NIELS BOHR AND THE DISCOVERY OF THE ATOM

BY NATE S.
ESSENTIAL QUESTION:

How did Niels Bohr’s contributions in particle physics change both the science and the society that came after him?
Anyone who thinks they can talk about quantum theory without feeling dizzy hasn’t understood the first thing about it.

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Niels Bohr
EARLY LIFE

 Born in Copenhagen, Denmark 1885
 Bohr’s father was a well known professor of physiology at the University of Copenhagen
EARLY LIFE

Bohr and his brother Harald played professional soccer in Denmark before leaving for college.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Bohr attended Cambridge University before receiving his doctorate at the University of Copenhagen in 1911.

He then studied under renowned scientists Ernest Rutherford and J.J. Thomson.
Bohr went on to found and chair the Institute of Theoretical Physics at the University of Copenhagen in 1920

This was the first such institute in the world and was Bohr’s first legacy to modern science.

It was later renamed the Niels Bohr Institute, in honor of its creator.
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In 1922 Bohr was awarded the Nobel Prize in Physics for his discoveries regarding atomic structure.
Later Life

- Bohr narrowly escaped arrest while living in Germany before WWII.
- He fled to London before eventually continuing on to the United States.
- In the US he worked on the Manhattan Project and became close friends with Albert Einstein.
EXISTING THEORY
BEFORE BOHR
The first modern scientist to speculate about atoms was Rudjer Boscovich, a Jesuit priest who published his theory in 1758 after reading Newton’s work.
English chemist John Dalton was the first to attribute inherent properties to specific atoms.
DALTON’S ATOMIC THEORY

 الأسبوعية’s theory is comprised of the following laws:

- Elements are made of tiny particles called atoms
- All atoms of a given element are identical
- The atoms of a given element are different from those of any other element
- Atoms of one element can combine with atoms of other elements to form compounds
- Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process
DALTON’S ATOMIC THEORY

_while the laws were true, they failed to cover every aspect of modern atomic theory.

* For one thing, Dalton believed that an atom was the most elementary particle in the universe.

* Dalton also believed atoms to be solid objects.
DALTON’S ATOMIC MODEL
Scientists believed atoms to be the smallest particles in the universe until the discovery of the electron.

J.J. Thomson discovered the electron using cathode ray tubes.
THE DISCOVERY OF SUBATOMIC PARTICLES

Thomson created a new model that differed from Dalton’s in one major respect.
Thomson dismissed the idea that atoms were homogenous - instead he proposed the existence of protons and electrons.

Thomson’s model described protons and electrons suspended in a neutral atomic medium.

This came to be known as the plum pudding model because the protons and electrons reminded Thomson of raisins in plum pudding.
THE PLUM PUDDING MODEL
RUTHERFORD’S GOLD FOIL EXPERIMENT

Ernest Rutherford designed an experiment to test the plum pudding model.

Rutherford wondered if the atom was actually solid, and questioned the existence of Thomson’s neutral atomic medium.

Rutherford beamed alpha particles at a thin piece of gold foil surrounded by a photo-sensitive screen.

The pattern on the screen showed that the majority of the alpha particles had passed directly through the foil, thereby disproving the plum pudding model of the atom.
RUTHERFORD’S GOLD FOIL EXPERIMENT
Rutherford was able to disprove the plum pudding model by demonstrating that atoms were primarily open space rather than solid objects.
BOHR’S MODEL
Using Thomson and Rutherford’s experiments as a basis Bohr began to speculate about the nature of the atom.

Bohr’s initial model included a central nucleus that contained almost all of the atom’s mass and a cloud of tiny orbiting electrons which comprised almost all of its volume.

This model allowed scientists to explain the patterns in the periodic table of elements.
Bohr’s second model

Bohr’s first model, called the planetary model, was simple and compelling but Bohr noticed incongruities between his model and the spectroscopy work of Johannes Rydberg, which suggested a more complex arrangement of electrons.
BOHR’S SECOND MODEL

Rydberg’s formula predicted an irregular arrangement of atoms, something that conflicted with Bohr’s first model.

\[ \frac{1}{\lambda_{\text{vac}}} = R_H \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \]

The Rydberg Formula
Bohr's Second Model

Bohr went back to the drawing board and decided to approach the question with more of an emphasis on physics.

This was the turning point from 19th century science to 20th century science!
Bohr took quantum physics, which had been “invented” only 15 years earlier by Max Planck, and applied it to his atomic question. Using quantum physics, Bohr arrived at the idea of complimentarity - dealing with wave -particle duality and the ramifications thereof.
BOHR’S SECOND MODEL

Bohr’s concept of complimentarity allowed him to create a new model which accounted for Rydberg’s formula by incorporating the idea of orbitals - places of high probability to find an electron.

For a detailed scientific explanation of orbitals and complimentarity visit this website:
http://www.chemguide.co.uk/atoms/properties/atomorbs.html#top
BOHR’S SECOND MODEL

Planetary model amended to show orbitals
BOHR’S SECOND MODEL

The second model made Bohr famous almost instantly. Complementarity was possibly the biggest scientific breakthrough since Newton’s revelation about gravity.

Bohr had taken a chemistry question and not only solved using physics, but solved it using a new kind of physics that unlocked the subatomic world. Bohr’s work earned him the nickname “the father of quantum physics”
FURTHER RESEARCH

Clockwise from left: Schrodinger, Millikan, Heisenberg, Einstein, Pauli and Conant
Louis De Broglie did experiments that supported Bohr’s model and defined orbitals more specifically.

De Broglie’s equation:
\[ \lambda = \frac{h}{mv} \]

De Broglie’s diagram of an electron in an orbital.
Werner Heisenberg described what he called the “Uncertainty Principle”.

The notion that it is impossible to measure anything without altering the measurement slightly.
HEISENBERG

- The Uncertainty Principle was particularly pronounced when dealing with objects on an atomic scale, like electrons.

- The idea that it was impossible to know where an electron was at a given time solidified quantum mechanics (which deals only in probability) as the primary means of atomic study.
Erwin Schrödinger combined the work of Bohr, De Broglie and Heisenberg and came up with a more complex version of Bohr’s model that showed the position of each orbital.

Schrödinger’s model agreed with Bohr’s but it used new technology and data to create a more accurate picture of the atom.
MODERN PICTURES OF THE ATOM

Model showing orbitals as complex orbits
MODERN PICTURES OF THE ATOM

Model showing orbitals by color-coded probability
MODERN PICTURES OF THE ATOM

Model showing orbitals by density
BOHR'S LEGACY

Einstein

Pickering

Oppenheimer
BOHR’S LEGACY

- Bohr’s work had a tremendous influence on the history of science, both in terms of the base of knowledge and the general approach to scientific research.

- Bohr was the leader of the movement that led to the decline of chemistry and the rise of physics in the 20th century.

- The 19th century was the century of the chemist, and science was dominated by the likes of Dalton, Faraday, Boyle and Avogadro.

- 20th century science was dominated by physicists, beginning with Bohr himself.
GREAT 20TH CENTURY PHYSICISTS

Albert Einstein - Inventor of the theory of general relativity
GREAT 20TH CENTURY PHYSICISTS

Enrico Fermi - the first person to successfully split an atom
GREAT 20TH CENTURY PHYSICISTS

Werner Heisenberg - Bohr’s protégé
GREAT 20TH CENTURY PHYSICISTS

J. Robert Oppenheimer - leader of the Manhattan Project
GREAT 20TH CENTURY PHYSICISTS

Steven Hawking - astrophysicist, cosmologist
STATUS OF SCIENTISTS IN SOCIETY

Perhaps Bohr’s most substantial contribution was the unique kind of celebrity that came with his discoveries.

Bohr changed the way society viewed scientists, and paved the way for the tremendous fame that came to be enjoyed by the most successful scientists.
Bohr’s protégé Heisenberg was notoriously flamboyant and publicly challenged Einstein to disprove his uncertainty principle on one occasion.
STATUS OF SCIENTISTS IN SOCIETY

Einstein himself was far and away the biggest celebrity of the group, capitalizing on his scientific success to appear on the cover of *Time* magazine no less than 7 times.
OTHER FAMOUS 20TH CENTURY SCIENTISTS

Marie Curie - Early 20th century chemist
OTHER FAMOUS 20TH CENTURY SCIENTISTS

Watson and Crick - discoverers of DNA structure
OTHER FAMOUS 20TH CENTURY SCIENTISTS

Linus Pauling - organic chemist
OTHER FAMOUS 20TH CENTURY SCIENTISTS

Jonas Salk - Inventor of the polio vaccine
Another facet of Bohr’s work that cannot be overlooked is the progress he unknowingly made toward the invention of the atomic bomb. After coming to America during World War II, Bohr joined the Manhattan project despite the protests of Winston Churchill, who distrusted Bohr.
THE ATOMIC BOMB

It was Bohr who identified that the U-235 isotope of Uranium was the one required to start a fission reaction, but believed that because of the difficulty of Uranium enrichment “It would take the entire efforts of a country to make a bomb”

Bohr was against the creation of the atomic bomb, but he saw its necessity and was aware of the progress of in Russia and Germany
Bohr was constantly preoccupied by his knowledge of the weapon he was creating. He foresaw the difficulties that would come of nuclear weapons after the war was over. His son Aage, also a scientist on the Manhattan Project, related: “My father's thoughts now constantly dwelt on the serious consequences of the atom bomb, on the terrifying perspectives opened, and on its profound effect on post-war problems.”
THE ATOMIC BOMB

Bohr saw himself not so much as a necessary scientist to the Manhattan Project, but rather as a sort of diplomatic intermediary between politicians and scientists, and as a father figure for some of the younger and more uncertain scientists.

Bohr also proved himself to be an adept political analyst, predicting almost perfectly what the ramifications of nuclear weapons would be in the future.
THE ATOMIC BOMB

Some key points from a letter Bohr wrote to president Roosevelt

Russia should be told soon that the west was working on the atomic bomb. The longer the west hid their a-bomb work from Russia, the more it would appear to Russia that the west intended to threaten them with the weapon.

If Russia felt threatened by the atomic bomb, they would hurry to build their own. The result would be the "terrifying prospect" of a nuclear arms race.

A nuclear arms race combined with fear and suspicion could lead to a disastrous nuclear war.

But the nuclear threat could be turned into a blessing: the need to prevent nuclear war could provide the basis for nations to overcome their differences and work together in the post-WWII world.
Bohr was right about the dangers of the atomic bomb but he agreed that it could not be prevented or ignored and that the US would be better off having their own nuclear weapons when Russia developed hers.

Bohr devoted his life after the Manhattan Project to advocating the use of nuclear power and distinguishing between the different uses of nuclear fission.
BOHR’S LEGACIES

Creators of the Bohr atomic model
Inventor of complimentarity
Father of quantum physics
Father of the nuclear era
First of the modern physicists
First scientific “celebrity”
Mentor to Heisenberg, friend of Einstein and father of Aage Bohr, who also won a Nobel prize for physics