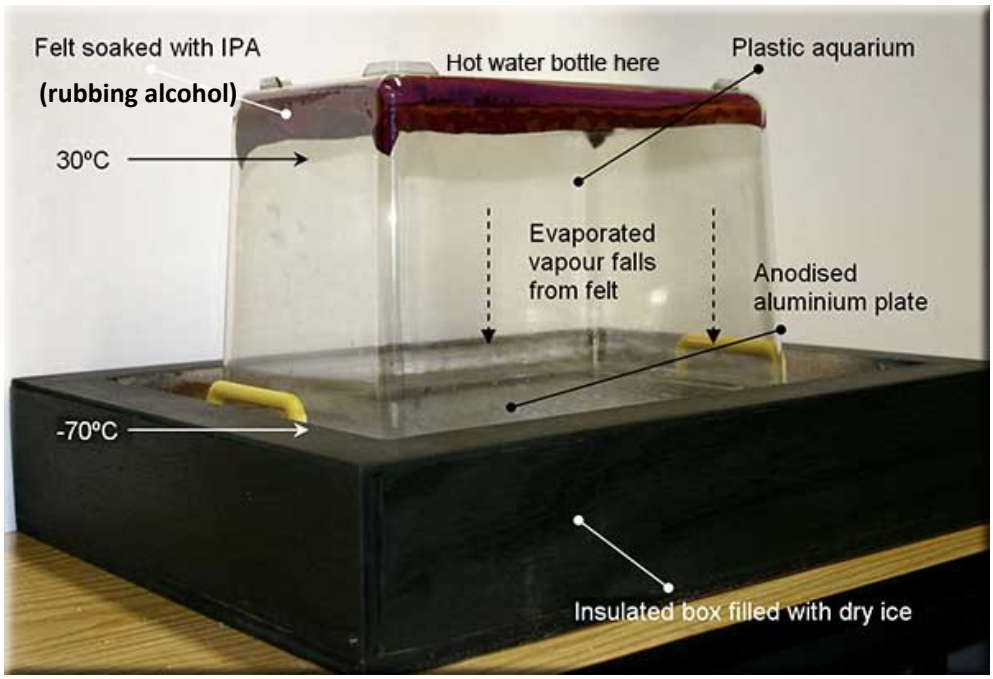
- A sequence of reactions where the product or one reaction causes several more reactions to take place.

The two processes for explosive chain reactions for nuclear fission for weaponry:

I. Purification of natural uranium to create explosively fissionable U235
II. Using slow fission of natural uranium (a mixture of U235 and U238) in a reactor to create the explosively fissionable element plutonium (Pu)

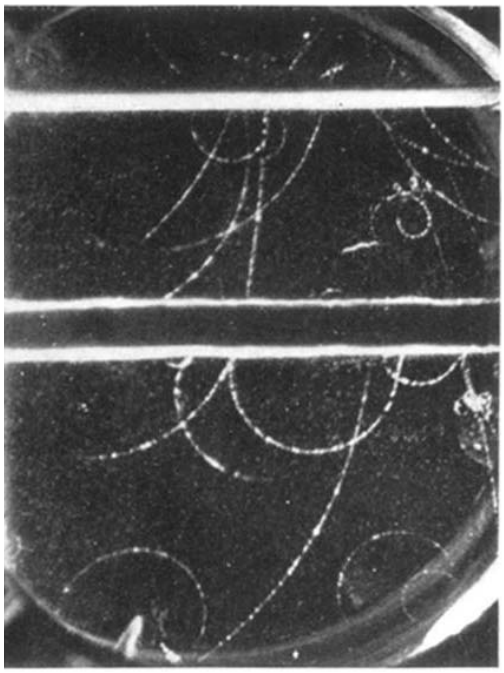
Cloud chamber:

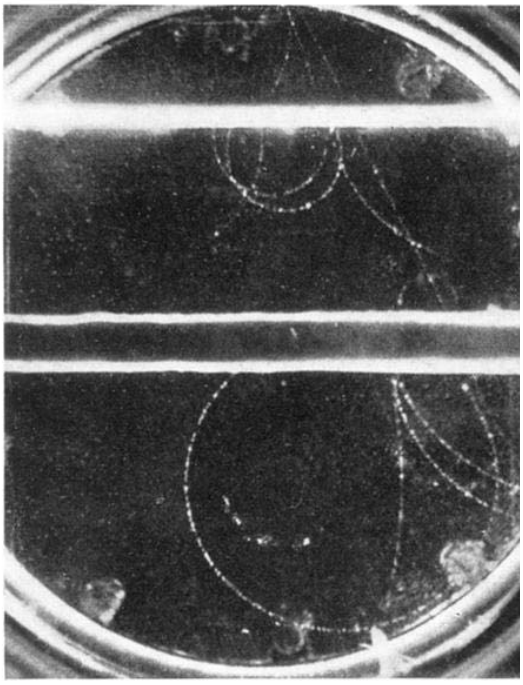
The cloud chamber was developed by Charles Wilson. It is used to detect highly energetic particles that leave behind a trail of water droplets in their wake. It basically consists of an extremely humid chamber of air where the slightest disturbance will cause a droplet to form, much like how clouds condense from water vapor in the air. A schematic for a table-top could chamber is shown below.



A cloud chamber photograph (below) shows how microscopically small particles leave behind a trail when they shoot through a cloud chamber.

In a cloud chamber, a magnetic field pointing out of the page makes the different particles behave differently. Positively charged particles spiral inwards *clockwise*, and negatively charged particles spiral inwards *counter-clockwise*. Neutral particles travel in a straight line.





In the two cloud chamber photographs above, can you locate which tracks were made by positively charged particles? Negatively charged particles? Neutral particles? Given that fast particles travel in larger circles, and slow particles travel in tighter circles. Which are the tracks from the fastest and the slowest particles?

Important Dramatic Themes

There are many important themes discussed in COPENHAGEN. Here are a few important ones:

Morality in a Time of War

What is the role of the scientist in a time of war? Frayn appears to ask this question in Copenhagen. Is it the scientist's duty to use the results of the most recent and significant research to help to protect his or her homeland, even if it means the destruction of thousands of lives? Or does a scientist have a moral obligation to use his research to improve life on this planet? Who made the better decision between Bohr and Heisenberg? Was it Bohr, when he helped create the atom bomb, thus saving the world from several cruel dictators, despite the cost to Japan? Or did Heisenberg make a better moral decision, if in

fact he did thwart the creation of an atomic bomb and thus disallowed the Nazis the upper hand in World War II? Can one even talk in terms of morality when the discussion of war is raised? Or do all morals go out the window in times of dire circumstances such as a war? These are some of the questions that Frayn raises in his play. And even though these questions are explored, no final answer can be given.

Friendship

Another underlying theme of this play is that of friendship, or more specifically, how the social and political circumstances surrounding two people can strain their relationship. No one will ever know for sure how politics interfered with the relationship between the real Heisenberg and Bohr, but Frayn attempts to demonstrate that, even in times of war, fragments of friendship remained intact between the two men, at least on a fictional basis. Despite their contradictory political beliefs, their oppositional positions on either side of a brutal war, and possibly a conflict in their concepts of how scientists should use new discoveries to create destructive weapons, readers come away from Frayn's play with a sense that the deep-seated friendship between Heisenberg and Bohr was not completely eradicated. For example, Heisenberg confesses that his network of friends was behind the successful attempts at hiding and ultimately saving Bohr from the Nazis when they came looking for him in Denmark. Frayn also tries to show the depths of the men's relationship by describing it as a father-and-son connection, implying that, no matter what hindrances might be placed between the men, there was no denying that they would be forever linked. The men, according to Frayn, thought alike and promoted and complemented one another's creative and scientific thoughts.

Uncertainty

Uncertainty is one of the concepts behind quantum physics, but it is not only in reference to quantum physics that Frayn uses this theme. There is, of course, the uncertainty of what actually happened between Bohr and Heisenberg during their meeting in 1941. That is one of the main focal points of the story. But uncertainty does not end with this unanswered question. It really only begins there. There is the

uncertainty in life itself. Heisenberg discusses some of his wartime experiences; and Bohr talks about the death of his son. As long as there are things to learn and discover, there will be uncertainty, as Frayn relates to his audience at the close of the play. Uncertainty is also linked to memory and history. The more meticulously that historical events are examined for motives, causes, and effects, the harder it is to determine whether some decisions were motivated by anything other than chance.

Power of Science

Bohr's and Heisenberg's discoveries in quantum physics might truly have, as Bohr states in the play, turned the world inside out. Not only did science change but also the view of reality itself was changed with the men's discoveries and theories, which put the men in prominent positions as revolutionary thinkers. Their knowledge made them into figures of international importance and both Bohr and Heisenberg became pivotal figures in world politics, and the peaceful application of atomic science.

Through Frayn's play, the reader grasps the significance of this political power, as well as the responsibility behind it. Frayn helps the reader realize the tremendous burden that falls on the shoulders of geniuses such as Heisenberg and Bohr — people whose intelligence allows them to shift fundamental perceptions in the way people all over the world think.

Fate

One of the more subtle themes of this play is fate. Consider the world, Frayn seems to be saying, if Heisenberg had created the atomic bomb and given it to the Nazis. What would the world be like if that had happened? As fate would have it, no matter what the reason that Heisenberg did not create the bomb — whether intentionally or by error — the explosion of the atomic bomb ended the war and eventually led to the supremacy of military power in the United States. If fate had also dictated that Bohr was killed while trying to flee Denmark to escape the Nazis, or if Bohr had been captured by the Nazis, the United States might not have been able to produce an atomic bomb. There is also the possibility that if Heisenberg and Bohr had not been brought together

by fate in the first place, quantum physics may never have been imagined.

And for a final consideration on fate: the date that Niels Bohr published his seminal paper on fission was Sept 1, 1939, and the date that Hitler invaded Poland to start WWII was Sept 1, 1939. Did fate spell the political beginning of WWII and the technological end of WWII on the same date?

Elsinore

In Shakespeare's HAMLET, Elsinore was where the castle of Hamlet's father was located. A palace tormented by ghosts and betrayal.

In COPENHAGEN the characters talk about Elsinore as a place that represents the darkness in the human soul. - A darkness which reflects the conflicting moral struggle that they encounter - the uncertainty that both Bohr and Heisenberg must confront.

Skiing

"You start a trickle of snow sliding as you ski. The trickle becomes a snowball..." This skiing metaphor also applies to what happens in a nuclear chain reaction - and to what has happened as a result of their research -- allowing others to access this information could lead to a chain reaction of nuclear development.

The playwright also uses other metaphors about skiing. Heisenberg was a notoriously fast skier and Bohr notoriously slow. Their style in skiing mirrored their style in how they attacked problems in physics.

Writing Exercises

Bohr was one of Heisenberg's greatest mentors, even though the disagreed about theories from time to time, Bohr helped Heisenberg become a great physicist. Do you have any teachers or mentors who have helped you achieve your best? Are there any times you have disagreed with them that have helped you learn more about yourself?

Heisenberg makes a discovery with dangerous implications. He is

unsure about who to tell. Have you ever known something that you were unsure about telling other people? How did you handle that knowledge?

Heisenberg and Bohr both remember the events of the evening of Heisenberg's visit to Copenhagen differently. Has your memory of a time or place ever been different than someone else's? How did those different memories effect your understanding of the situation?

Was Heisenberg working for the German government and for Hitler, or secretly against Hitler? What evidence do you have from the play to support your argument? What evidence from the play would contradict your argument? Is there any other historical evidence you can find outside the play to strengthen your point?

In the play Niels Bohr says "What does the mathematics mean in plain language? What are the philosophical implications?" Think back to a time you have learned something in school that has made a larger impact in your life. How did understanding concepts in history, mathematics, science, or ethics change how you viewed the world? How did it cause you to change your behavior? What were the larger "philosophical implications" of that knowledge?

Interview Exercise

Interview a mentor or someone who is important to you in your life

Has there ever been a decision that was difficult for you to make? Did you ask anyone for advice? How did that effect your decision? Have you ever had a great accomplishment that affected other people?

This packet was assembled with help from:
The Copenhagen theatrical program by Magnolia Six Artists,
Answers.com, csep10.phys.utk.edu/astr162/lect/light/**bohr**.html - 8k
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