What Happens in Copenhagen Stays in Copenhagen:
Using the Play *Copenhagen* to Understand the Nature of Knowledge

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This curriculum unit is recommended for:
International Baccalaureate physics SL, HL, and Theory of Knowledge (TOK)

Keywords: Physics, Theory of Knowledge, International Baccalaureate, Copenhagen, Nuclear Fission, Heisenberg, Bohr.

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: The atomic scientist of the early twentieth not only created a great uncertainty in the world, but they generated moral and ethical dilemma through their discovery of nuclear fission and fusion and the creation of atomic weapons. This curriculum unit uses Michael Frayn play *Copenhagen* to address International Baccalaureate Theory of Knowledge curriculum concepts of memory and reasoning and to examine how comparisons between the different areas of knowledge, reflect on how knowledge is arrived at in the various subject areas and what each subject area have in common. Students will also study the impact of physics on society, the moral and ethical dilemmas created by scientific discovery, and the social economic and environmental impact of the work of scientists in a global context.

I plan to teach this unit during the coming year in to 70 students in International Baccalaureate Theory of Knowledge and International Baccalaureate Physics HL II.

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Introduction

> *Heisenberg and* Schrödinger *are speeding in a car and get pulled over…*
> *Heisenberg is in the driver's seat; the officer asks, "Do you know how fast you were going?"*
> *Heisenberg replies, "NO, but I know exactly where I am!"*
> *The officer looks at him confused and says, "You were going 108 mph!"*
> *Heisenberg throws his arms up and cries, "Great! Now I'm lost!"*
> *The officer, now more confused and frustrated orders the men outside of the car, and proceeds to inspect the vehicle. He opens the trunk and yells at the two men,*
> *"Hey! Did you guys know you have a dead cat back here?"*
> *Schrödinger angrily yells back,*
> *"We do now!"*[1]

What most high school students know about Werner Heisenberg is that Heisenberg is the alias for a high school chemistry teacher turned illegal drug manufacture from *Breaking Bad* television show. They know less, if anything, about Schrödinger-- only that he had a cat named after him but not much more. But these great scientists have changed the way we think about the how atoms work and how matter and energy are linked. The discoveries made by these and other atomic scientists have changed the world not just the world of science. The atomic scientist of the early twentieth century not only created a great uncertainty in the world, but they generated moral and ethical dilemma through their discovery of nuclear fission and fusion and the creation of atomic weapons. This curriculum unit uses Michael Frayn play *Copenhagen* to address International Baccalaureate Theory of Knowledge curriculum concepts of memory and reasoning and to examine how comparisons between the different areas of knowledge, reflect on how knowledge is arrived at in the various subject areas and what each subject area have in common. Students will also study the impact of physics on society, the moral and ethical dilemmas created by scientific discovery, and the social economic and environmental impact of the work of scientists in a global context.

Classroom and School Environment

I teach at an urban, partial magnet high school with a total population of roughly 1900 students, with approximately 850 students who are part of the International Baccalaureate (IB) magnet. The school is comprised of approximately 52% Africans American, 25%

white, 16% Hispanics and 6% Asian. More than 50% of the student population is on free and reduced lunch. I will be using the curriculum unit with the all International Baccalaureate seniors in their Theory of Knowledge classes; and with my IB physics HL senior students. The International Baccalaureate physics course is a college level physics curriculum divided over two years that includes a minimum of 60 hours of experimental work. The International Baccalaureate Theory of Knowledge course (TOK) is a required class in the IB curriculum, which engages student in the reflection of the nature of knowledge. All International Baccalaureate diploma candidates at East Mecklenburg High School take the theory of knowledge class in their senior year.

Rationale

I want to use Michael Frayn play *Copenhagen* as a guide to address the following objectives in the IB curriculum.

The aims of the International Baccalaureate Physics course is to expose students to the most fundamental experimental science, which seeks to explain the universe from the smallest particles to an understanding of the origins of the universe. Yet more importantly, students will study the impact of physics on society, not simply by comprehending the scientific impact it had, but by exploring the moral and ethical dilemmas, and the social economic and environmental that emerged from impact of the work of scientists in a global context.

Science and the theory of knowledge

One required course in the International Baccalaureate program is the theory of knowledge (TOK), which engages students in the reflection on the nature of knowledge and on epistemology, that is, how we know what we claim to know. The course identifies eight ways of knowing: reason; emotion; language; sense perception; intuition; imagination; faith; and memory. International Baccalaureate students explore the means of production knowledge with in the context of the various subject areas including the natural sciences. The course also requires students to make comparisons between the different areas of knowledge, reflection on how knowledge is arrived at in the various subject area and what each subject area have in common.[2]

Science Objectives

One of aims in the International Baccalaureate science curriculum is to integrate the overarching theme of the Nature of science to: become critically aware, as global citizens, of the ethical implications of using science and technology develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities.

In addition, one of the stated aims of the International Baccalaureate science curriculum is to engage the human face of science, by understanding that science is a collaborating exchange of results, in which scientist work in small and large scale groups between disciplines, laboratories and organizations. One example noted in the International Baccalaureate curriculum guide is The Manhattan Project, the project that brought scientist and technical experts together to build and test an atomic bomb. It eventually employed more than 130,000 people and has change the world in myriad ways. The Manhattan Project has been controversial and arouses emotions among scientist and the public because of its destructive history, as well as the growing potential for many nuclear powers to change the world. The building of the atomic bomb has created uncertainty in the world, despite the fact that it has also helped advance national development world wide as a new source of electrical power. In addition, to exploring *Copenhagen* I want to include questions dealing with the American involvement in building and using the atomic bomb.[3]

Quantum Mechanics and the Uncertainty Principle

> "The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa."
>
> –Heisenberg, uncertainty paper, 1927[4]

The theories of the atom and of quantum mechanics are perhaps the most successful theories in the history of science. But they are also theories that challenge our imagination. Modern atomic theories seem to violate some of the most fundamental principals of classical physics of Newton but also the classical electromagnetic theory of Maxwell. Bohr described an electron orbiting in a quantum energy state without radiating away its energy as the Maxwell's electromagnetic theory required. Bohr postulated, but could not explain, that each quantum orbit could be considered a "stationary state" with energy losses or gain occurring only when electron jumped *between* the stationary states.[5]

At the heart of atomic science and quantum mechanics is the duality of nature. It starts with James Clerk Maxwell and his electromagnetic theory and his thought experiment he created to contradict the second law of thermodynamics, call "Maxwell's Demon." Maxwell suggested that if you have a box filled with a gas at some temperature, the average speed of the molecules in the box depends on the temperature. Some of the molecules will be going faster than average and some will be going slower than average. But, suppose that a partition is place across the middle of the box separating it into into left and right. Both side of the box are now filled with the gas at the same temperature. Maxwell imagined a molecule size trap door in the partition with a minuscule creature (called, by some, "the demon") poised at the door that is observing the molecules. When a faster than average molecule approaches the door he makes certain that is ends up on the left side and maintains his vigilance so that all the slower than average ones are in the right side. The inevitable outcome will be that the box is hot on the left and cold on the right. Then one can use this separation of temperature to run a heat engine by allowing the heat to flow from the hot side to the cold side. The demon is trying to crate more useful energy from the system than there was originally. No less important, is that he was decreasing the randomness of the system (by ordering the molecules according to certain rule), which is decreasing the entropy. No such violation of the second law of thermodynamics has ever been found. Maxwell's theoretical supposition was not that this would ever happen, but that there is some probability---however remote---that hot and cold molecules could find themselves on separate sides of the box.[6]

Einstein Duality of Light

At the turn of the nineteenth century electromagnetic radiation (such as a radio emission) was understood to be a wave; it was a proposition firmly established by Maxwell and Lorentz theories, and numerous experiments on interference, diffraction and scattering of light had confirmed it. Einstein argued in 1905 that, under certain circumstances, light behaves not as a continuous wave but as discontinuous, individual particles. These particles, or "light quanta," were also confirmed by experimentation, most notably the photoelectric effect that cannot be explained by wave theory. Bohr and Heisenberg call this, complementarity that light exists simultaneously as a wave and as a particle. The description of complementarity is what leads to Heisenberg's uncertainty principle, because the ideas of the movement of electrons around a nucleus must agree with classical physics and quantum theory of probabilities at the same time. Heisenberg's uncertainty principle states: "The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa." What we see again, is again a duality this time with respect to momentum and position; the upshot is that we can know one but not both at the same time.[7]

Uncertainty Theory is followed in 1927 by Louis de Broglie's matter waves. He assumed that because light had both particle and wave properties, that this may also be true for matter. He thus began looking for the wave structure of matter. His results, was that each particle expressed its own wavelength and this thus confirmed the wave duality for both light and matter. It also explained why only certain orbits of the electron (which relate to whole numbers of standing waves) were allowed, a finding, which fitted beautifully with Bohr model of the atom.

Schrödinger who also was involved in the development of quantum mechanics was not in agreement with Heisenberg's uncertainty theory and the idea of complementarity and as a result developed his own thought experiment proposed in 1935, now known as Schrödinger's Cat. His experiment states:

A cat is place in a steel box along with a Geiger counter, a vial of poison, a hammer, and a radioactive substance. When the radioactive substance decays; the Geiger detects it and triggers the hammer to release the poison, which subsequently kills the cat. The radioactive decay is a random process, and there is no way to predict when it will happen. Physicists say the atom exists in a state know as superposition-both decayed and not decayed at the same time.

Until the box is opened, an observer does not know whether the cat is alive or dead-because the cat's fate is intrinsically tied to whether or not the atom has decayed and the cat would, as Schrödinger put it be "living and dead…in equal parts" until it is observed.

What Schrödinger was illustrating with the cat paradox, is that in any physical system, without observation you cannot say what something is doing. You have to say it can be any of these thing it can be doing-even if the probability is small. What Schrodinger was arguing is that two contradictory thing cannot be occurring simultaneously which undermines the duality of nature that Heisenberg, Bohr and de Broglie theories used to explain the unusual nature of matter and energy.[8]

In Michael Frayn *Copenhagen* the intersections of these dualities and the science that discovered it collide. The dualities (complementarity) play out in their interactions. How can two men, Frayn asks his audience, have one conversation but have two different memories of that conversation.[9] This same duality can be seen in other literary text. In Mary Shelley's *Frankenstein* there is the duality in the Dr. Frankenstein creating the monster and also having to destroy his creature. In the play "RED" about Mark Rothko, the renowned artist, tell his protégé:

"The child must banish the father. Respect him, but kill him."[10]

The scientists who created the atomic bomb have this same duality with the scientific discovery of how the matter can be converted into energy in the fission and fusion processes resulting in the possibly of producing inexpensive reliable source of energy which would move forward the economy (without creating harmful carbon dioxide). Yet this same discovery could and did kill thousands of innocent people and subsequently, it has continued to create unrest in the world to this day.

***Copenhagen* the Play**

Key figure from the play

Copenhagen is about the 1941 meeting of Niels Bohr and Werner Heisenberg. Niels Bohr won the 1922 Nobel Prize in physics for his study of the structure of the atom, which is still used in science classroom today. Bohr's theory proposed that protons and neutrons are found in the small nucleus and are surrounded by electrons in circular orbits separated by different quanta of energy. In 1921, Bohr was named director of the Institute for

Theoretical Physics in Copenhagen, which is now, know as the Bohr Institute. The institute became a vital destination for atomic physicists from around the world and Werner Heisenberg was one of those students who came to work with Bohr. In 1933, after Nazis authorized German universities to dismiss staff on the ground of both politics and race, Bohr invited fired physicist to come to his institute. When Germany occupied Denmark, Bohr fled with his family to Sweden and then to the United States where he helped with the development of the atomic bomb. As early as 1944, however, his concern about harnessing the power of nuclear energy led him to advocate control of nuclear weapons in the pursuit of world peace and he was the first recipient of the Atoms for Peace Award.[11]

Werner Heisenberg won the Nobel Prize in physics, in 1932, for establishing the field of quantum mechanics, which has been the dominant influence on the development of atomic, and nuclear physics in our lifetime. By providing a model for calculating the critical mass in sustain nuclear reactions leading to the development of nuclear reactors and the atomic bombs. Heisenberg is best known for his Uncertainty Principle of 1927. The principle acknowledges the limits the accuracy of knowledge about atomic behavior, since the means by which the researcher measures such phenomena actually alter the behavior. Heisenberg worked for Bohr in Copenhagen from 1922 until 1927 when he returned to teach physics at the University of Leipzig in Germany. After WWII Heisenberg directed the Max Planck Institute in Berlin, and then moved to the Max Planck Institute for Physics at Gottingen where he remained for the rest of his career

In the early years of the Second World War, Heisenberg conducted experiment with heavy water that led him to believe in the feasibility of a nuclear weapon. Heisenberg visited his mentor and former teacher, Bohr, in Copenhagen in 1941, perhaps to ask his advice on the right course of action for the development of atomic energy.[12]

Robert Jungk's book, *Brighter than a Thousand Suns*, about the German atomic bomb effort during the war included an excerpted letter from Heisenberg detailing his meeting with Bohr in Copenhagen in 1941.[13] Heisenberg's account of their meeting so upset Bohr that he dictated a letter to Heisenberg detailing his own, and very different, recollection of what had transpired. In the end Bohr never sent his letter. In 2002, the Bohr family published the draft letter to Heisenberg on the internet. The issue of what Heisenberg and Bohr said to one another is 1941 in Copenhagen is still open for debate and is the premise for the play *Copenhagen* by Michael Frayn.

Synopsis of the play

The play is from the vantage point of the memory, the spirits of Bohr, Heisenberg, and Bohr's wife Margrethe, are uncomfortable with unanswered questions from the 1941 meeting. The most significant is: Why did Heisenberg, the leading physicist on the

German atomic bomb team, go to Copenhagen, as the war was escalating, to meet with his old mentor Bohr, a half-Jewish Dane living in Nazi-occupied Denmark?

The cinematic version of the play begins in present-day Copenhagen with the spirits of the Bohrs and of Heisenberg encountering each other. They then flashback to 1941 and when Heisenberg first arrives at the Bohrs' house, which they are certain, has been bugged by the Gestapo. When they begin to discuss physics Bohr reiterates his belief that atomic fission has no military use. Heisenberg tells Bohr he is now in charge of the German atomic program, which he suggests, is simply devoted to energy reactors.

Was Heisenberg trying to extract form Bohr any information about the Allied bomb efforts? Was he trying to assure Bohr that the Germans had no hope of building their own atomic bomb during the war, in hopes that Bohr would persuade American physicist not to develop such a terrible weapon either? Or did he simply wish to ask his old mentor whether physicists were morally justified in applying their knowledge to weapons.

Bohr contended that Heisenberg had been trying to elicit information and had claimed that a German bomb could be built. Heisenberg, who after the war openly opposed research on atomic weapons said he raised with Bohr the possibility that the world's physicists might refuse, even in wartime, to build atomic weapons, because of their enormous cost and incredible power.

After three attempts—in the context of the play--to understand and agree on what happened at their Copenhagen meeting in 1941, the Bohrs and Heisenberg are no closer to an answer. Firm answers are, of course, always elusive; which is as the playwright Michael Frayn states; "The heart of Copenhagen is how we know why people do what they do, and even how one knows what one does oneself." [14]

Strategies

As part of the International Baccalaureate program at East Mecklenburg High School all senior IB students take the Theory of Knowledge class. As part of the class students have small group discussion on a variety of topics with the instructor called Socrates' café. This curriculum unit will be used to replace the Socrates' café with a movie and pizza evening and discussion. Prior to watching the film student will read David C. Cassidy's paper "A Historical Perspective on Copenhagen" from *Physics Today*, July 2000. It is about five pages long and replete with images of Heisenberg and Bohr meeting prior to the 1941 meeting in Copenhagen. The paper is a summarizes the history surrounding the Copenhagen meeting but it also includes important side notes about forgotten facts, such as in 1937, the SS accused Heisenberg of teaching so called "Jewish physics" that is, modern theoretical physics. The article called Heisenberg a "white Jew" and a "representative of the Einsteinian 'spirit' in the new Germany"[15]

Cassidy also notes the following statement, which he attributed to Heisenberg, "Democracy cannot develop sufficient energy to rule Europe. There are, therefore, only two alternatives: Germany and Russia. And then a Europe under German leadership would be the lesser evil." Having witnessed a traumatic Soviet revolution in Bavaria as a teenager, Heisenberg always considered Soviet domination an even worse evil than Nazi domination (This goes to the heart of the quote on page 42.) Another statement from Heisenberg is the observation that "For us there remains nothing but to turn to the simple things; we should conscientiously fulfill the duties and tasks that life presents to us without asking too much about the why or the wherefore… and then we should wait for whatever happens…reality is transforming itself without our influence"[16]

After watching the PBS movie, students will break into small discussion groups with an International Baccalaureate trained teacher to insure that the discussions stays on topic. Students will be given the following passages from the play that I want students to read and use as part of their table discussion. In addition, students will be given the following questions to start their table discussions. The final assignment will be for students to write a reflection of what they learned from watching the play and their table discussions.

Page 42 (movie time: 56 minutes)

> *Heisenberg*: Bohr, I have to know! I'm the one who has to decide! If the Allies are building a bomb, what am I choosing for my country? You said it would be easy to imagine that one might have less love for one's country if it's small and defenseless. Yes, and it would be another easy mistake to make, to think that one loved one's country less because it happened to be in the wrong. Germany is where I was born. Germany is where I became what I am. Germany is all the faces of my childhood, all the hands that picked me up when I fell, all the hearts that speak to my heart. Germany is my widowed mother and my impossible brother. Germany is my wife. Germany is out children. I have to know what I'm deciding for them! Is it another defeat? Another nightmare like the nightmare I grew up with? Bohr, my childhood in Munich came to an end in anarchy and civil war. Are more children going to starve, as we did? Are they going to have to spend winter nights as I did when I was a school by, crawling on my hands and knees through the enemy lines, creeping out into the country under cover of darkness in the snow to find food for my family?[17]

Page 71 (movie time: 1hour 18 minutes)

> *Bohr*: It works, yes. But it's more important than that, because you see what we did in those three years, Heisenberg? Not to exaggerate, but we turned the world inside out! Yes, listen, now it comes; now it comes….

We put man back at the centre of the universe. Throughout history we keep finding ourselves displaced. We keep exiling ourselves to the periphery of things. First we turn ourselves into mere adjunct of God's unknowable purposes, tiny figures kneeling in the great cathedral of creation. And no sooner have we recovered ourselves in the Renaissance, no sooner has man become, as Protagoras proclaimed him, the measure of all thing, than we're pushed aside again b the products of our own reasoning! We're dwarfed again as physicists build the great new cathedrals for us to wonder at –the laws of classical mechanics the predate us from the beginning of eternity, that will survive us to eternity's end, that exist whether we exist or not. Until we come to the beginning of the twentieth century and we're suddenly forced to rise from our knees again.[18]

Heisenberg: It starts with Einstein.

Bohr: It starts with Einstein. He shows that measurement –measurement, on which the whole possibility of science depends—measurement is not an impersonal event that occurs with impartial universality. It's a human act, carried out from a specific point of view in time and space, form the one particular viewpoint of a possible observer. Then here in Copenhagen in those three years in the mid –twenties we discover that there is not precisely determinable objective universe. Treat the universe exist only as a series of approximations. Only within the limits determined by our relationship with it. Only through the understanding lodged inside the human head.[19]

Page 77 (movie time: 1 hour 30 minutes)

Heisenberg: Most interesting. So interesting that it never even occurred to you. Complementarity, once again. I'm your enemy; I'm also your friend. I'm a danger to mankind; I'm also your guest. I'm a particle; I'm also a wave. We have one set of obligations to the world in general, and we have other sets, never to reconcile, to our fellow-countrymen, to our neighbours, to our friends, to our family, to our children. We have to go through not two slits at the same time but twenty-two. All we can do is to look afterwards, and see what happened.[20]

Student Discussion Questions

Science Related Questions:[21]

Bohr and Heisenberg both argue that Quantum Mechanics put humans back “at the center of the universe” (from page 71). What do you think this means in terms of the role of science in popular culture and the way that we now view the observable world and ourselves?

Scientific discovery is often viewed in the lens of the “great man” perspective that attributes genius to a single individual who makes breakthrough. In what ways does Copenhagen support/refute this perspective?

Nuclear Fission—putting aside the problem of nuclear waste—How do you feel about the development of nuclear fission, which ultimately could have benefitted humanity in many ways before becoming a force of destruction?

Some big social/ character questions:

Heisenberg notes that unlike Bohr, who developed a detonating mechanism for the Nagasaki bomb, he never contributed to the loss of a single life despite working for the Nazi regime?

How does the play view the impact and potency of nuclear power?

The later discovery of Bohr’s draft letters to Heisenberg was not available to Michael Frayn (the playwright), but he seems unfazed by that finding. In what way does this quirky twist fit precisely into the nature of knowing and unknowing that distinguishes the play?

Why use the theatrical form, requiring performances that are exactly the same yet change subtly with every new performance?

As Frayn notes in *Copenhagen*, page 96, dialogue play an important role in Heisenberg’s own memories, because he wanted “to demonstrate that science rooted in conversation.” In the play Margrethe says of her husband and Heisenberg, “The first thing they ever did was to go for a walk together… walk, and talk, long, long before wall had ears.”

How important is conversation to learning any new material?[22]

Student Resources

Since this is a unit taught to all International Baccalaureate seniors, students have a variety of scientific and historical background. Included in their assignments is a list of atomic science vocabulary starting from the most basic too more complex. In addition, I have included two historical time lines one for atomic science discovery and one historical time line.

Atomic Science Vocabulary[23]

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 non- electrically 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.

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 **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.

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. Moving electrons creates electricity.

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.

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 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 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 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 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 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 is chemically the same as H_20. 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

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

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

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.

A **Cyclotron** is a machine used to accelerate charged particle to high energies. The first cyclotron was built be Ernest Orlando Lawrence and his graduate student, M. Stanley Livingston, at the University of California, Berkley, in the early 1930's.

Scientific Discovery Time Line[24]

1895 -- Electrons Discovered: J.J. Thomson discovers the electron, the extremely light, negatively-charged particle orbiting inside the atom which gives it its chemical properties.

1900 -- Quantum Theory-Energy as discrete Packets: Max 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 transactional are in multiples of it.

1905 -- Einstein's Photoelectric Effect: Albert Einstein realizes that light, too, has to be understood not only as waves but as quantum particles, he later called photons.

1910 -- Electrons Orbit Nucleus: Ernest Rutherford shows that the electrons orbit around a tiny nucleus, in which almost the entire mass of the atom is concentrated.

1913 -- The Bohr Atom: Niels 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.

1915 -- Einstein Postulates General Theory of Relativity

1924 -- Matter Suggested as Waves: Louis de Broglie in Paris suggests that just as radiation can be treated as particle, so the particles of matter can be treated as a wave formation.

1925 -- Quantum Mechanics Formulated: Werner Heisenberg abandons electron orbits as unobservable, completing a paper on quantum mechanics. Max Born finds a mathematical formulation in terms of matrices for what can be observed which is derived from the effects they produce upon the absorption and emission of light.

1926 -- The Wave Equation Solutions: Erwin Schrödinger finds the mathematical equation for the wave interpretation and proves that wave and matrix mechanics are mathematically equivalent.

1927 -- Heisenberg's Uncertainty Principle: Heisenberg demonstrates that all statements about the movement of a particle are governed by the uncertainty relationship that states the more accurately you know its position; the less accurately you know its velocity, and vice versa.

1928 -- The Copenhagen Interpretation: Bohr relates Heisenberg's particle theory and Schrodinger's wave thereby 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 interpretation of quantum mechanics.

August 1931 -- Cyclotron Developed: Ernest Lawrence and M. Stanley Livingston of the University of California at Berkeley developed the first cyclotron for smashing atoms.

February 1931 -- Chadwick Discovers Neutron: James Chadwick discovers the neutron, a particle, which can be used to explore the nucleus because it carries not electrical charge, and can penetrate it undefeated.

1932 -- Exploring the Nucleus: Heisenberg opens the new ear of nuclear physics by using neutron theory to apply quantum mechanics to the structure of the nucleus.

1934 -- the Transmutation of Uranium: Enrico Fermi in Rome bombards uranium with neutrons and produces a radioactive substance, which he cannot identify.

1937 -- Bohr's Liquid Drop: Bohr explains the properties of the nucleus by analogy with a drop of liquid.

January 1939 -- Splitting the Atom: Lise Meitner and Otto 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.

February 1939 -- Fission Produces Neutrons: Bohr and John Wheeler at Princeton realize that fission also produces free neutrons. These neutrons are moving too fast to fission other nuclei in uranium 238, the isotope that makes up 99% of all natural uranium, and will fission only the nuclei of uranium -235, which constitutes less than 1% of all uranium.

1939 -- Nuclear chain Reaction Possible: Frederic Joliot and Irene Joliot-Curie in Paris and Fermi in New York demonstrate the release of two or more free neutrons with each fission, providing the possibility of a chain reaction in pure uranium-235.

1940 -- Critical Mass Is Calculated: Otto Frisch and Rudolf Peierls in Birmingham calculate, wrongly but encouragingly, the minimum amount of uranium 235 needed to sustain an effective chain reaction

January -- 1941 Plutonium Discovered: Glenn Seaborg and others at the University of California at Berkeley discover Plutonium, a man-made heavy metal ideal for use in nuclear weapons.

1942 -- First Nuclear Reactor: Enrico Fermi in Chicago achieves the first self-sustaining chain reaction, in a prototype reactor.

July 16, 1945 -- The Trinity Test: At about 5:29 in the morning the fist atomic bomb is exploded near Alamogordo, New Mexico.

Historical Time Line

June 28, 1914 -- World War I Begins: Archduke Ferdinand assassinated in Sarajevo. WWI begins.

November 11, 1918 -- Armistice, Germany surrenders

1922 -- Mussolini Marches into Rome and Forms Fascist Government

October 1929 -- New York Stock Market Crashes: The great depression starts.

January 1933 -- Hitler Comes to Power: Adolph Hitler become Chancellor of Germainy.

August 1939 -- Einstein Writes Warning: Einstein writes a letter to President Roosevelt warning that Germany may be developing atomic weapons.

September 1939 -- World War II Begins: Germany invades Poland and the Nazis commence serious research into the military possibilities of fission.

April 1940 -- Germany Invades Demark

December 7, 1941 -- Japan Attacks Pearl Harbor: the United States enters the war.

September 1942 -- Manhattan Project Gets a Director: Colonel Leslie R. Groves is appointed as the director of the atomic bomb program and it is given top priority.

March 1943 -- Los Alamos Lab Gears Up: Dr. J. Robert Oppenheimer arrives at Los Alamos as the director of the lab responsible for designing and building the atomic bomb.

June 6, 1944 -- D-Day: The Normandy invasion by Allied forces.

May 8, 1945 -- War over in Europe: Germany surrenders and the German nuclear scientist are rounded up and held in custody in Farm Hall, England.

August 6, 1945 -- Hiroshima Bombed: Atomic bomb dropped on Hiroshima, Japan, 140,000 casualties result.

August 9, 1945 -- Nagasaki bombed

August 10, 1945 -- Japan Surrenders

1950 -- Outbreak of Korean War

1952 -- United States Explodes the First Hydrogen Bomb: The H-bomb is 700 times more powerful than the Hiroshima atomic bomb.

Appendix 1: International Baccalaureate Objectives

Aim 8-Raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology.

Aim 9- Develop an appreciation of the possibilities and limitations associated with science and scientists.

IB Learner Profile

The aim of all IB programs is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

IB learners strive to be:

Inquirers: The student develops their natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They actively enjoy learning and this love of learning will be sustained throughout their lives

Knowledgeable: The student explores concepts, ideas and issues that have local and global significance. In so doing, they acquire in-depth knowledge and develop understanding across a broad and balanced range of disciplines.

Thinkers: The student understands and expresses ideas and information confidently and creatively in more than one language and in a variety of modes of communication. Each student works effectively and willingly in collaboration with others.

Communicators: The student understands and expresses ideas and information confidently and creatively in more than one language and in a variety of modes of communication. They work effectively and willingly in collaboration with others.

Principled: The student act with integrity and honesty, with a strong sense of fairness, justice and respect for the dignity of the individual, groups and communities. They take responsibility for their own actions and the consequences that accompany them

Open-minded: The student understands and appreciates his/her own cultures and personal histories, and is open to the perspectives, values and traditions of other individuals and communities. They are accustomed to seeking and evaluating a range of points of view, and are willing to grow from the experience.

Caring: The student show empathy, compassion and respect towards the needs and feelings of others. They have a personal commitment to service, and act to make a positive difference to the lives of others and to the environment.

Risk-takers: The student approaches unfamiliar situations and uncertainty with courage and forethought, and have the independence of spirit to explore new roles, ideas and strategies. They are brave and articulate in defending their beliefs.

Balanced: The student understands the importance of intellectual, physical and emotional balance to achieve personal well being for themselves and others.

Reflective: The students give thoughtful consideration to their own learning and experience. They are able to assess and understand their strengths and limitations in order to support their learning and personal development.

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