Copenhagen Study Guide

The original London Production set.

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Some Bits About the Play:

“What is so refreshing about an artistic interpretation of the historical event of the Copenhagen visit is that it approaches the truth as a multifaceted and ultimately delicate construct, and that we learn to respect it as such, doubts and all.” – Jochen Heisenberg, Werner Heisenberg’s son, on Michael Frayn’s Copenhagen

The attention given to Michael Frayn’s imagined meeting between the Bohrs and Heisenberg went well beyond the normal theatre accolades. It also sparked renewed interest in the physics, the history and the ethics of a bygone event. Frayn himself was astonished at the way the play gripped the public imagination.

Michael Frayn was invited to be among the lecturers at a 1999 Seminar at the Niels Bohr Institute. As a result of the interest in the play, the Bohr estate released the drafts of the letter Bohr wrote (but never sent) to Heisenberg about their 1941 meeting after becoming angered by the account given in Robert Jungk’s book Brighter Than A Thousand Suns.

Historians have criticized Frayn for being too soft on Bohr or neglecting the contributions of other physicists in the development of quantum mechanics.

Because of this interest actor David Burke, who performed in the London production, was able to perpetuate on Frayn an elaborate practical joke in which he had a friend claim to be in possession of papers written and hidden by Heisenberg during his internment at Farm Hall. All the while the actor was forging damaged documents designed to tantalize Frayn with possible details about Heisenberg.

Public interest in the play extends beyond the merely historical. Frayn’s background in philosophy draws him to ask the big questions: how humans experience our own existence, how we can understand our own behavior and the behavior of others, and what is our ethical responsibility in our interaction with others. These larger questions take on great resonance against the backdrop of Nazi Germany and the atomic bomb, but are no less important in our current lives.

History Time:

Nuclear Family: Niels and Margrethe Bohr

“Bohr is the first scientist who also makes an impression as a human being . . . he is not just a physicist but much more” – Werner Heisenberg on his first meeting with Niels Bohr

The Danish physicist Niels Bohr was at the forefront of understanding the discipline that would come to be known as quantum mechanics. Niels Bohr was born in Copenhagen on October 7, 1885. His father, Christian Bohr, was a professor of Physiology and his
mother, Ellen Adler, was from a prominent Jewish family. His home life was very content, and he was particularly close to his brother the mathematician Harald Bohr.

After Bohr received his Ph.D. at the University of Copenhagen, he spent a brief and unhappy period as a student under J.J. Thompson at Cambridge. Bohr studied physics with Ernest Rutherford at the University of Manchester where he developed his model of the atom and proposed the idea that an electron in an atom releases a photon as it drops from a higher energy state to a lower one. It was his friendship with Rutherford that would be the model for Bohr’s own working relationship with the students he would mentor later in Copenhagen.

“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.” – Richard Courant describing Niels Bohr’s marriage to Margrethe Nørlund

In 1912, Bohr married Margrethe Nørlund, however, he postponed his honeymoon a week to finish his paper on the atom. The Bohrs’ marriage was remarkable not only because of Margrethe’s patience with Niels’ passion for physics, but also because of her own intelligence and interest. Although she had no training in physics, she typed Bohr’s papers and hosted the numerous physicists who would visit their home. She was familiar with the language of physics and Bohr respected her opinion in everything. Their marriage produced six sons and weathered the tragic loss of two of them. Christian, the eldest was just 17 when he drowned in a tragic sailing accident. His family had hoped Christian would be a poet. Harald Bohr suffered brain damage from meningitis early in his childhood. Never well, Harald had to be institutionalized. He died by age 10.

In 1920, Bohr became head of the newly formed Institute for Theoretical Physics at the University of Copenhagen. He received the 1922 Nobel Prize in physics “for his services in the investigation of the structure of atoms and of the radiation emanating from them.” Bohr enjoyed working with other physicists and brought many of the finest minds in physics to work at his Institute in Copenhagen. Bohr was often instrumental in securing the funding the students needed to stay in Copenhagen. The Carlsberg Brewery offered fellowships to many student physicists. The young physicists who came to Copenhagen not only spent time at the institute but also were frequent visitors in Bohr’s home in Copenhagen and their summer home in Tisvilde.

In September 1943, the Bohrs fled Copenhagen to escape deportation because of Niels Bohr’s Jewish heritage. They escaped in a fishing boat to Sweden. In February 1944, Bohr and his son Aage arrived in Los Alamos to work on the Manhattan Project. After the war, he returned to Copenhagen and resumed his work at the Institute. He died in Copenhagen in 1962.

“Bohr fathered many scientific ‘children’. Almost every country in the world has physicists who proudly say, ‘I used to work with Bohr.’” – George Gamow
**Movie Westerns: A Thought Experiment**

For Bohr, any event could become a thought problem. George Gamow, in his book, *Thirty Years that Shook Physics*, says that Bohr loved movie Westerns. He always took his students along to the movies with him to have them explain the plot complications. After one Western, he began to argue with Gamow and some other students about why the good cowboy always shoots the bad guy even though the bad guy always draws his gun first.

Bohr theorized that the hero was quicker because he responded on instinct and was not delayed by having to decide when to shoot. To test the hypothesis Gamow bought cap pistols and Bohr spent an afternoon at the Institute shooting his students.

**The Uncertain History of Werner Heisenberg**

> "Every word or concept, clear as it may seem to be, has only a limited range of applicability." – Heisenberg, *Physics and Philosophy*, 1963

In 1924, a young German physicist named Werner Heisenberg came to Copenhagen to work with Niels Bohr. Heisenberg was born December 5, 1901, into an upwardly mobile and academic family. His father, August Heisenberg, was a professor of Classical Greek; his mother, Annie Wecklein, was the daughter of a teacher and school administrator. Werner Heisenberg studied physics at first at Göttingen, then Munich under Max Born. He won the Nobel Prize in physics in 1932 for his work on quantum mechanics.

Heisenberg and Bohr’s collaboration resulted in the Uncertainty Principle, Complementarity and the Copenhagen Interpretation of the new field of Quantum Mechanics, which they presented and defended at the 1927 Volta Conference at Lake Como.

"I remember discussions with Bohr which went through many hours till very late at night and ended almost in despair, and when at the end of the discussion I went alone for a walk in the neighboring park I repeated to myself again and again the question: "Can nature possibly be as absurd as it seemed to us in these atomic experiments?" – Werner Heisenberg on his preparations with Bohr for the 1927 Como Conference

Heisenberg has been much criticized for his decision to remain in Germany during World War II in spite of the fact that he had offers from several universities outside Germany.

The decision to remain could not have been an easy one. Heisenberg and theoretical physics were attacked in 1936 and 1937 in the Nazi party newspaper and the SS newspaper respectively. Heisenberg was interrogated at the Prinz Albrecht Strasse but was not exonerated until 1938.
“The relationship between two people is the most important thing in our existence. At this central point from which derive happiness and unhappiness to the highest degree, one should not make any unnecessary mistakes.” – Werner Heisenberg in an unsent letter to a family member quoted by Jochen Heisenberg

**HEISENBERG’S 1941 VISIT TO COPENHAGEN**

In September or October 1941 (the accounts vary), Heisenberg went to Denmark, which had been under German Occupation since April 9, 1940. While in Copenhagen, Heisenberg visited his former mentor and friend Niels Bohr. The dispute and uncertainty over exactly what was said during this visit, what Heisenberg’s intentions were, and the irresistible explanations for Heisenberg’s behavior put forth by myriad scientists and biographers, form the historical basis for Frayn’s play.

In 1947, Heisenberg returned to visit Bohr in Copenhagen with his British custodial escort Ronald Fraser, but his attempt to reconstruct their 1941 conversation proved disastrous. Heisenberg said of their second meeting, “we both came to feel that it would be better to stop disturbing the spirits of the past.” Heisenberg gave several explanations for his 1941 visit to different people. The one that most angered Bohr appeared in Robert Jungk’s book *Brighter Than A Thousand Suns* where Jungk quotes Heisenberg as suggesting that he was attempting to undermine the German atomic program. Bohr was angered by this statement and drafted several letters to Heisenberg on the matter, but never sent them.

In 1942, concern over Heisenberg’s potential contribution to a German atomic bomb was sufficient for some in Allied intelligence to suggest kidnapping Heisenberg. However, the plot was never executed. In 1945, as Germany capitulated, Heisenberg and other German scientists were taken into custody by the Allies. In spite of one American general’s claim that it would be easier to kill the scientists, they were taken instead to Farm Hall in England. The Allies were not only concerned about the secrecy of their own atomic bomb project, but they were also beginning to have concerns about the Russians. In part, the scientists were removed to protect them from falling into Soviet hands.

Heisenberg ultimately returned to Germany and did rebuild German physics at the Max Planck Institute formerly the Kaiser Wilhelm Institute. However, he never escaped the shadow of having worked for the Nazi regime. When he visited America in 1949, many physicists avoided meeting him. Until his death in Munich in 1976, Heisenberg faced question about the German atomic project.
THE RESCUE OF DANISH JEWS

"There is no Jewish question in Denmark" - Foreign Minister Erik Scavenius to the German Hermann Göring in autumn, 1941.

A remarkable and little known piece of history amidst the atrocities of World War II is the story of the rescue of the vast majority of Denmark’s Jewish population. Denmark was invaded by Germany on April 4, 1940. The Danish army was no match for the German army. To save further bloodshed, the Danish government capitulated with little fighting. During the early years of the German occupation, the Danish Jews were not removed for fear of upsetting the Danish government, which still controlled many aspects of daily life.

However, as the war moved on, acts of sabotage perpetrated by the Danish resistance proved successful and relations with the German occupiers deteriorated. The Danish government resigned on August 28, 1943.

An Astonishing Escape

On September 28, 1943, SS officer, Werner Best received Hitler’s order to deport Denmark’s approximately 8,000 Danish Jews on October 1, 1943, at 10:00 p.m. – Rosh Hashanah – the Jewish New Year. Best confided the information to German diplomat Georg Dukwitz who told the Danish Social Democrat Hans Hedtoft who, in turn, warned Jewish leaders. On September 29, 1943, Rabbi Marcus Melchior told his congregation of the planned removal of Danish Jews and urged them to go into hiding. Most Danish Jews were hidden for a time then made the dangerous ocean crossing in small fishing boats from the Danish island of Zealand (Sjaelland) to Sweden where they were offered asylum.

Nearly one-fifth of Danish Jews escaped via the fishing port Gilleleje. Of the Jewish population, only about 481 were captured by the Nazis. Most of these were sent to Theresienstadt in Czechoslovakia. 51 of those deported had died by the end of the war.

“We stayed very low on the floor. We heard there were German patrols outside. We saw flashlights going through the windows.” – Leif Wasserman’s recollection of the boat ride to Sweden

The hiding and transport of nearly 7,500 Danish Jews required the coordinated efforts and secrecy of numerous ordinary Danes. The Jewish population was hidden in hospitals, schools, mental institutions, churches and ordinary homes. Dr. Kosten and the staff of the Bispebjerg Hospital housed hundreds of Jews before their escape. Copies of the Torah from Rabbi Melchior’s congregation were hidden in the crypt of nearby Trinity Church. Many fishing vessels added hidden compartments to avoid Nazi inspection. When the Nazi’s began using dogs to detect hidden passengers, chemists in Sweden prepared handkerchiefs soaked in rabbit’s blood and cocaine. The rabbit’s blood was to attract the dog and the cocaine would temporarily impair the dog’s sense of smell.
Separating Fact and Folklore

Even before the war, Denmark’s response to the Anti-Semitism in Germany was felt in the person of Danish King Christian X. On April 12, 1933, he attended a service in honor of the one hundredth anniversary of the Copenhagen Synagogue even though a boycott against Jews had already been declared in Germany. The stories that King Christian and other Danes wore gold stars on their garments to prevent the identification of Jews are not true. Since the race laws were never enforced in Denmark, Danish Jews were never forced to wear the stars. However, accounts of Danish officials calling Jewish-sounding names in the phonebook to warn them of the impending deportation are based in fact. After the war, when Jewish families returned to Denmark, they discovered their homes had been cared for. The looting that occurred elsewhere in Europe was virtually non-existent in Denmark.

QUANTUM LEAP: THE RAPID PROGRESS OF EARLY 20th CENTURY PHYSICS

"Anyone who is not shocked by quantum theory has not understood a single word."
- Niels Bohr

Many people alive today have grown up with both the atom and the atom bomb. It is difficult to imagine the world into which Bohr and Heisenberg embarked, in beginning to visualize the unseen world of the atom. Prior to the 20th Century, physics had been based on Newton’s laws. The electron was not discovered until 1895. The new understanding of the atom that physicists reached in the 1930s and 1940s was lightning fast by comparison with the centuries that preceded it.

Quantum Mechanics

The branch of physics that deals with the motion of bodies (a ball, a train, a drop of water) is called mechanics. Classical or Newtonian Mechanics describes the motion of objects in the observable world. Quantum Mechanics is the branch of physics that was developed by physicists when they discovered that Newtonian Mechanics could not adequately describe the motion of bodies on atomic and subatomic levels. In 1900, Max Planck discovered that heat energy is not continuous (like a wave) but exists in discrete packets or quanta (like a particle), and that all transmissions of energy are made in these units. In 1905, Albert Einstein discovered that light, too, must be thought of not just as waves but also as quantum particles. By 1913, Niels Bohr discovered that quantum theory applies not just to energy but to matter as well. Bohr used his understanding of quanta to create his model of the atom. The Bohr Model of the Atom is the one many of us were taught in school; with the nucleus sitting in the center like the sun and electrons moving like planets in orbits around the nucleus. Out of his work with Rutherford, Bohr realized that electrons in an atom exist at certain energy levels, which he described as orbits. By applying quantum theory to the atom, Bohr explained how the number of electrons in an atom is limited to certain whole number possibilities. The Bohr model of
the atom was ultimately supplanted by the quantum theory of the atom, as orbits may
incorrectly imply that an electron has an unchanging pathway. Electrons are still
imagined as moving around an atom, but the model is more like an electron cloud with
mathematical probabilities of finding an electron in various places around the nucleus of
an atom.

“The opposite of a correct statement is a false statement. But the opposite of a
profound truth may well be another profound truth.” –Niels Bohr

Heisenberg’s Uncertainty Principle

Heisenberg succinctly described his Uncertainty Principle, “The more accurately you
know the position of a particle the less accurately you know its velocity and vice versa.”
Sometimes referred to as the “indeterminacy principle,” it expresses the limitations of
simultaneously measuring the position and the momentum of a particle. One common
metaphor for understanding the Uncertainty Principle is photography. Rather than
particles, imagine bullets. If you photograph a speeding bullet, you could have a picture
of a blurry bullet and you might be able to calculate its velocity from the blurriness in the
image, but you would not know its exact position. Alternately, you could have a photo of
a bullet suspended in air from which you could determine where the bullet was but not
how fast it was moving when it was photographed.

Complementarity

Complementarity describes wave-particle duality, in which different measurements
(experiments) done on a system reveal it to have both wave-like and particle-like
properties depending on the experiment. A system can behave as a particle or a wave but
never as both at the same time. Bohr discovered complementarity as an adjunct to
Heisenberg’s Uncertainty Principle. Bohr noted that the principle of complementarity
"implies the impossibility of any sharp separation between the behavior of atomic objects
and the interaction with the measuring instruments which serve to define the conditions
under which the phenomena appear."

Schrödinger’s Cat

Theoretical physicists regularly work by proposing a “Gedankenexperiment,” a thought
experiment, to sort out the answer to a difficult question. Erwin Schrödinger proposed
one such famous experiment. A cat is placed in a box with a radioactive isotope, a Geiger
counter, a hammer, and a vial of cyanide. Each hour there is a 50-50 chance the isotope
will decay, registering on the Geiger counter, and causing the hammer to break the vial of
cyanide and poison the cat. Is the cat in the box dead or alive? Intuitively we would say
the cat must be dead or alive. However, on average, the cat is half alive and half dead,
and in physics the cat is both alive and dead until the box is opened. When the box is
opened the act of observing then changes to state of the cat to being either alive or dead.
The dual state of the cat can be described as a wave function, which collapses when the
observer opens the box.
Double slit experiment

Light is shown through a panel that contains two slits. The light on the opposite side of the panel appears in bands of light and dark indicating the interference of waves that have passed through the two slits and supporting the wave-like nature of light. Thomas Young first did the double slit experiment in 1805 to determine whether light was composed of particles or waves traveling through ether. It was revived as a “Gedankenexperiment” or thought experiment in quantum mechanics. By the 1920s, quantum physicists had already shown that light interacts with matter in discrete quantum packets. So the thought experiment asked what would happen if a single photon of light was aimed at the two slits and hit a sensitive surface on the other side. If just one slit in the panel is open, the photon hits on the sensitive surface will pile up in the same general location if the experiment is repeated. If both slits are open and the experiment is repeated, the pattern of bands will appear. Since the photons are being sent through the slits one at a time, this suggests that they could not be “interfering” with each other. To resolve this problem, modern quantum mechanics postulates probability waves that indicate the likelihood of finding a particle in a particular place. These probability waves provide the interference that ordinary waves would supply.

Particle or Wave: Wave-Particle Duality

Since subatomic particles exhibit characteristics of both waves and particles, a phenomenon known as the wave-particle duality. The terminology of quantum mechanics can be tricky. Sometimes subatomic particles may be referred to as subatomic systems in an effort to avoid the word “particle” when it may not be accurate for the circumstances. Wave-particle duality is a key concept of quantum mechanics. It holds that light and matter can exhibit the properties of both waves and particles. This was contrary to the understanding of classical mechanics in which something was either a wave or a particle, but not both. This is part of what made quantum mechanics such a giant shift in the prevailing thinking that had dominated physics for hundreds of years.
Character Guidelines:

General note: The Bohrs and Heisenberg exist in this play on two planes: Firstly as ghost or spirits, detached and somewhat omniscient, certainly removed from the cares of the world. The second is the present: The here/now of the timeline – the visit in 1942 of Heisenberg to Bohr, where they are living their real emotions of that time. They keep slipping back and forth between these two states, in a constant quantum flux. The poetry of quantum physics still engulfs them, even though each has (in retrospect) participated in the development of the Bomb. Margrethe is both internal observer and the eternal feminine. For the greater part of the play, Margrethe remains above the here/now state. In describing the characters, I will be talking of the here/now state almost exclusively.

The multi-layered nature of the relationships is vital. On one level the three characters we see are a family united by love. That Bohr and Heisenberg have a strong paternal and filial bond is clear enough (it's even announced in the play—and reinforced by Bohr's patriarchal authority in the science community), and Margrethe's response to this bond registers first and foremost as arising from the family dynamics of a partially estranged wife—estranged by the way in which Heisenberg has replaced her drowned son (perhaps drowned, we are led to believe, by Bohr's failure to take the bold step and dive into the sea to attempt a rescue of his son) and by the way the two of them form a bond which seems to shut her out (they pursue their scientific interests, for example, by abandoning her to look after two very young children, whose names Bohr cannot get right). She serves their scientific enterprise by typing manuscripts endlessly and by acting as the sounding board for their ideas, but there's strong sense of resentment in Margrethe, as if the success of the men in her life has come at considerable personal cost to her family (although there is no questioning her absolute loyalty to her husband).
So in that sense, the play is a family dispute, and there is a family explanation for the events of the play: that Heisenberg came to Copenhagen seeking Bohr's approval, to obtain his blessing, or, as he calls it, "absolution," or alternatively that he came to proclaim his independence and superiority over and independence of the other members of his family.

We also are given a sense of some of the cut-throat rivalry of modern science, where professional success, fame, the ability to earn a living rest on the publication of a paper, where rivals are dangerous (both to one's ego and to one's prospects), and where motives for particular theories are often obscure (Is the Copenhagen school a genuine melding of rival theories or an uneasy compromise stitched together for the mutual professional benefit of both parties? Was Heisenberg's major motive for coming up with the Uncertainty Principle a personal resentment of a rival physicist, and so on?).

Out of this dimension of the story emerge more interpretative possibilities for Heisenberg's visit. Perhaps he came to Copenhagen to restore or regain a sense of that imaginative vitality in the great years, perhaps he is seeking direct assistance from Bohr in some scientific problems associated with his present work, perhaps he comes to Copenhagen to assert his new power and prestige in the presence of his old patron and collaborator—all of these possibilities arise naturally out of the conduct of the characters as we witness them probe through the evidence.

Beyond that, Bohr, Margrethe, and Heisenberg live in a sharply demarcated political environment in which the Germans have occupied Denmark and are on the point of moving against the Danish Jews, with ample evidence by 1941 of what that "moving against" involves. As a successful and prominent German scientist, Heisenberg stands out as a collaborator with the racist murderers determined to conquer Europe and exterminate the race to which Bohr belongs. We see clearly that the political situation places Heisenberg in a conflict (a problem which has aroused the suspicions of his Nazi superiors and earned him the title of a White Jew), but it is by no means clear where he stands exactly. For although there is no suggestion the Heisenberg is a Nazi or sympathetic to the Nazi, it is clear that he is a strong German nationalist, ready to compromise whatever distaste he has for the Hitler regime in order to protect Germany and to avert the disasters he witnessed as a child and to promote and advance German science.
Heisenberg

Heisenberg, in the play and in the world, is the unknown. His role in the Nazi atomic bomb project is the subject of much speculation, and his German nationalism created and creates suspicion and ambiguity. He reveres Bohr as his scientific father, but his speeches suggest a less than comfortable relationship in which the son would like to supplant the father in scientific achievement and in which the son is jealous of another German scientist, Erwin Schrödinger.

In the play, Heisenberg is younger than Bohr or Margrethe. Flush from his new sense of authority and somewhat filled with that maddening Germanic matter-of-fact arrogance, he is nonetheless still in the thrall of his mentor and there is a touching plaintiveness to his relationship to Bohr. He feels strongly, although subconsciously, that he is a child of Bohr’s, and his defensiveness is therefore typical of the child under attack by the parent – he is eager to defend himself, to explain, to shift the blame, to be returned to the good graces, yet at the same time, his adult self is rebelling, demanding to be recognized as a individual and a self-determined being.

This play is the trial of Heisenberg. What exactly prompted his trip to Copenhagen? What did he want? How does his behaviour before and after the trip illuminate his actions? In particular, what sort of moral judgment are we to make of the man based on the evidence and the character presented to us? And, beyond that, what if anything do we learn from the process we have to go through in sifting the evidence presented to us?

The play offers two different accounts for the Nazi failure to develop the bomb, both equally coherent: the first is that Heisenberg knew what he was doing and made sure his program would not be successful, the second is that Bohr deliberately withheld from Heisenberg (at the meeting) the information or encouragement Heisenberg needed to be successful. In the same way, the play puts pressure on us to distribute our moral sympathies in different ways: Heisenberg may have worked for the Nazis but he saw to it that their bomb project never reached fruition; Bohr was a persecuted Danish Jew who
ended up helping to inspire and design the bombs dropped on Hiroshima and Nagasaki. Alternatively, Heisenberg was a keen scientist working hard to resolve key problems for his tyrannical racist sponsors, while Bohr's scientific efforts on the bomb were either trivial (as he mentions) or part of a worthwhile cause. Which is the case? And which Heisenberg is the one we see?

Frayn defended his balanced and human portrayal of Heisenberg and his participation in the Nazi's nuclear project most clearly in a piece he wrote for the March, 2002, edition of The New York Review of books. "Why shouldn't [Heisenberg] have the same conflicting loyalties and the same mixed motives and emotions that we all have? Why shouldn't he try to juggle principle and expediency, as we all do? Why shouldn't he fear his country's defeat, and its destruction by nuclear weapons? Why shouldn't he lament its ruin and the slaughter of its citizens?" In the play, and in real life, Heisenberg recounts with bitterness the refusal of some of the scientists who had worked at Los Alamos (and who had produced the atom bomb) to shake his hand on the grounds that he had tried to tried to make such a bomb for Hitler.

**Bohr**

Niels Bohr seems to be the known in Michael Frayn's play. Although Heisenberg in the play says that Bohr is both the Holy Office and the Inquisition in one person, Bohr has not the mystery or the fascination Heisenberg has. He is the half-Jewish father (Pope) of the spiritual seekers who hope to find Truth in understanding the atoms that constitute the universe. He escaped from Nazi-occupied Denmark and so holds the moral high ground, in spite of his never confirming an active role in the execution of the Allies' atomic bomb project.
In the play, he is the grand old man of science to Heisenberg’s tightly wound nerves, apprehension, fear, anger, and ego, both hesitantly seeking to re-establish a lost camaraderie and understanding. Bohr wants to reignite the warmth he felt to his old student, but is kept at arm’s length by both the behaviour of Heisenberg and the knowledge of all that is to come – he is Sphinx-like and uncanny. There is a certain heaviness about his emotional being, something of a grey fog that lightens when he discusses physics with Heisenberg and flashes red when he searches for the truth under all of Heisenberg’s conflicting and enigmatic explanations for the advent of his visit.

Bohr later joined the Los Alamos project, and in the play admits his feelings of guilt over the destruction of Hiroshima and Nagasaki. Heisenberg makes clear that he feels the barbarity of this act rivalled that of the Nazis, and Bohr is hard pressed to disagree.

Bohr and Heisenberg met a kind of a need in one another. Bohr was older and sort of a father figure, not only to Heisenberg but for a lot of young scientists. This comes through in the play by Bohr’s taking on the Inquisitor’s role, seeking confession and truth from Heisenberg, willing, even wanting to visit absolution on him, and in respect, on himself as well.

Their relationship was one of the classic friendships of science.

Bohr did most of his original work as a young man. By the time he reached middle age he was doing some original work, but his best work was done in collaboration with young physicists who came and worked with him in Copenhagen. And so his reaction to Heisenberg in the play is also one of need – to rekindle his creative fires and bring his best self forward again – yet he does not wish to give that away, and shows his excitement only carefully.

Bohr was very good at challenging people to think about what they were saying, to go further in their thinking than they had dared to go before. Heisenberg was exactly the converse of this, someone who needed a father figure.

Added to which Bohr is put on the spot and is more than a little embarrassed. Bohr did and does and does not want to be visited by a German in 1941. He did not want to appear to be collaborating.
The wife and complement of Niels Bohr, Margrethe Norlund Bohr was an integral part of his life and his work. In Act I of Copenhagen, Bohr says that he is "a mathematically curious entity: not one but half of two." He paradoxically half of his marriage, and half of his friendship and collaboration with Heisenberg. Although Margrethe was not present during the conversation between Bohr and Heisenberg, her being in the play is essential since the conversation in the play is akin to Nietzsche's eternal recurrence at the personal level, an exploration of the loss of their sons: Christian, Harald, and Werner. In the play, the characters are like ghosts who haunt those who caused and participated in their pain. Like analysands trapped in memory and trauma, they talk and talk without resolution.

Her role in the play is multi-dimensional. We can suggest that Margrethe's presence is a way of keeping the physics at the audience's level: two physicists left to themselves would talk like physicists, but the two men have to discuss physics in terms Margrethe (and the audience of the play) can understand. What she certainly is is like the chorus in Greek tragedy: she clarifies the conversation/action for the audience. But she also has a more traditionally female function in that she opens the emotional discussions about Heisenberg as the enemy, and her comments keep the men from sublimating jealousy and other negative emotions into disagreements about physics. The scientific is the personal, as the political is the personal. Observer and observed are intertwined in life as in science; the resulting observations are not simple data points. As a complement to her husband, she seems at times the contrary of Heisenberg. Frayn's sharp-tongued fictionalization of her appears at odds with the usual portrait of her as a stately woman who was also a mother to his students.

Frayn: “I thought we needed three characters. We obviously needed Werner Heisenberg and she was particularly suspicious of that meeting in 1941. She said afterwards, whatever anyone says, that was a hostile meeting.

Margrethe is there in the way that all the other people in the world are attempting to explain his behavior. And almost everyone who is not Heisenberg took a very hostile view of Heisenberg's behavior. So the Margrethe character expressed that side.”
For the most part, she inhabits the spiritual plane in the play, commenting, probing and clarifying on the emotional truth of the two men – yet she does descend into the here/now strongly with the loss of her children and her deep antipathy toward Heisenberg’s seeming taking their place, and the effect is shattering.

She is the clarifier of history for us, but also the play’s moral voice. Margrethe accuses Heisenberg of failing to understand their situation under a German occupation; of being willing to work for Hitler; of working on a German nuclear reactor that could be employed for the construction of a bomb; of trying to show off. And Niels Bohr, but I thought we needed Niels Bohr's wife Margrethe as well.

We needed her for two reasons. Partly because she historically had no scientific training and yet her husband discussed all his work with her. And they agree at the beginning that they are going to make everything plain to Margrethe. So Margrethe is our representative there.

The second thing about Margrethe is that she didn't much like Heisenberg. Niels Bohr adored Heisenberg. She always had a much more negative view of him:

Margrethe: And if you want to know why you came to Copenhagen in 1941 I'll tell you that as well. You're right--there's no great mystery about it. You came to show yourself to us.

Bohr: Margrethe! Margrethe! No!

Margrethe: When he first came in 1924 he was a humble assistant lecturer from a humiliated nation, grateful to have a job. Now here you are, back in triumph--the leading scientist of a nation that's conquered most of Europe. You've come to show us how well you've done in life.

Bohr: This is so unlike you!

Margrethe: I'm sorry . . . but isn't that really why he's here? Because he's burning to let us know that he's in charge of some vital piece of secret research. And that even so he's preserved a lofty moral independence, preserved it so famously that he's being watched by the Gestapo.

This attribution of Heisenberg's motives sounds exaggerated; but it is Frayn's purpose to portray a triangular relationship, with Margrethe differing not only from Heisenberg but also from Bohr. Only at the very end of the play does Margrethe relent somewhat. We emerge from the play with a considerable respect for Heisenberg, who is (and was) not a villain. In their last agonized and philosophic conversation, all three of them accept uncertainty and talk about themselves having turned to dust, and perhaps the world laid to dust, though in the last words of the play Heisenberg appears as the vitalist and perhaps even optimist.
Afterthoughts

This play is in no way about the Atomic Bomb, or Hiroshima or Nagasaki. It is about many things – truth, guilt, love, the romance of science, culpability and regret, but the shadow of the Bomb is not truly upon it, at least not more than a slight smudge – to try to work that theme in any real way into the piece is to do a disservice to the themes of the play.

The play is not so much about the science itself as it is about how scientific ideas can help us to understand the manifold possibilities the future holds, and how history consists of a constant transformation from this indeterminate future, through the present to a single past.

Science, even brilliant science, does not define an age. It’s what human beings do with it, and the effect it has on them, that matters. For all the offered, simplified explanations of the science at the core of Copenhagen, it’s the story of these three people, Werner, Neils and Margrethe, that touches us. Copenhagen asserts that human motives are knowable only within definite limits. The characters in the play argue that even the past is difficult, and, in terms of motives, impossible to determine. Frayn compares the psychological difficulty of understanding motive with the difficulty in simultaneously measuring the movement and speed of subatomic particles, which is the subject of Heisenberg's Uncertainty Principle.

Although Frayn is using scientific concepts outside their proper range of application, his intention is to inspire the audience to ask questions and not accept a fatalistic and shallow view of events. The artistic device is effectively used to illustrate the uncertainties animating the play. It is also meant to urge the audience on to a consideration of the great uncertainties that lie in front of the human race.

Bohr’s Letter (unsent)

Dear Heisenberg,

I have seen a book, “Stærkere end tusind sole” [“Brighter than a thousand suns”] by Robert Jungk, recently published in Danish, and I think that I owe it to you to tell you that I am greatly amazed to see how much your memory has deceived you in your letter to the author of the book, excerpts of which are printed in the Danish edition.

Personally, I remember every word of our conversations, which took place on a background of extreme sorrow and tension for us here in Denmark. In particular, it made
a strong impression both on Margrethe and me, and on everyone at the Institute that the two of you spoke to, that you and Weizsäcker expressed your definite conviction that Germany would win and that it was therefore quite foolish for us to maintain the hope of a different outcome of the war and to be reticent as regards all German offers of cooperation. I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, under your leadership, everything was being done in Germany to develop atomic weapons and that you said that there was no need to talk about details since you were completely familiar with them and had spent the past two years working more or less exclusively on such preparations. I listened to this without speaking since [a] great matter for mankind was at issue in which, despite our personal friendship, we had to be regarded as representatives of two

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sides engaged in mortal combat. That my silence and gravity, as you write in the letter, could be taken as an expression of shock at your reports that it was possible to make an atomic bomb is a quite peculiar misunderstanding, which must be due to the great tension in your own mind. From the day three years earlier when I realized that slow neutrons could only cause fission in Uranium 235 and not 238, it was of course obvious to me that a bomb with certain effect could be produced by separating the uranums. In June 1939 I had even given a public lecture in Birmingham about uranium fission, where I talked about the effects of such a bomb but of course added that the technical preparations would be so large that one did not know how soon they could be overcome. If anything in my behaviour could be interpreted as shock, it did not derive from such reports but rather from the news, as I had to understand it, that Germany was participating vigorously in a race to be the first with atomic weapons.

Besides, at the time I knew nothing about how far one had already come in England and America, which I learned only the following year when I was able to go to England after being informed that the German occupation force in Denmark had made preparations for my arrest.

All this is of course just a rendition of what I remember clearly from our conversations, which subsequently were naturally the subject of thorough discussions at the Institute and with other trusted friends in Denmark. It is quite another matter that, at that time and ever since, I have always had the definite impression that you and Weizsäcker
had arranged the symposium at the German Institute, in which I did not take part myself as a matter of principle, and the visit to us in order to assure yourselves that we suffered no harm and to try in every way to help us in our dangerous situation.

This letter is essentially just between the two of us, but because of the stir the book has already caused in Danish newspapers, I have thought it appropriate to relate the contents of the letter in confidence to the head of the Danish Foreign Office and to Ambassador Duckwitz.

GLOSSARY OF KEY TERMS IN COPENHAGEN

Atom
An atom is a submicroscopic structure found in all matter. Originally from the Greek, it was believed to be the smallest indivisible particle of matter; however, research soon proved that there are smaller subatomic particles. An atom contains a nucleus of positively charged protons and nonelectrically charged neutrons at its core. Most of the mass of an atom is contained in its nucleus. Smaller negatively charged electrons are found around the nucleus. Atoms are classified by their atomic number, the number of protons in the nucleus. Niels Bohr, working under Ernest Rutherford, postulated an atom with orbitals in which the electrons moved around a nucleus. An electron had to exist in one of the orbitals and when an excited electron dropped to a lower orbital the energy emitted was a specific quantum amount. Now electrons are perceived as existing in a cloud, that is, the probability of finding an electron at a certain point around the nucleus. Sometimes the area that electrons occupy is referred to as an electron shell.

Proton
A proton is a positively charged subatomic particle it has about 1836 times the mass of an electron. Ernest Rutherford discovered the proton in 1918. The proton with neutrons makes up the nucleus of an atom and the number of protons determines which element the atom is. The proton itself is made up of smaller subatomic particles not discussed in Copenhagen.

Neutron
The neutron is a subatomic particle that has a slightly larger mass than a proton and no electrical charge. Together with electrons, neutrons make up the nucleus of an atom. An atom may have a different number of neutrons and remain the same element; it has the same atomic number. If its atomic mass changes however and it is known as an isotope. Carbon-12 has 6 protons and 6 neutrons, but carbon-14 had 6 protons and 8 neutrons. Carbon-14 is an isotope.
**Electron**
Electrons are negatively charged subatomic particles that move around the nucleus of an atom. Electrons determine how atoms interact with each other and determine the chemical properties of an element. Electricity is created by moving electrons.

**Photon**
A photon is considered an elementary particle. It is a quantum of energy. It exhibits the characteristics of both a wave and a particle. Light is composed from a large quantity of photons. A very high-energy photon is called a gamma ray.

**Isotope**
Isotopes are forms of a chemical element that have the same atomic number but a different atomic mass. The atomic mass is different because there are additional neutrons in the nucleus of the atom. The atomic number of an isotope remains the same because the number of protons remains the same. The number attached to the element indicates the additional neutrons. Uranium-238 and uranium-235 are isotopes. Isotopes occur in nature as a percentage of the element.

**Uranium-235**
Uranium-235 is an isotope of uranium that differs from uranium-238 in its ability to cause a rapidly expanding fission chain reaction. A uranium nucleus that absorbs a neutron splits into two new nuclei. It then releases two or three more neutrons, which, in turn, can fission other nuclei. In a nuclear reactor, the reaction is slowed down by control rods made of an element that absorbs neutrons such as cadmium, boron or hafnium. In a nuclear bomb, the reaction is uncontrolled and the energy release creates a nuclear explosion. Only .72% of natural uranium is uranium-235.

**Uranium-238**
Uranium-238 is the most commonly occurring isotope of uranium. When a neutron hits uranium-238 it becomes the unstable uranium-239, which decays into another element known as neptunium-239, which ultimately decays into plutonium-239. Uranium-238 is important because it impedes fission. For use in a weapon, minimizing the amount of uranium-238 is ideal. However, in a nuclear reactor uranium-238 is best to breed plutonium.

**Plutonium**
Plutonium is a radioactive metallic element that is used in most modern nuclear weapons. The most important of its isotopes is plutonium-239. Plutonium is desirable in nuclear weapons because the critical mass for a nuclear explosion is between 10-16 kilograms, a sphere about ten centimeters in diameter. Detonation of plutonium will create an explosion of about 20 kilotons per kilogram of plutonium. Almost all plutonium is manufactured from uranium.
**Fission**
Fission is a nuclear process, which means it occurs in the nucleus of an atom. When the nucleus of an atom absorbs a neutron and the atom splits into two more, smaller nuclei and some by products such as free neutrons and photons occur.

**Cadmium**
Cadmium is a metallic element that is useful in nuclear reactors for its ability to absorb neutrons and thus slow a chain reaction. Cadmium and its compounds are extremely toxic to the human body.

**Heavy Water**
Heavy water is chemically the same as H₂O. However, the atoms of hydrogen are of the heavy isotope deuterium. In deuterium, the nucleus contains a neutron in addition to the single proton that would be found in the nucleus of hydrogen. For this reason, it is also known as deuterium oxide. Heavy water is used in some nuclear reactors as a neutron moderator. It slows neutrons so they can react with the uranium in the reactor.

**Nuclear Pile**
A nuclear pile is another term for a nuclear reactor, a device in which nuclear reactions can be controlled and sustained. It was called a pile because of the layering of a fissile element such as uranium with a control element such as cadmium. Enrico Fermi and Leo Szilard were the first to create such a nuclear reactor at the University of Chicago.

**Chain reaction**
A nuclear chain reaction takes place when more than one nuclear reaction is caused by another nuclear reaction leading to an exponential increase in nuclear reactions. In fission, a chain reaction occurs when the neutrons released by the fission of an atom of an element in turn strike other nuclei and fission them.

**Critical Mass**
Critical mass is the mass of a fissile material required for a sustained nuclear reaction

**Slow Neutron**
Slow neutrons, also called thermal neutrons, are often used in fission because they are more easily absorbed by atomic nuclei.

**Fast Neutrons**
Fast neutrons are so-called to distinguish them from slow neutrons. They are the neutrons produced by nuclear fission and have higher kinetic energy. In reactors, neutron moderators are used to slow down fast neutrons.