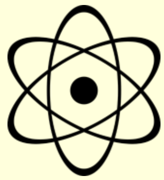
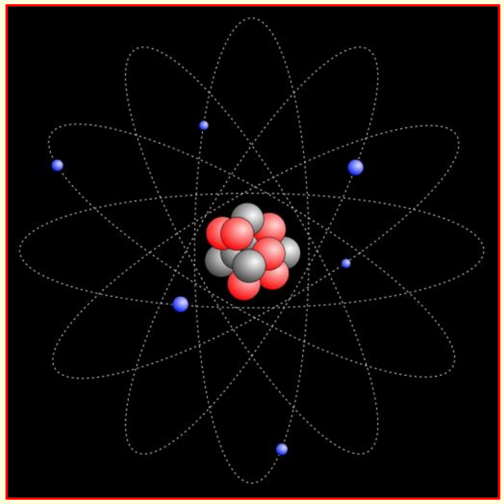
Atoms

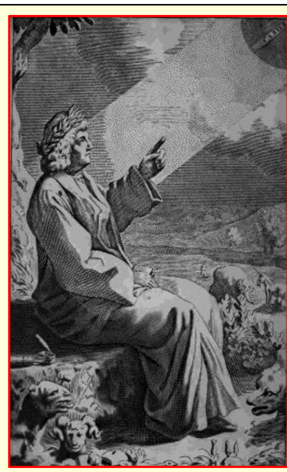




Carbon Atom by
Ernst Rutherford, 1911

Rutherford's concept of the atom is the basis for the symbols used for atomic energy (on the left).

The rendition on the right of Rutherford's concept of the atom has been adapted from his original idea, since he did not know about neutrons, and simply thought that the nucleus was a densely charged region at the center of the atom. He also did not specifically state that the electrons moved in orbits. The other misconception in the diagram is that the particles are much smaller relative to the space occupied by the orbits, and that the electrons are much smaller than represented (if we were to consider their mass). Though this is the model of the atom that many of us learned in school, we shall find out that it is now long obsolete.



De Rerum Natura translated
by Thomas Creech, 1685

Titus Lucretius (99-55 BCE)

In his *De Rerum Natura*, Lucretius revived the atomism of Democritus and Epicurus:

The whole of nature consists of two elements:
There are material bodies, and there is empty space.

The bodies themselves are of two kinds: the particles
And complex bodies constructed of many of these;
Which particles are of an invincible hardness
So that no force can alter or extinguish them.

translated by C. H. Sisson,1976

The first quotation is often rendered as "Nothing exists but atoms and the void" and is considered as originating with Democritus (460-370 BCE).

The second quotation describe the particles as *atomos* (Greek, uncuttable).

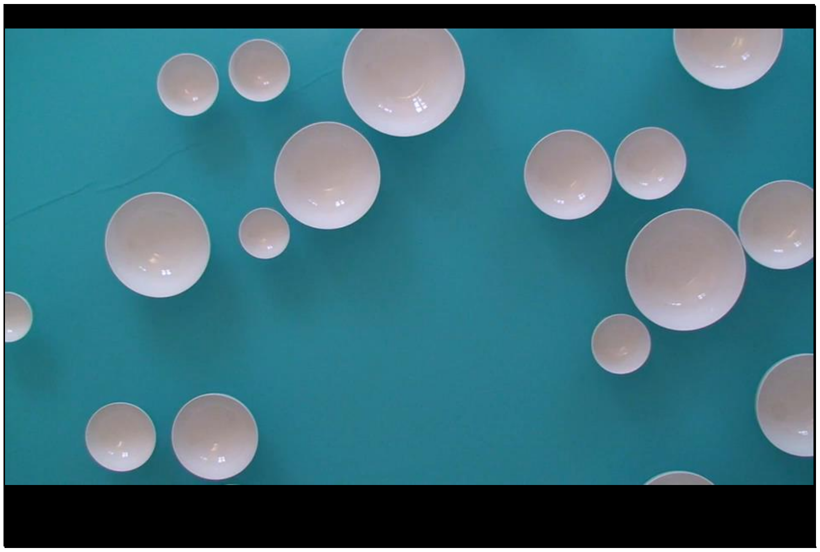
Clinamen

The Epicureans however proposed that there must be something in addition to atoms and the void. In Book II of *De Rerum Natura* Lucretius suggested that an atom could be occasionally deflected away from its completely determined path This swerve (clinamen) could explain our sense of choice. The nature of the clinamen – and whether it is random or purposeful – is not known.

Bird's-eye view of *Clinamen*, 2012, by Céleste Boursier-Mougenot, installed at San Francisco Museum of Modern Art.

The installation by Céleste Boursier-Mougenot is random in the movements of the porcelain cups in water activated by a pump, and in the sounds they produce.

The Swerve is the title of a 2011 book by Stephen Greenblatt. He recounts the 1417 discovery of a copy of *De Rerum Natura* by the Italian scholar Poggio Bracciolini, and the effect of this long-lost book on the Renaissance.



Clinamen, Céleste Boursier-Mougenot
https://www.sfmoma.org/publication/soundtracks/celeste-boursier-mougenot/

Classical Mechanics

There are three laws of motion:

1. every object will remain at rest or in uniform motion unless acted upon by an external force
2. force equals mass time acceleration
3. for every action there is an equal and opposite reaction

To these laws can be added the law of universal gravitation: every object attracts every other object with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Isaac Newton (1642-1726)
by Geoffrey Kneller, 1702

The term "classical" is often used to denote something coming from the time of the Ancient Greeks and Romans. However, it is also used to characterize Newtonian physics, and (from an even later time) the music of Haydn and Mozart. Here it is used to mean "exemplary"

Newton's physics worked well for the planets. Indeed it accurately predicted the movements of any object greater than an atom.

Pierre-Simon Laplace
(1749-1827)

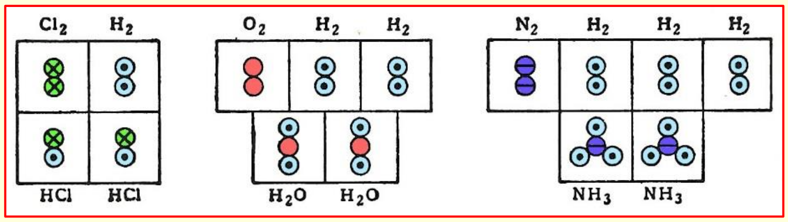
Determinism

We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it – an intelligence sufficiently vast to submit these data to analysis – it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes. (Laplace, 1812)

Newton was able to predict the exact motions of the planets. Using his laws, later physicists were able to determine the existence of planets, such as Neptune, that had not yet been observed. Newton's science suggested that everything occurred according to the laws of nature. Nothing happened by chance, or by choice. This is the philosophy of determinism, as clearly delineated by Laplace.

We shall return to this idea when we consider the physics of the early 20th century, which concluded that some events may not be fully predicted by what occurred before. They are "indeterminate."

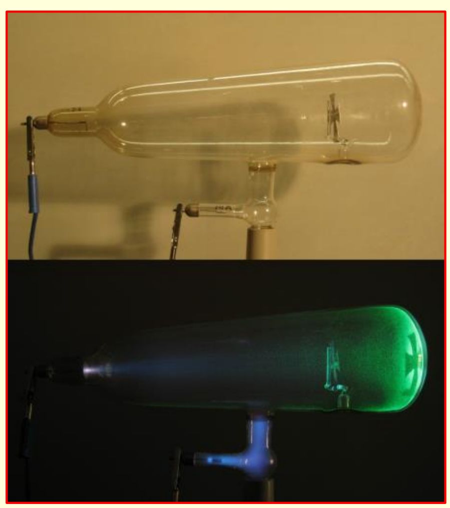
Atoms and Molecules



In the early 19th Century, chemists such as John Dalton and Amedeo Avogadro considered atoms to be the fundamental building blocks of matter. These billiard balls joined together to make molecules. Exactly how the molecules combined – whether by hooks or by glue – was not known. The diagram represents these ideas as presented by Marc Antoine Auguste Gaudin in 1833.

Cathode Rays

In the late 19th Century physicists began to pass currents through glass tubes that been partially evacuated of air. When the voltage was high rays passed from the cathode (negative) toward the anode positive). These rays could make the glass fluoresce when they struck it. The illustration shows a gas discharge tube such as made by William Crookes around 1870. The Maltese cross demonstrates that the rays travel in straight lines.



The upper part of the illustration shows the Crookes' Tube in natural light without any current passing. The lower part shows it lit by its own fluorescence. Several thousand volts is applied between the negative electrode on the left (cathode), and the positive electrode (anode) at the bottom of the tube. This releases electrons (cathode rays) from the cathode. They accelerate

down the tube to the right. Because of inertia, many electrons speed past the anode and hit the glass wall of the tube at the right, making it fluoresce green; after that, they eventually travel to the anode. The cross-shaped metal plate blocks the electrons, casting a cross-shaped shadow on the glowing wall, and demonstrating that the electrons travel in straight lines. Adapted from Wikipedia:
https://commons.wikimedia.org/wiki/File:Crookes_tube_two_views.jpg

Though not known at the time, fluorescence is caused by atoms absorbing electromagnetic radiation and then re-emitting energy in the form of light waves. This explanation depends on the Bohr model of the atom (1913). Typically the absorbed radiation is of shorter wavelength (higher energy) than the emitted radiation, e.g. the fluorescence that occurs under ultraviolet light. Electrons in the orbits absorb the energy of the incoming radiation and move out to higher orbits. They then quickly fall back into the lower orbits and emit a characteristic radiation.

The fluorescence in glass depends upon impurities in the glass, most usually atoms of uranium which cause a characteristic green glow.

The cathode ray is composed of electrons and is not electromagnetic radiation. (A major difference is that the electron is charged and electromagnetic radiation is not). Nevertheless collisions between the incoming electrons and the electrons of the fluorescent material cause them to move out to higher orbits and then emit light as they return to lower levels. Phosphorescence is similar although the emission is delayed from the time of the absorption.

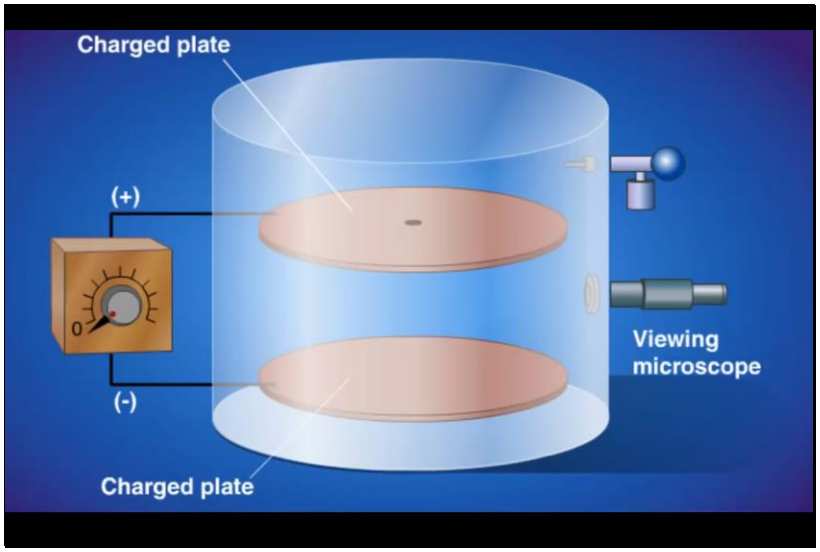
John Joseph Thomson (1856-1940) by Arthur Hacker, 1903

Electrons

Using several ingenious experiments with the cathode ray tube, John Joseph Thomson showed in 1897 that cathode rays were composed of very lightweight negatively charged particles. By deflecting the particles by electrostatic fields he could calculate the ratio of the charge of the particle to its mass. He obtained a value of 1.7×10^7 coulombs per gram, some 1700 times greater than that of a hydrogen ion. He proposed that these particles were held in the atom by electrostatics charges like the pieces of fruit in a plum pudding.

The English physicist J. J. Thomson is not to be confused with the Scottish physicist William Thomson (1824-1907), commonly known as Lord Kelvin though both investigated electricity.

In the portrait Thomson is holding one of the cathode ray tubes that he used to study the electron. J. J. Thomson received the Nobel Prize for Physics in 1906.



In 1910 Robert Millikan (1868-1953) and his graduate student Harvey Fletcher measured the actual charge of an electron using oil drops. The paper reporting the work was published with Millikan as the sole author, although much of the experimental detail was taken care of by Fletcher. Millikan received the Nobel Prize in Physics in 1923. Fletcher went on to study the physics of human speech.

There is also some controversy about data selection in the original Millikan paper. He discarded many of the measurements because he felt they were "wrong," rather than through any objective criteria.

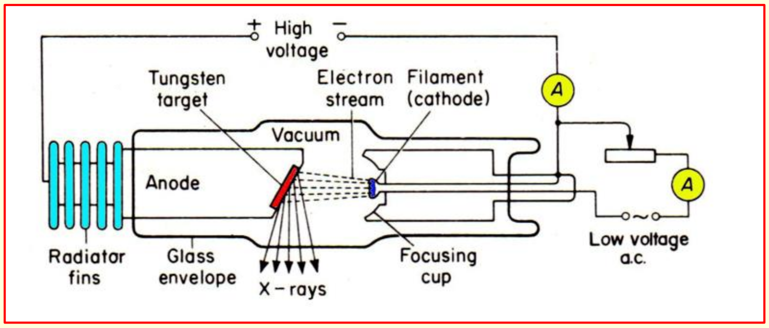
X-Rays

While studying the fluorescent effects of cathode rays, Wilhelm Conrad Röntgen (1845-1923) discovered fluorescence at a distance away from the tube. This occurred even when the tube was covered with cardboard or aluminum. He attributed this to a "new kind of ray," calling it "x" to signify that it was an unknown. He found out that x- rays would expose photographic paper and that placing his hand in the path of the rays would give a shadow picture of its bones. The discovery found rapid clinical use. Röntgen was awarded the first Nobel Prize in Physics in 1901.

X-ray of Albert von Kölliker's hand, 1896

Kölliker, an early proponent of the cell theory, was a colleague of Röntgen at the University of Würzburg.

Coolidge X-Ray Tube

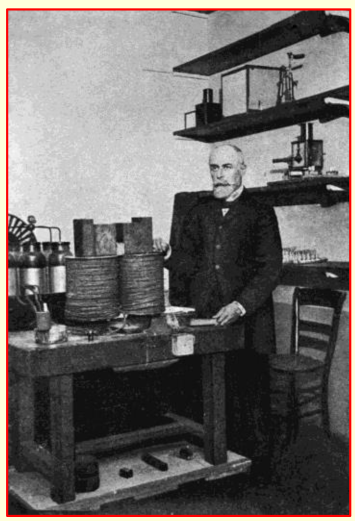


In 1913, William Coolidge patented an improved x-ray tube. The tungsten cathode was heated using a low-voltage circuit, the voltage between anode and cathode was increased (to about 50 kV) to accelerate the emitted electrons and a special electrostatic cup focused the electron beam on a small area of the target (which had to be cooled).

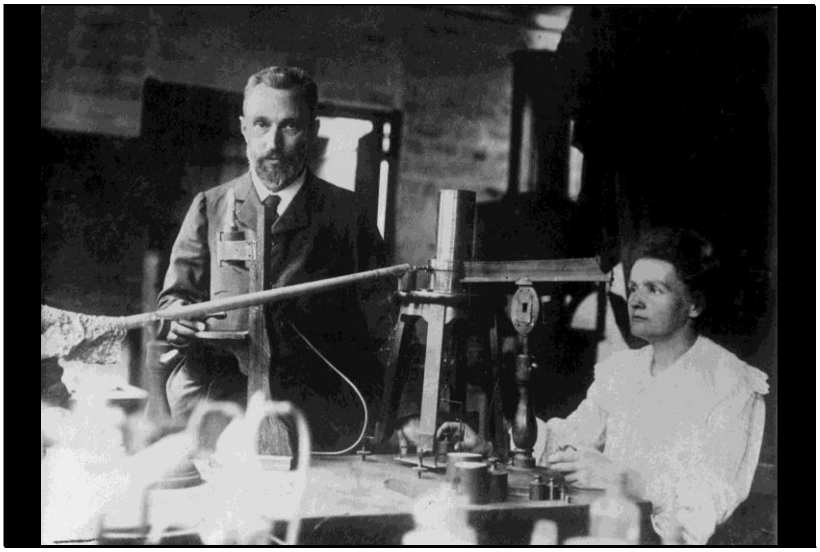
Further improvements were to have a rotating anode so that the focused beam of electrodes did not over-heat one region.

Radioactivity

In 1896, Henri Becquerel (1852-1908) noted that photographic paper was exposed by uranium even when covered by dark paper. He initially thought that this might be caused by Röntgen's x-rays, but it soon became apparent that the 'rays" were more complicated. For example, the rays could be affected by magnetic fields. In 1898 Pierre and Marie Curie found that other elements acted in the same way. They named the new elements thorium, polonium and radium, and first used the term "radioactivity." Becquerel and the Curies received the 1903 Nobel Prize in Physics.



Photograph shows Becquerel in his laboratory with a large electromagnet.



This photograph shows Pierre and Marie Curie in their laboratory in Paris. The French physicist Pierre Curie (1859-1906) had made important contributions to piezo-electricity and ferromagnetism before turning to radioactivity. Maria Skłodowska became his doctoral student in 1894 and together they worked to identify the elements polonium (named after Skłodowska's homeland) and radium in pitchblend. They were married in 1895 and in 1898 they published their discoveries. They were awarded the Nobel Prize in Physics in 1903. Pierre was killed in an accident with a horse-drawn cart in 1908. Marie continued their work and was finally able to isolate pure radium in 1910. This led to her Nobel Prize in Chemistry.

Marie Skłodowska Curie (1867-1934)

Born in Poland Marie Curie helped to support his sister through her medical studies and then came to Paris to study physics. She was awarded the Nobel Prize in Physics in 1903 and the Nobel Prize in Chemistry in 1911. She was the first woman to receive a Nobel Prize and the first person to win two Nobel Prizes. Despite these achievements she was not elected to the French Academy of Science.

An excellent website dealing with Marie Curie is https://history.aip.org/history/exhibits/curie/contents.htm

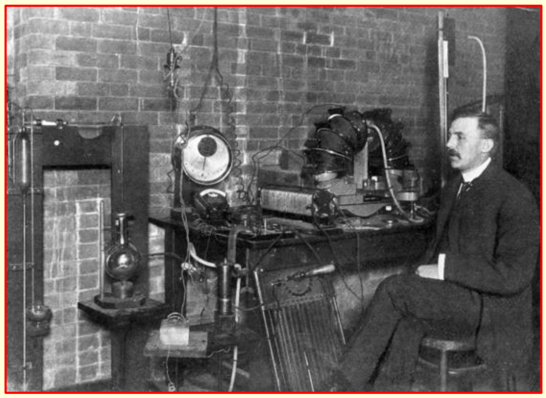
During World War I Marie Curie organized (and drove) a mobile x-ray vehicles to assist in the care of wounded soldiers.

One of the early papers by the Curies reported that tumor cells were killed by radiation more rapidly than normal cells. This lead to the treatment of tumors by radiotherapy. X-rays are still used in radiotherapy. Radium was briefly used but proved too dangerous. Cobalt-60, produced in a nuclear reactor, was long used to treat cancer. The first Cobalt-60 treatment was given by Dr. Harold Johns in London, Ontario, in 1951.

Marie Curie died of aplastic anemia caused by her prolonged exposure to radiation.

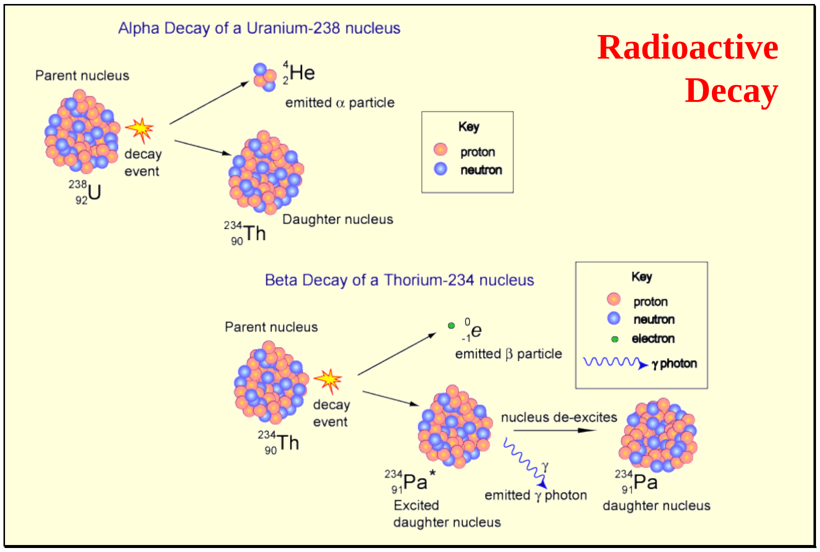
Ernest Rutherford (1871-1937)

Born in New Zealand, Rutherford studied at Cambridge University and then worked at McGill University, Montreal, from 1898-1907.

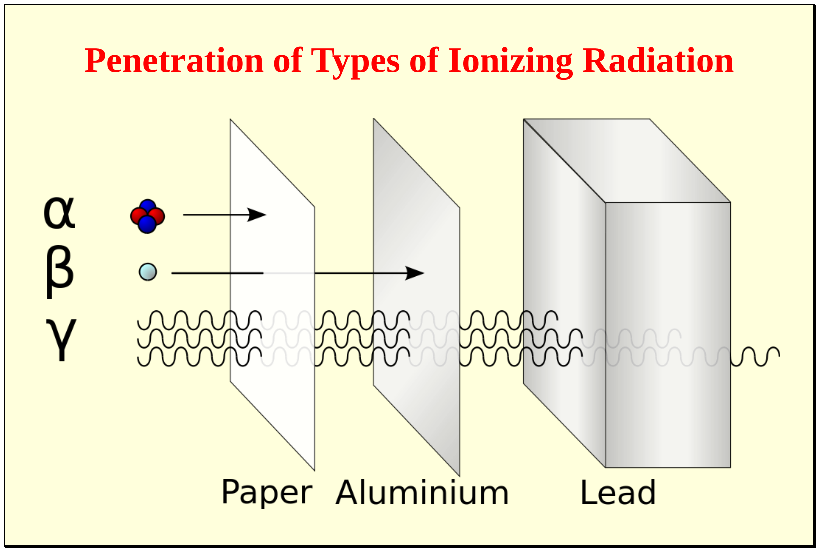


While there, he demonstrated that Becquerel rays were heterogeneous. He called the different components: alpha particles (equivalent to a helium nucleus), beta particles (electrons), and gamma rays. .

Much of Rutherford’s work in Montreal was done in collaboration with Frederick Soddy. They showed that the emission of the particles led to the transmutation of the radioactive element into another element. They also determined that the rate of decay was proportional to the amount of radioactive material and that radioactive decay thus followed an exponential time-course (characterized by “half-lives”). Rutherford received the Nobel Prize in Chemistry in 1908 for his “researches on the disintegration of the elements and the chemistry of radioactive substances.”

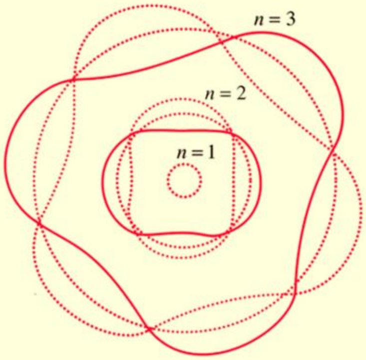


This illustration shows the nature of radioactive decay. The upper diagram shows Uranium-238 decaying to Thorium-234 (half life 4.5 billion years) by the release of an alpha particle. The lower diagram shows the decay of thorium-234 to Protactinium (half live 24 days) with the release of an electron and a gamma ray (photon).



Ionizing radiation is radiation that carries enough energy to knock electrons from atoms or molecules thereby rendering them ions.

Electron Orbits



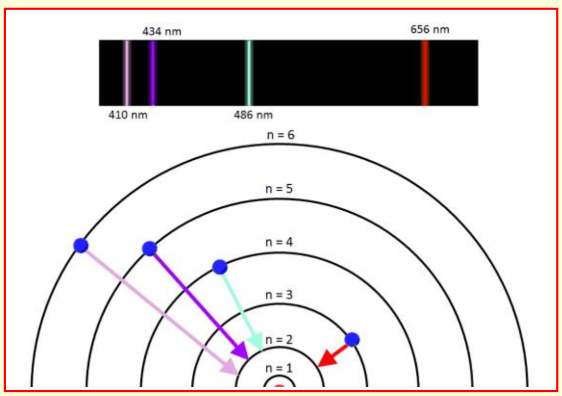
Bohr concept of the orbits for the hydrogen atom

In 1911 Ernest Rutherford proposed that the electrons in an atom orbited around a tiny central nucleus. This was based on experiments that measured the scattering of alpha particles by a thin sheet of metal. This improved on Thomson's plum pudding model. However, Niels Bohr (1885-1962) could not understand why the orbiting electrons did not just fall into the nucleus. He therefore reasoned that there must be many possible stable orbits for the electrons, each associated with a particular energy level, and proposed this new structure of that atom in 1913.

Bohr later reasoned that that the stable orbits would have a circumference equal to an integer number of "waves." The idea that everything could be waves came from the French physicist Louis de Broglie who in 1924 postulated that all matter has wave properties. Thus electrons in stable orbit around the nucleus could be considered as waves. De Broglie was awarded the 1929 Nobel Prize for Physics.

Emission Spectra

When excited by heat or radiation, elements emit energy at discrete lines in the visible spectrum. These are specific to the element.



The new atomic structure of Niels Bohr provided an explanation for these emission spectra. When excited the electrons move out to higher-energy orbits. They then fall back, releasing photons with energy equal to the energy-difference between the orbits

Bohr received the 1922 Nobel Prize in Physics for his "investigation of the structure of atoms and of the radiation emanating from them." The emission spectra is for hydrogen.

Emission spectra were first studied by Jonas Angstrom in Sweden in 1853, and by Gustav Kirchoff and Robert Bunsen in Germany in the 1860s. The latter two investigators used the

"Bunsen burner" to activate elements. Emission spectra are the opposite of absorption spectra. Radiation passing through a material will be absorbed at the same frequencies that the heated material emits radiation.

Quantum Mechanics

20th Century Physics showed that the world was stranger than we might imagine.

Complementarity: To explain earlier findings that light can act as both a wave and a particle. Bohr (1927) proposed that all matter at the level of the atom can be conceived in these two complementary ways.

Werner Heisenberg and Niels Bohr, 1934

Uncertainty: Heisenberg (1927) showed that the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa

Bohr had won the Nobel Prize in 1922 for his work in defining the energy levels of the electron orbits. Heisenberg won the prize in 1932 for his studies of uncertainty.

Complementarity

The two views of the nature of light are rather to be considered as different attempts at an interpretation of experimental evidence. …. we are not dealing with contradictory but with complementary pictures of the phenomena, which only together offer a natural generalization of the classical mode of description. (Bohr, 1928)

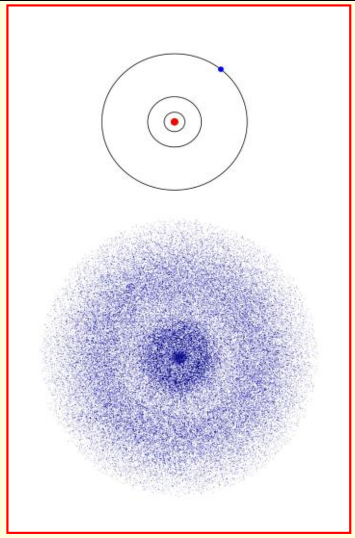
In 1947 when Bohr was awarded the Order of the Elephant, he chose to place the *taijitu* symbol on his shield. The motto was "Opposites are complementary"

The *Taijitu* or Yin-Yang symbol is part of Taoism. the outer circle represent the whole and the light and dark areas represent its opposing manifestations. Yin is water, earth, night, female; yang is fire, sky, day, male. The symbol is often described as sunlight on a mountain, with yin the shady slope and yang the sunlit.

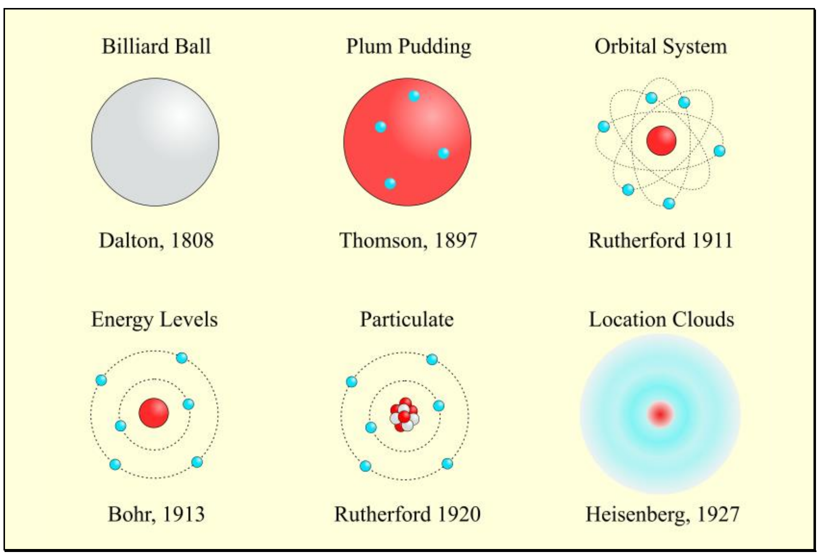
Atomic Structure

The nucleus consists of positively charged protons and uncharged neutrons. Negatively charged electrons orbit around the nucleus at a distance determined by their energy level (Bohr). The hydrogen atom has a nucleus with one proton and a single orbiting electron.

Heisenberg showed that it was impossible to determine the location of the electron. Rather it could exist within the probability density function (orbital) determined by its wave function (Schrödinger).



This shows how the Rutherford-Bohr idea of the atom changed to the probability density functions of Schrödinger. The orbit of an electron around the nucleus is no longer a clearly defined path. The electron could occur in a cloud of possible locations around the nucleus.



This illustration shows the evolution of how we conceive the atom. Dalton (1808) thought of atoms as tiny billiard balls. This then changed to the idea that there are negatively charged particles stuck in a positively charged (Thomson). Rutherford and Bohr proposed orbits. Heisenberg and Schrödinger described "orbitals" that followed probabilistic wave functions.

Orbitals

The nucleus sets up a box or shell around itself to contain the electrons. The probabilities of where these particles exist take up shapes or "orbitals" that are determined by wave equations

From a poster at
http://toutestquantique.fr/en/

1933 Photograph

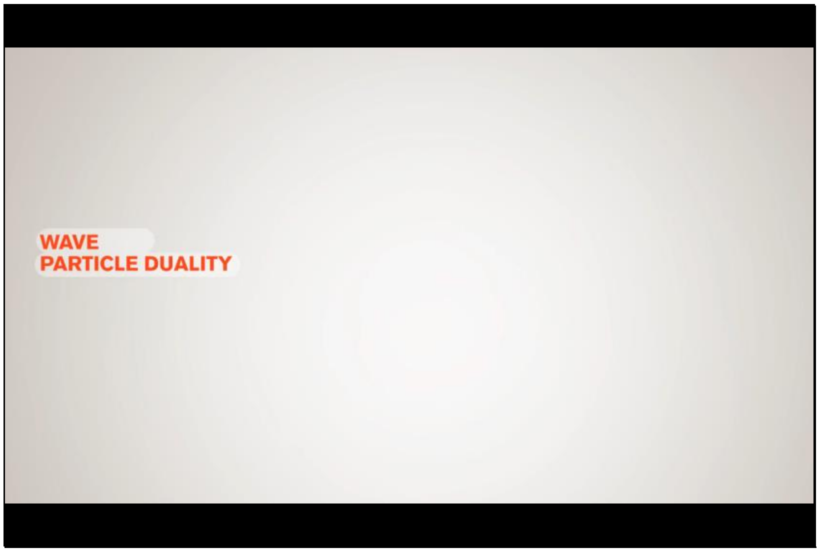
Erwin Schrödinger (1887-1961)

In 1926, Schrödinger created the equations that would define the behavior of all subatomic particles in time and space.

$$i\hbar \frac{\partial}{\partial t}\psi(\mathbf{r},t) = -\frac{\hbar^2}{2m}\nabla^2\psi(\mathbf{r},t) + V(\mathbf{r},t)\psi(\mathbf{r},t)$$

i is the imaginary number, $\sqrt{-1}$.
$\hbar$ is Planck's constant divided by 2π: 1.05459×10^{-34} joule-second.
$\psi(\mathbf{r},t)$ is the wave function, defined over space and time.
m is the mass of the particle.
∇^2 is the Laplacian operator, $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$.
$V(\mathbf{r},t)$ is the potential energy influencing the particle.

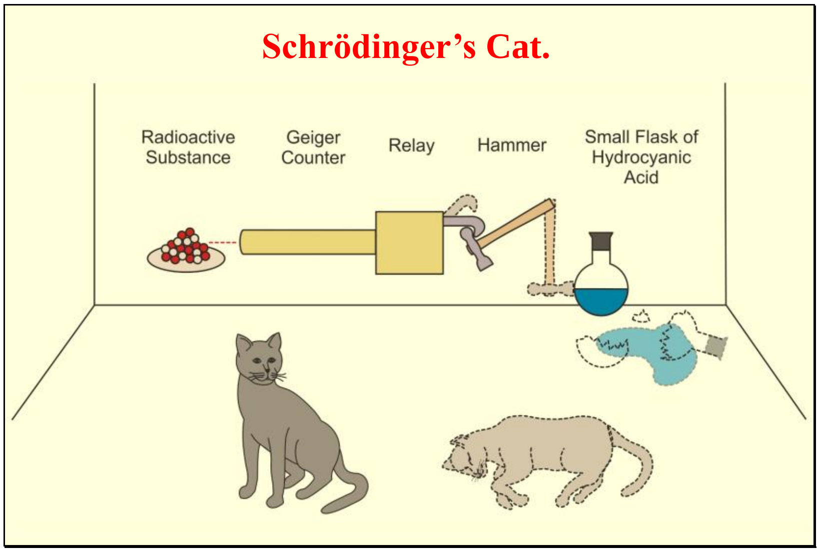
Schrödinger won the Nobel Prize for this work in 1933.



One of the foundational findings of the new physics was that light sometimes acted like a wave and at other times like a particle. One of the main experiments that demonstrate wave-particle duality is the passage of light through a diffraction grating. If light were composed of particles (photons) these would reach all sections of the screen. If it were composed of waves these would cancel each other out at various locations giving a "diffraction pattern' on the screen.
In quantum mechanics each photon is a wave-function. Thus it acts as a wave when going through the grid.

One key aspect of quantum mechanics is that measurement determines the properties of a quantum by collapsing the wave-function. What was once a whole range of possibilities becomes limited by observation.

video clip is from
https://toutestquantique.fr/dualite/



One of the thought experiments that illustrated the indeterminacy of quantum mechanics involved Schrödinger's cat. We can imagine how a cat could be placed in a closed chamber together (with a glass flask containing deadly hydrocyanic acid, a hammer, a Geiger counter and a small amount of radioactive substance. If the Geiger counter is activated by a particle emitted during the decay of the radioactive substance, it will cause a hammer to break the flask, releasing the hydrocyanic acid and killing the cat. At a particular time after setting up the experiment, the probability that one atom will have decayed is 0.5. At that time, is the cat dead or alive? Physicists are not sure. Some say that the cat is both alive and dead until an observer looks into the box and determines the outcome one way or the other. The act of observation collapses the probabilistic wave function that underlies radioactive decay. Other physicists postulate that two universes have diverged, with the cat alive in one and dead in the other.

The experiment is directly related to the postulate of determinism. The past state of the world is known. The laws of physics concerning the decay of the radioactive substance are known. Although expressed in terms of probability, these laws are very precise. Yet the present state of the cat in the box is indeterminate. It cannot be predicted, not by me, not by you, not even by an omniscient God. It can only be observed.

In *The Big Bang Theory*, Penny is uncertain about whether she should date Leonard. Sheldon tells Penny about Schrödinger's cat.

Einstein-Bohr Debates

Albert Einstein was never comfortable with quantum mechanics, and had many debates with Niels Bohr Einstein's "God does not play dice" comes from these debates. Einstein, Podolsky and Rosen designed a thought experiment to demonstrate the inadequacy of quantum mechanics. Collapsing the wave function of one particle of a pair (by observing it) would affect the measurements of the other particle in the pair. Einstein considered that this was "spooky action at a distance."

Einstein and Bohr
Brussels, 1934

Schrödinger's cat was one of many thought-experiments debated by Einstein and Bohr in the 1930s.

"Spooky action at a distance" also goes by the name of quantum entanglement. This remains one of the unexplained mysteries of physics.

Participatory Anthropic Principle

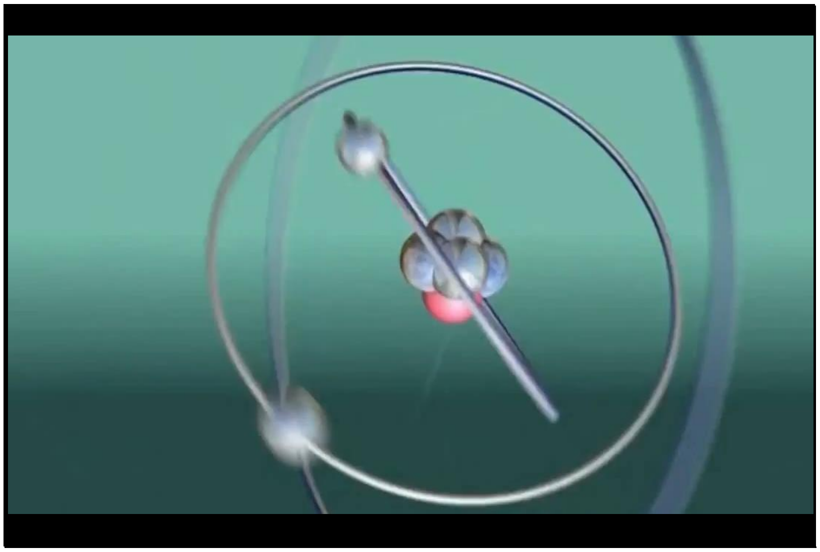
John Wheeler (1911-2008), an American physicist, described three types of baseball umpires:

Number 1: I calls 'em like I see 'em.
Number 2: I calls 'em the way they *are*.
Number 3: They ain't *nothing* till I calls 'em.

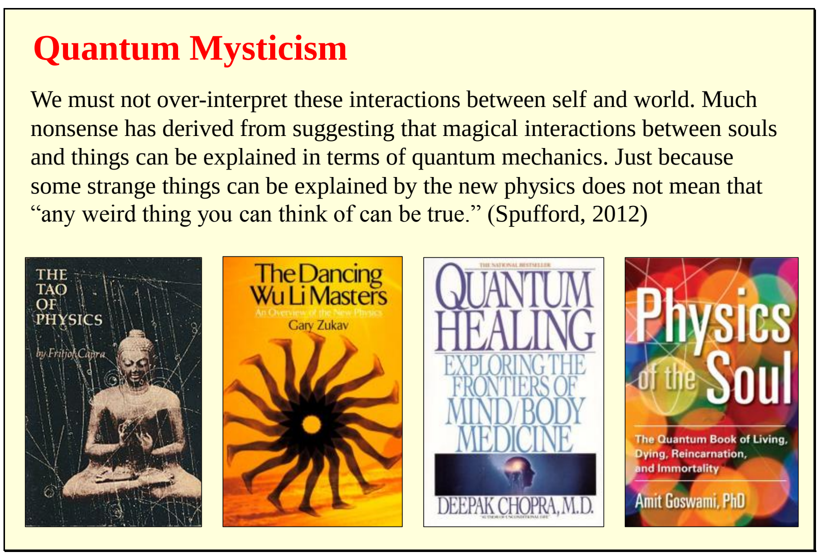
The second is like Einstein. The third is like Bohr.

The role that observation plays in determining what is happening is the essence of the participatory anthropic principle: "They ain't nothing till I calls 'em."

This principle differs from the more general anthropic principle which proposes that the Universe is fine-tuned to allow the development of consciousness.



In the TV program *The Big Bang Theory*, Sheldon asks Leonard about the Anthropic Principle.

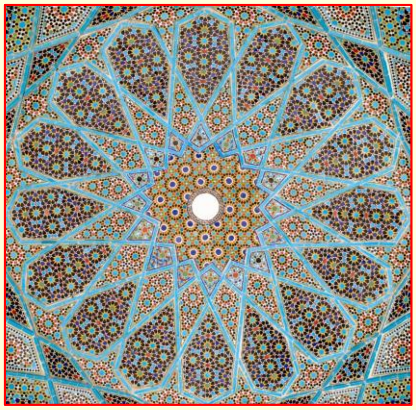


Nevertheless, the quantum physicists were very partial to Eastern mysticism.

Mind and Matter

In his 1958 lectures, Schrödinger quoted from the Sufi mystic Aziz Nafazi (13th Century CE):

"The spiritual world is one single spirit who stands like unto a light behind the bodily world and who, when any single creature comes into being, shines through it as through a window. According to the kind and size of the window less or more light enters the world. The light itself however remains unchanged."



Ceiling of the tomb of the 13th century Sufi poet Hafez built in 1773

Nuclear Fission

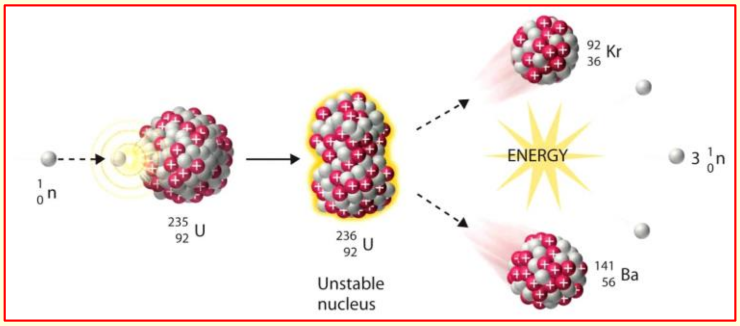
Born in Vienna, Meitner was educated at the Universities of Vienna and Berlin. After graduating she became an assistant to Max Planck, and ultimately rose to be the first female full professor of Physics in 1926. Her colleague Otto Hahn and his student Fritz Strassmann, found that of bombarding uranium with the newly discovered neutron produced barium. Meitner's interpretation of these experiments in terms of nuclear fission was published in 1939. However, by then she was in Sweden, having left Germany in 1938 for fear of the Nazi's actions against the Jews.

Lise Meitner (1878-1968)

In 1944 Otto Hahn was awarded the Nobel Prize in Chemistry for "his discovery of the fission of heavy atomic nuclei." Most scientists believe that Meitner should certainly have been a co-recipient since it was she who clearly demonstrated what the findings meant.

Physicists such as Rutherford, Bohr, Einstein and Heisenberg were quick to realize that tremendous amounts of energy could be produced by nuclear fission. The possibility of an atomic bomb became real.

On August 2, 1939 Albert Einstein and Leo Szilard wrote to President Roosevelt warning of the possibility of an atomic bomb, informing him of German research efforts, and urging him to support American research on nuclear fission. One month later Europe was at war.



Given a sufficient concentration of Uranium-235, the neutrons released from the fission of one nucleus could then cause fission of more nuclei. Such a chain reaction would release tremendous amounts of energy.

There is a tiny loss of mass during the fission. However this is converted to huge amounts of energy according to Einstein's formula $e = mc^2$

In nature Uranium-235 (half life 700 million years) is only 0.7%. Most of uranium is Uranium-238 (half life 4.5 billion years).

St Nicholas Church

Copenhagen

During World War II, Werner Heisenberg became the scientist in charge of Germany's effort to make nuclear weapons. In 1941, Heisenberg visited Niels Bohr in occupied Denmark. Exactly what happened at that meeting is uncertain. Michael Frayn's play considered some of the possibilities. Heisenberg may have thought that Bohr could know whether the allies were making progress on nuclear fission. Perhaps, Heisenberg wished to request absolution from his scientific father, to have Bohr agree that it was not immoral to work on nuclear physics even though this could lead to atomic weapons.

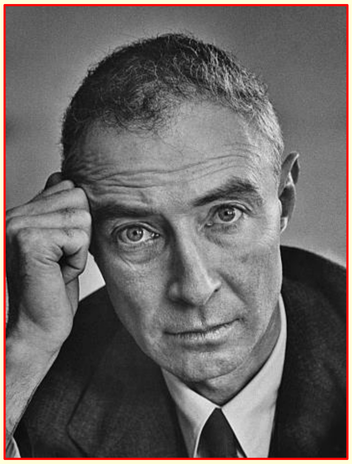
Michael Frayn's 1998 play *Copenhagen* imagines a meeting between Bohr and Heisenberg after the war. At this time they attempt to find out what actually happened in 1941. What were Heisenberg's intentions?
A brief recent paper on this meeting is
http://www.defensemedianetwork.com/stories/the-copenhagen-meeting-of-heisenberg-and-bohr/

The play and movie try to understand why Heisenberg met with Bohr. However there is one scene wherein Bohr discusses the new ideas of quantum physics and how they changed the role of humanity in the universe much like the findings of Copernicus 500 years before.

This clip is from Michael Frayn's *Copenhagen*. The play was originally produced in 1998. A TV Movie was created in 2002. Stephen Rea is Niels Bohr, Daniel Craig is Werner Heisenberg and Francesca Annis is Margrethe Bohr. In this scene Bohr considers how quantum mechanics changed our idea of the world. Piano music is Schubert's B flat major Sonata D960.

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 a 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 things, than we're pushed aside again by 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 that 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.
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, from 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 no precisely determinable objective universe. That the universe exists 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.



J. Robert Oppenheimer (1904-1967)
by Alfred Eisenstadt, 1954

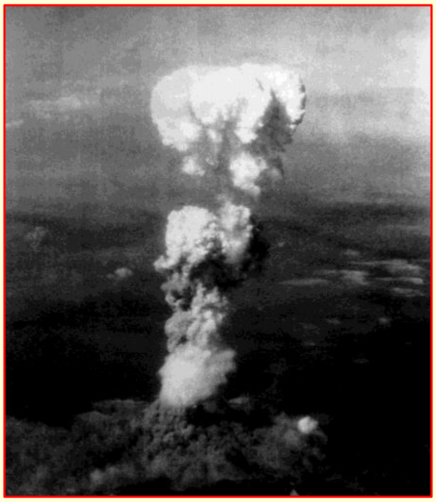
The Manhattan Project

In 1942 President Roosevelt arranged the funding for a multi-center project for building an atomic bomb. Oak Ridge in Tennessee was the center that produced the enriched uranium-235 necessary for the bomb. Chicago investigated the physics of a chain reaction under the direction of Enrico Fermi. Under the leadership of Robert Oppenheimer, the Los Alamos laboratory constructed and tested the bomb. Observing the first explosion of the bomb – the Trinity test of July 16, 1945 – Oppenheimer quoted from the *Bhagavad Gita* the words of Krishna:

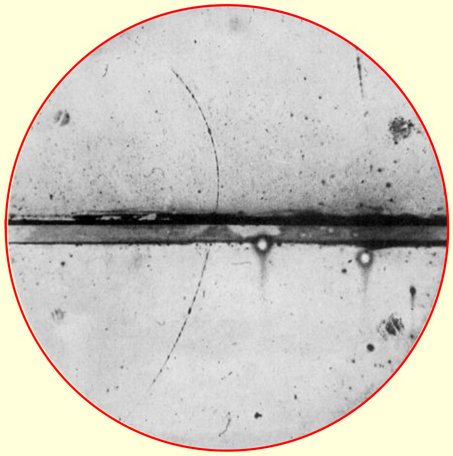
"Now I am become Death, the shatterer of worlds."

Hiroshima

On August 6, 1945, an atomic bomb was dropped on Hiroshima. Six planes participated in mission: one to carry the bomb (*Enola Gay*), one to take scientific measurements of the blast (*The Great Artiste*), a third to take photographs (*Necessary Evil*), and three others who flew approximately an hour ahead to act as weather scouts. About 140,000 people, most of them civilians, died in the bombing or in the months following.



Positrons



Cloud chamber photograph of the first positron to be identified

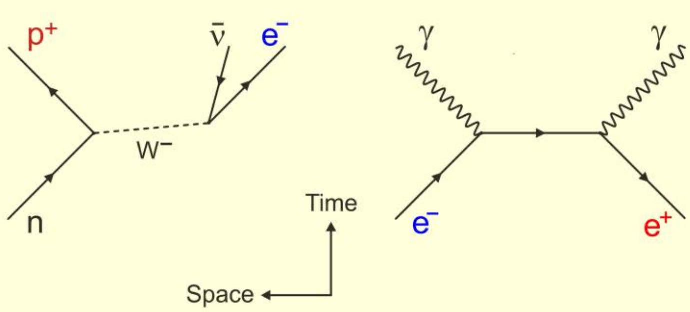
In 1928 Paul Dirac (1902-1984) predicted the existence of a positron – a particle with similar mass to an electron but with a positive charge. It was discovered in 1932 by Carl Anderson in 1932. Positrons are very short-lived since they quickly collide with an electron. The collision annihilates both particles and releases energy.

In a cloud chamber the passage of an atomic particle such as an electron (or a positron) knocks the electrons off atoms resulting in ions. If the gas (e.g. water or alcohol vapor) is supersaturated these ions will be the focus of condensation. The trail of the particle can thus be observed. Its behavior in a magnetic field will demonstrate its charge.

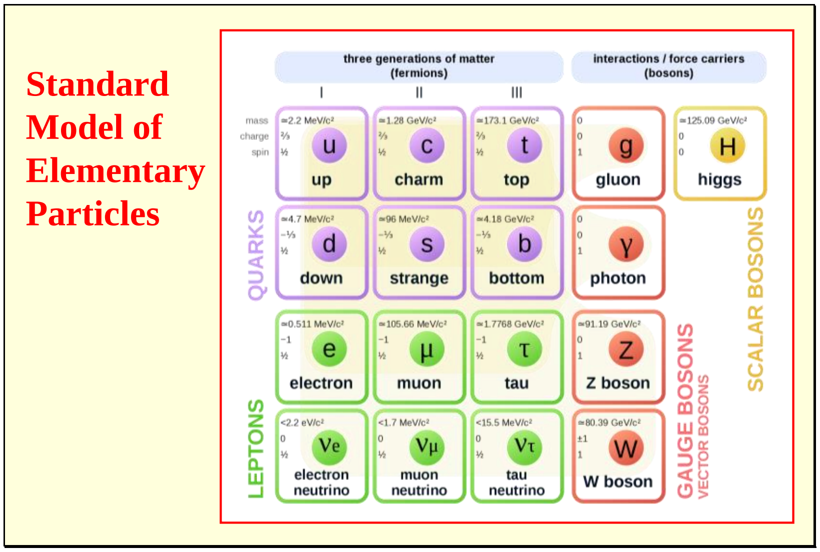
The physics of the first part of the 20th Century settled on an atom composed of protons, neutrons and electrons. The positron was the first of many other subatomic particles to be discovered. O brave new world that has such particles in it.

Feynman Diagrams

β^- Decay **Annihilation**



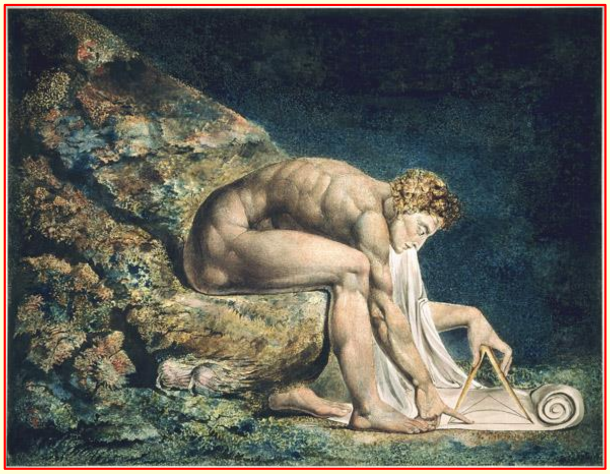
Richard Feynman (1918-1988) proposed a graphic way to examine the interactions of subatomic particles. The left shows the process of beta decay: a neutron becomes a proton with the emission of an electron and an anti-neutrino through the intermediary of a W-boson. The right shows electron-positron annihilation. In the diagrams time goes vertically from below to above. The left-right axis represents a one-dimensional version of three-dimensional space. By convention, the arrows for anti-particles (the anti-neutrino on the left and the positron on the right) have the opposite direction to those of the normal particles.



This table represents observed particles. The graviton mediating gravitational attraction remains only hypothesized.

The nuclear particles – neutrons and protons – are actually composed of more elementary particles called quarks. These were proposed by Murray Gell-Mann in 1964. The term was invented but Gell-Mann later found it in James Joyce's *Finnegan's Wake:* "Three quarks for Muster Mark." This seemed appropriate since quarks usually occur in groups of three.

Atoms



William Blake, *Newton*, 1805

This is Blake's ink-and-watercolor print of *Newton* (1805). From the notes at the Tate website:

Blake, however, was critical of reductive scientific thought. In this picture, the straight lines and sharp angles of Newton's profile suggest that he cannot see beyond the rules of his compass. Behind him, the colourful, textured rock may be seen to represent the creative world, to which he is blind.

http://www.tate.org.uk/art/artworks/blake-newton-n05058

The new standard model of the elementary particles shows that physicists are far from being devoid of imagination.