Quantum Alchemy?

Prof. David Kaiser

Matter unit

Overarching question: Is the stuff of the world indivisible and unchanging or transmutable?

I. Particles, Waves, and Cats

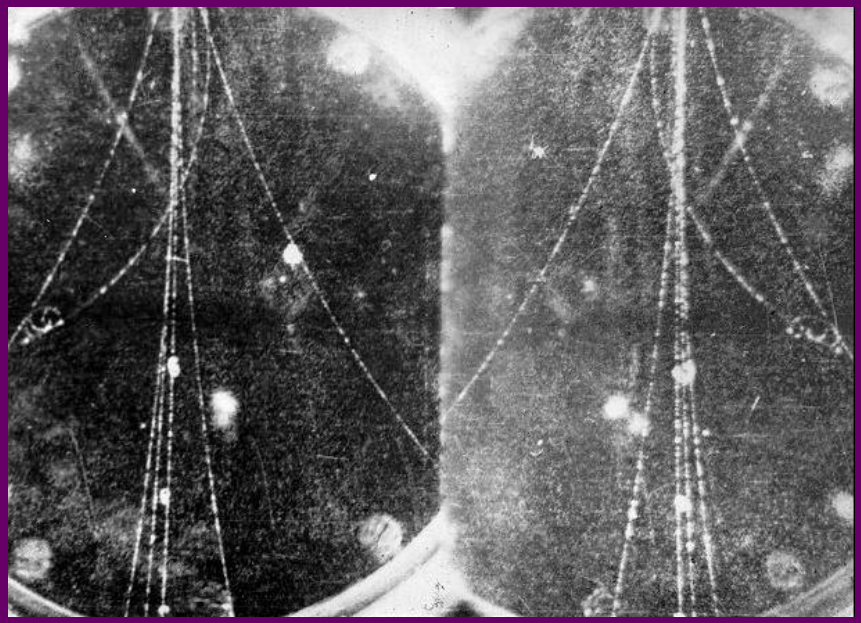
II. Nuclear Transmutation

III. Open Questions

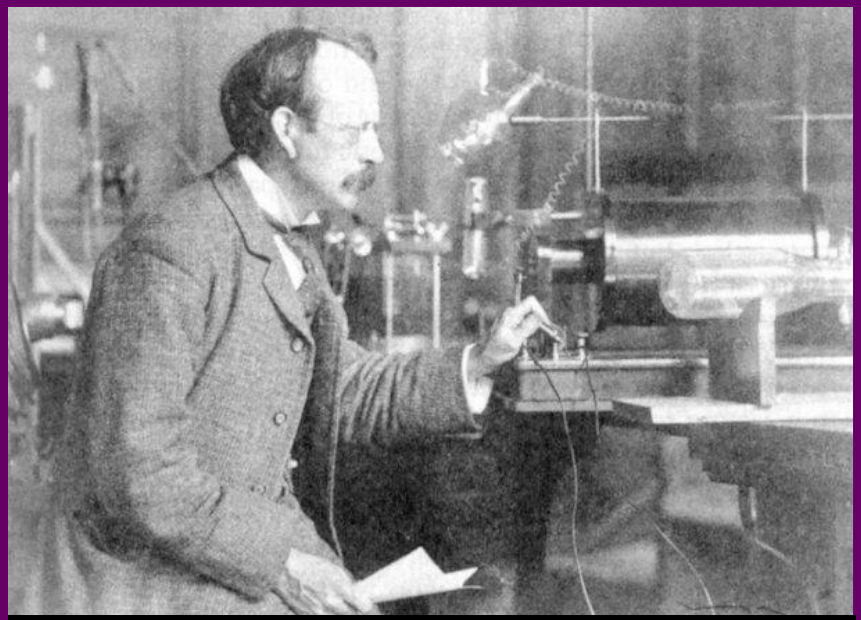
Readings: Smyth, *Atomic Energy for Military Purposes*, 206-226; Dear, *Intelligibility of Nature*, 141-172.

Things Fall Apart

By the 1880s, matter seemed to be well understood: chemical elements and physical atoms.



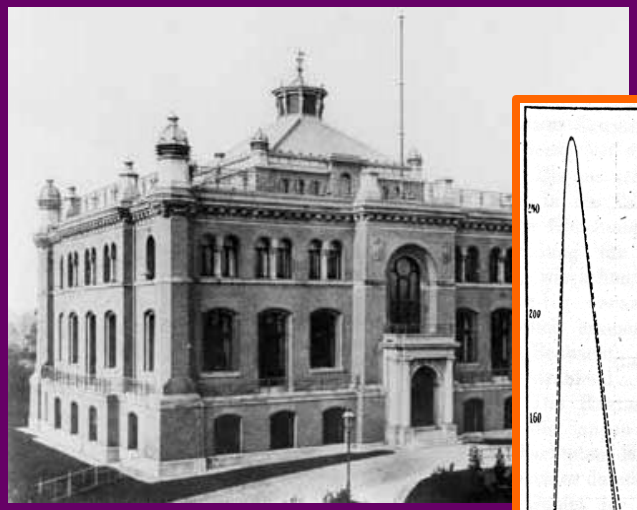
Cloud chamber photographs, early 1900s



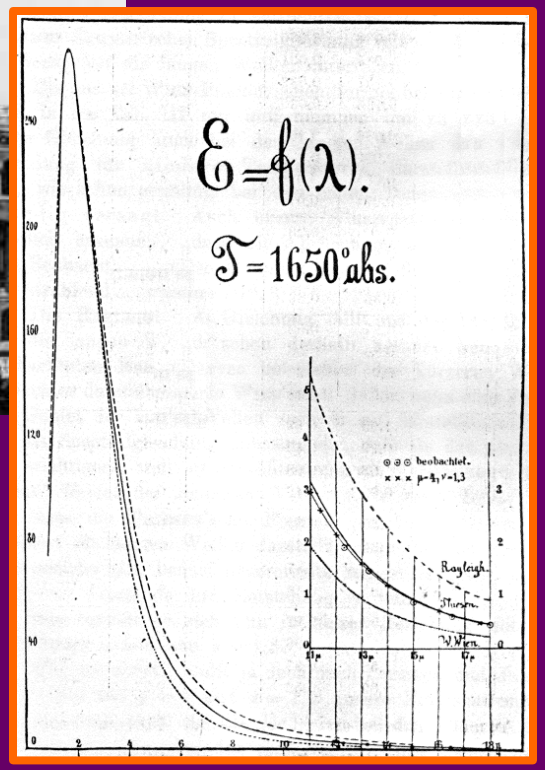
J. J. Thomson with his cathode, ca. 1897

The mid-1890s, however, brought rapid changes: new radiations heralded *structure* and *change* within the atom. Atoms were neither indivisible nor eternal after all.

Introducing Discreteness (?)



Physikalisch-Technische Reichsanstalt, Berlin, ca. 1900



Lummer and Pringsheim, blackbody spectrum, 1890

Max Planck (1858 – 1947)

$$u(\nu, T) = \frac{8\pi\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1}$$

Not So Solid

Albert Einstein (1879 – 1955)

Albert Einstein proposed in 1905 that light might be corpuscular.

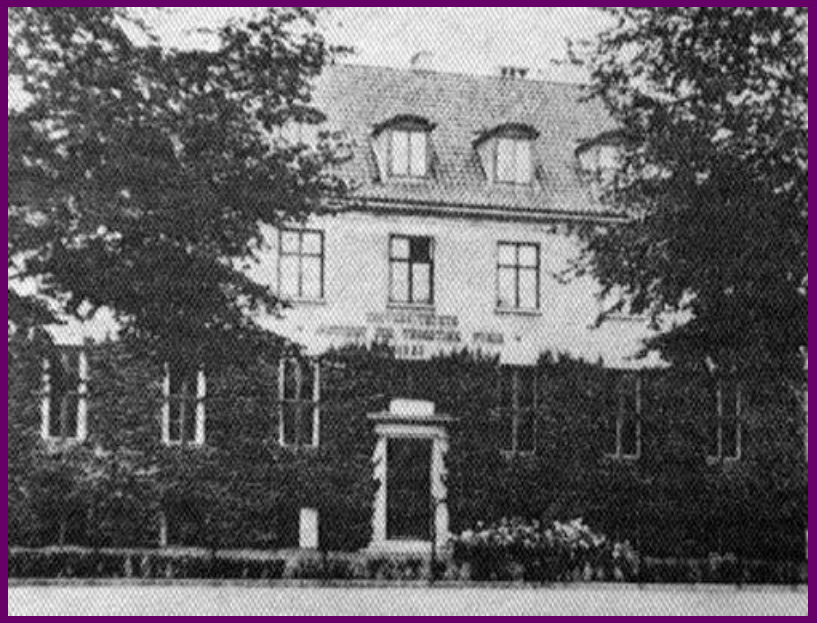
Between 1900 – 1924, physicists across Europe sought to make sense of puzzling phenomena involving light and matter.

Louis de Broglie proposed in 1924 that matter might be wavelike.

Louis de Broglie (1892 – 1987)

Quantum Mechanics

Werner Heisenberg
(1901 – 1976)



Niels Bohr's Institute for Theoretical Physics, Copenhagen, 1920s

Erwin Schrödinger
(1887 – 1961)

Papers by W. Heisenberg and E. Schrödinger removed due to copyright restrictions.

Not A Happy Union

"My theory was inspired by L. de Broglie...and by short but incomplete remarks by A. Einstein.... No genetic relation whatever with Heisenberg is known to me. I knew of this theory, of course, but felt discouraged not to say repelled, by the methods of transcendental algebra [matrices], which appeared very difficult to me and by the lack of visualizability."

Erwin Schrödinger, 1926

Schrödinger and Heisenberg receiving Nobel Prizes, 1933

"The more I reflect on the physical portion of Schrödinger's theory the more disgusting I find it. ... What Schrödinger writes on the visualizability of his theory... I consider trash."

Werner Heisenberg, 1926

But What Does It Mean?

Niels Bohr and Albert Einstein discussing quantum theory, ca. 1927

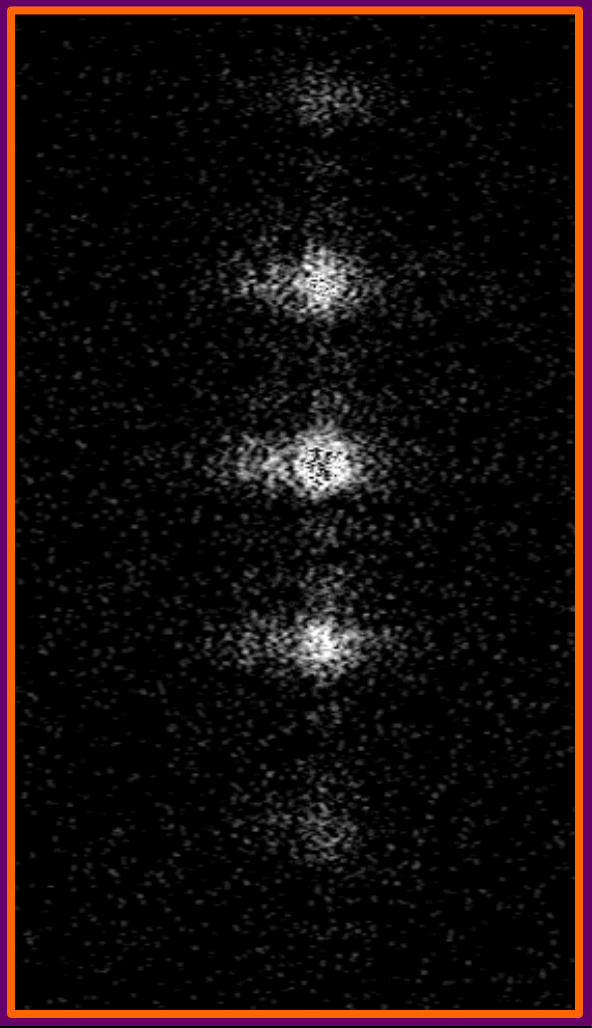
Illustration of the double-slit experiment removed due to copyright restrictions.
See: http://commons.wikimedia.org/wiki/File:Doubleslit.svg.

$$|\psi(x,t)|^2 = \text{Probability}$$

Send One Photon Through At A Time...

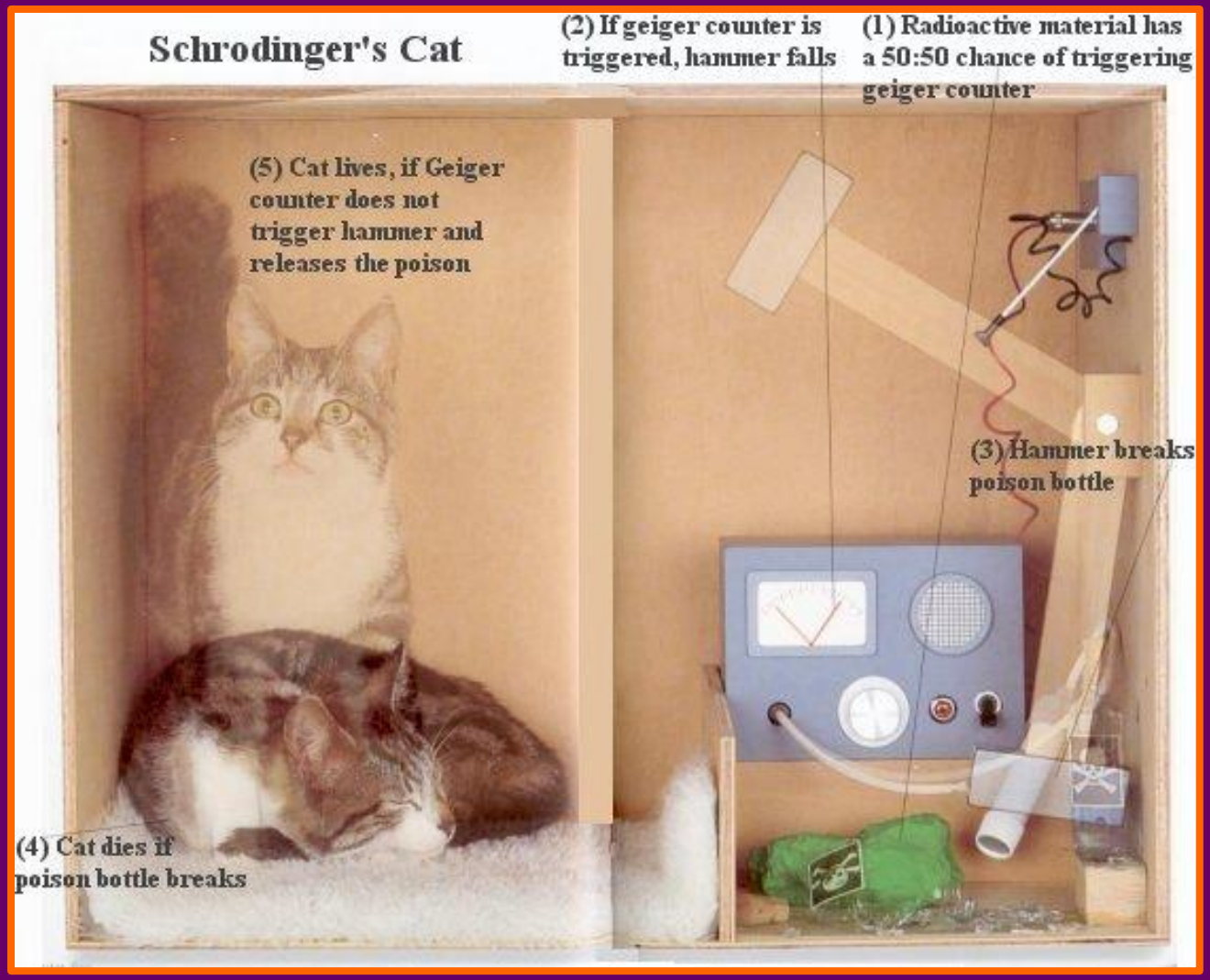
$t = 1/30$ s

$t = 1$ s



$t = 100$ s

That Pesky Cat



Going Nuclear

Enrico Fermi (1901 – 1954)

Article Fermi, E. "Possible Production of Elements of Atomic Number Higher than 92." *Nature* 133 (1934): 898-899 removed due to copyright restrictions. See: Nature.

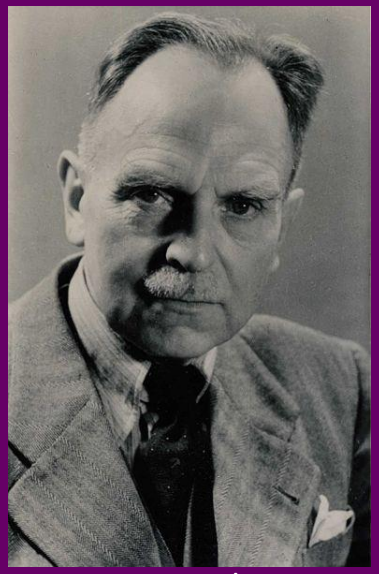
$$U_{92}^{238} + n \rightarrow U_{92}^{239} \rightarrow Np_{93}^{239} \; ?$$

$$n \rightarrow p + e + \nu$$

Photo of Fermi receiving a Nobel Prize, December 1938, removed due to copyright restrictions.

Fermi receiving Nobel Prize, December 1938

Fission on the Benchtop



Otto Hahn
(1879 – 1968)

Fritz Strassmann
(1902 – 1980)

Image of Hahn and Strassmann's experimental arrangement removed due to copyright restrictions. See: Wikimedia Commons.

$$U_{92} + n \rightarrow Ba_{56} + Kr_{36}$$

"As chemists, we must actually say the new particles do not behave like radium but, in fact, like barium; as nuclear physicists, we cannot make this conclusion, which is in conflict with all experience in nuclear physics." Hahn and Strassmann, Dec. 1938

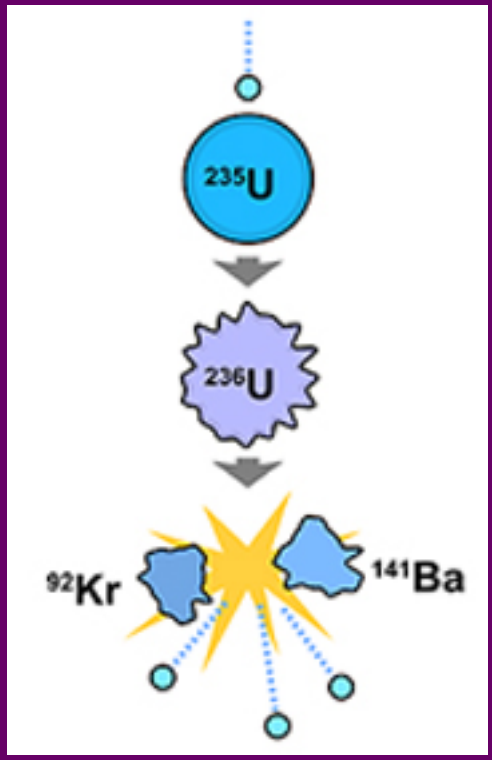
Explaining Fission

Lise Meitner
(1878 – 1968)

Otto Robert Frisch
(1904 – 1979)

Photo of Lise Meitner and Otto Hahn in Berlin, ca. 1938, removed due to copyright restrictions.

$1 \text{ kg } U^{235} = 20{,}000 \text{ tons of TNT}$



This image is Public Domain.

Einstein Alert

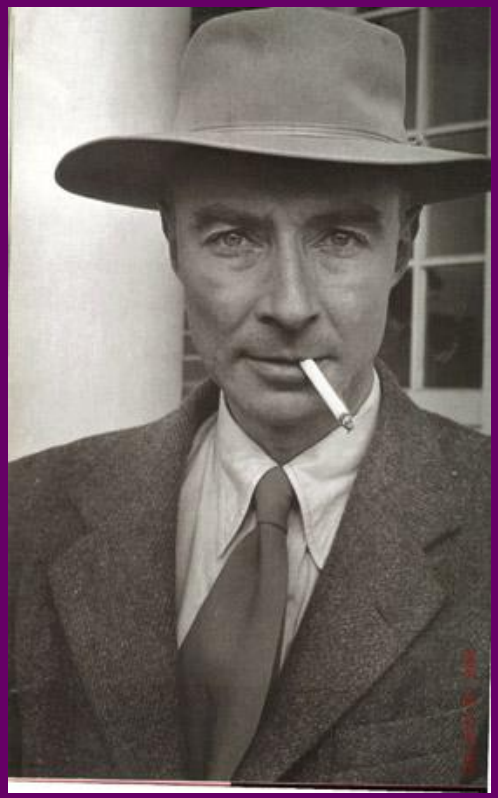
Einstein with Leo Szilard
(1898 – 1964)

Image of Einstein with Leo Szilard removed due to copyright restrictions. See: Life.

Albert Einstein's letter to President Roosevelt removed due to copyright restrictions.
See: Argonne National Laboratory.

Oppenheimer and S-1

Not long after the attack on Pearl Harbor (December 1941), the atomic bomb project received higher priority. Leslie Groves – who had overseen the construction of the Pentagon – was put in charge of the project, under the auspices of the US Army Corps of Engineers.



J. Robert Oppenheimer (1904 – 1967)

Leslie R. Groves (1896 – 1970)

Groves surprised everyone by selecting J. Robert Oppenheimer, a theoretical physicist, to become scientific director of Los Alamos.

Factory Production

U_{92}^{235} vs. U_{92}^{238}

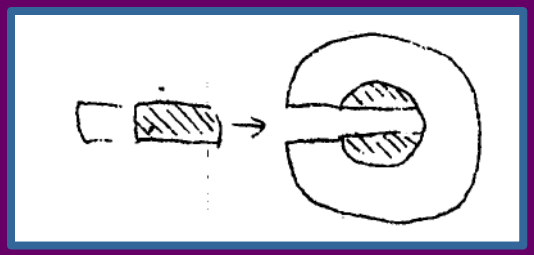
Uranium isotope separation plant, Oak Ridge, Tennessee, ca. 1944

$$U_{92}^{238} + n \rightarrow Np_{93}^{239}$$

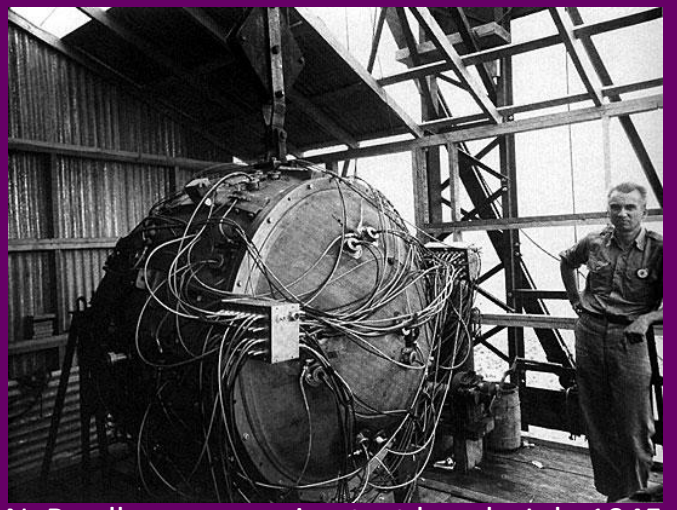
$$Np_{93}^{239} + n \rightarrow Pu_{94}^{240}$$

Plutonium reactor facilities, Hanford, Washington, ca. 1945

Working Bombs

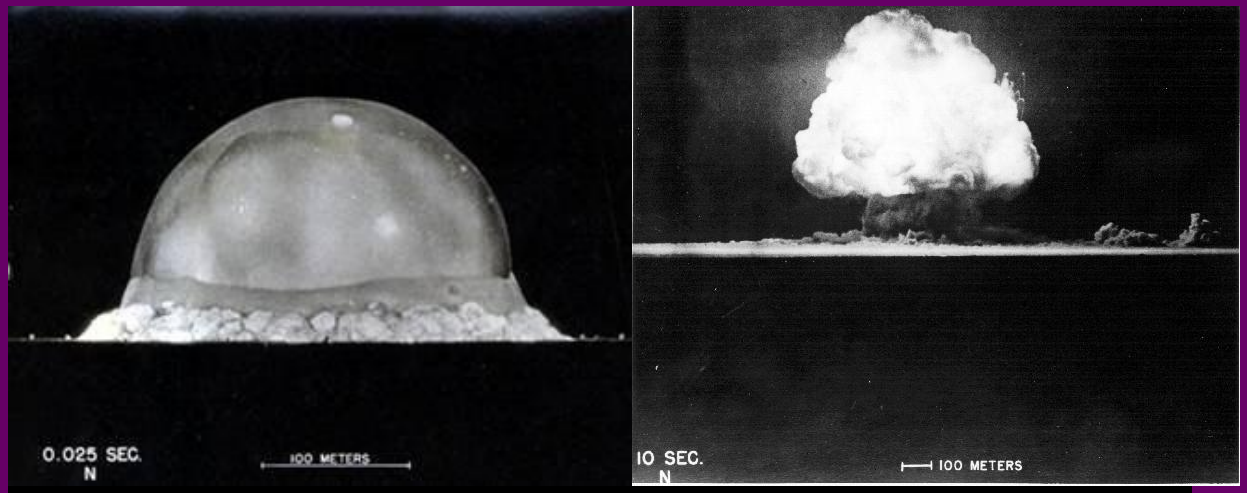


Uranium bomb:
gun assembly



N. Bradbury preparing test bomb, July 1945

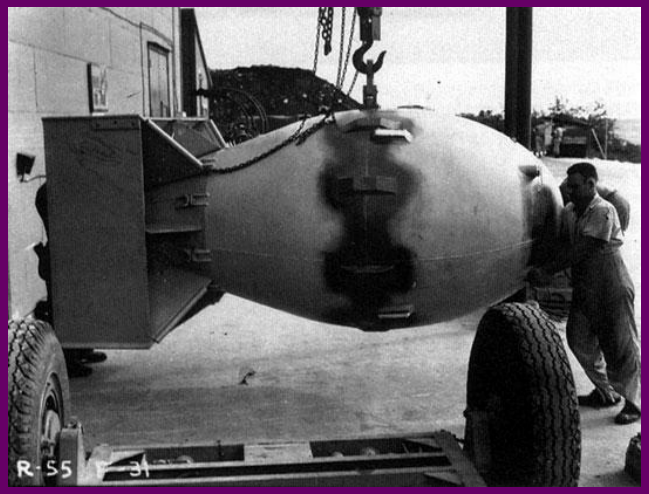
Image of implosion assembly removed due to copyright restrictions.
See: Implosion Nuclear Weapon.



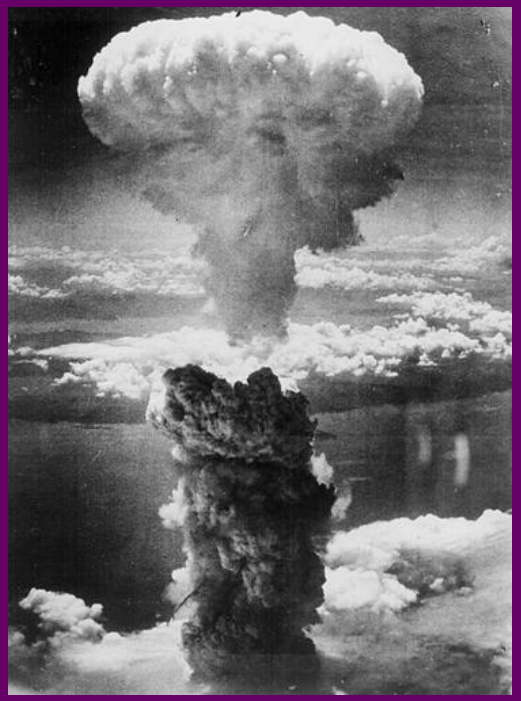
Trinity test, 16 July 1945

Oppenheimer and Groves inspect ground zero

Nuclear War



Loading “Fat Man” Pu bomb on Tinian island, August 1945



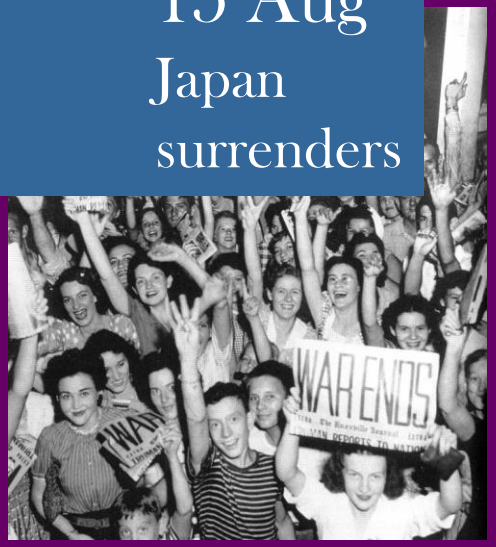
Bombing of Nagasaki

“...a demonstration of the new weapon might best be made, before the eyes of the representatives of all the United Nations, on the desert or barren island.”

(s) J. Franck, Chairman
D. J. Huges
J. J. Nickson
E. Rabinowitch
G. T. Seaborg
J. C. Stearns
L. Szilard

June, 11, 1945

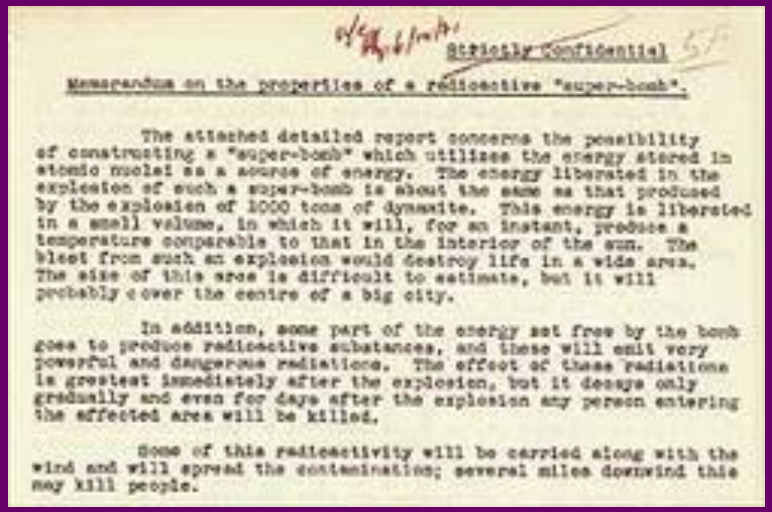
6 Aug	9 Aug	15 Aug
Hiroshima bombed	Nagasaki bombed	Japan surrenders



Oak Ridge workers celebrate “V-J” day

Failed Calculations

UK, March 1940:
Frisch and Peierls
underestimated the
critical mass of U^{235}
by a factor of 10.



Strictly Confidential

Memorandum on the properties of a radioactive "super-bomb".

The attached detailed report concerns the possibility of constructing a "super-bomb" which utilizes the energy stored in atomic nuclei as a source of energy. The energy liberated in the explosion of such a super-bomb is about the same as that produced by the explosion of 1000 tons of dynamite. This energy is liberated in a small volume, in which it will, for an instant, produce a temperature comparable to that in the interior of the sun. The blast from such an explosion would destroy life in a wide area. The size of this area is difficult to estimate, but it will probably cover the centre of a big city.

In addition, some part of the energy set free by the bomb goes to produce radioactive substances, and these will emit very powerful and dangerous radiations. The effect of these radiations is greatest immediately after the explosion, but it decays only gradually and even for days after the explosion any person entering the affected area will be killed.

Some of this radioactivity will be carried along with the wind and will spread the contamination; several miles downwind this may kill people.

Image of "Copenhagen," Michael Frayn, removed due to copyright restrictions.

Germany, 1939-42:
Heisenberg et al.
overestimated the
critical mass of U^{235} by
a factor of 10.

Big Science

Chart of funds expended by the U.S. on basic physics research between 1935 - 1960 removed due to copyright restrictions.

Picture of the Berkeley University Bevatron (1955) removed due to copyright restrictions. See: Bevatron.

Berkeley Bevatron, 1955

New Mendeleevs

Image of a proton removed due to copyright restrictions.
See: Quark Structure Proton.

Hypothesis, 1964:
Particles like protons consist of *quarks.*

Murray Gell-Mann with John Seely Brown

Photo courtesy of Joi Ito on Flickr.

Photo of George Zweig removed due to copyright restrictions.
See: George Zweig.

George Zweig (1937 –)

A New Atomism?

Are quarks the new "atoms" – indivisible and eternal corpuscles – imagined by the ancients?

Image of "The Lightness of Being," Frank Wilczek, removed due to copyright restrictions.

Probably not: our current view is that matter is more like *light* than like "solid, massy, hard, impenetrable, moveable Particles." If certain popular models are correct (e.g. SUSY), particles of matter (like quarks) can transmute into quanta of pure force (like photons) and back again.

Geneva Dreamin’

Photo courtesy of bbworldservice on Flickr.

Large Hadron Collider, CERN

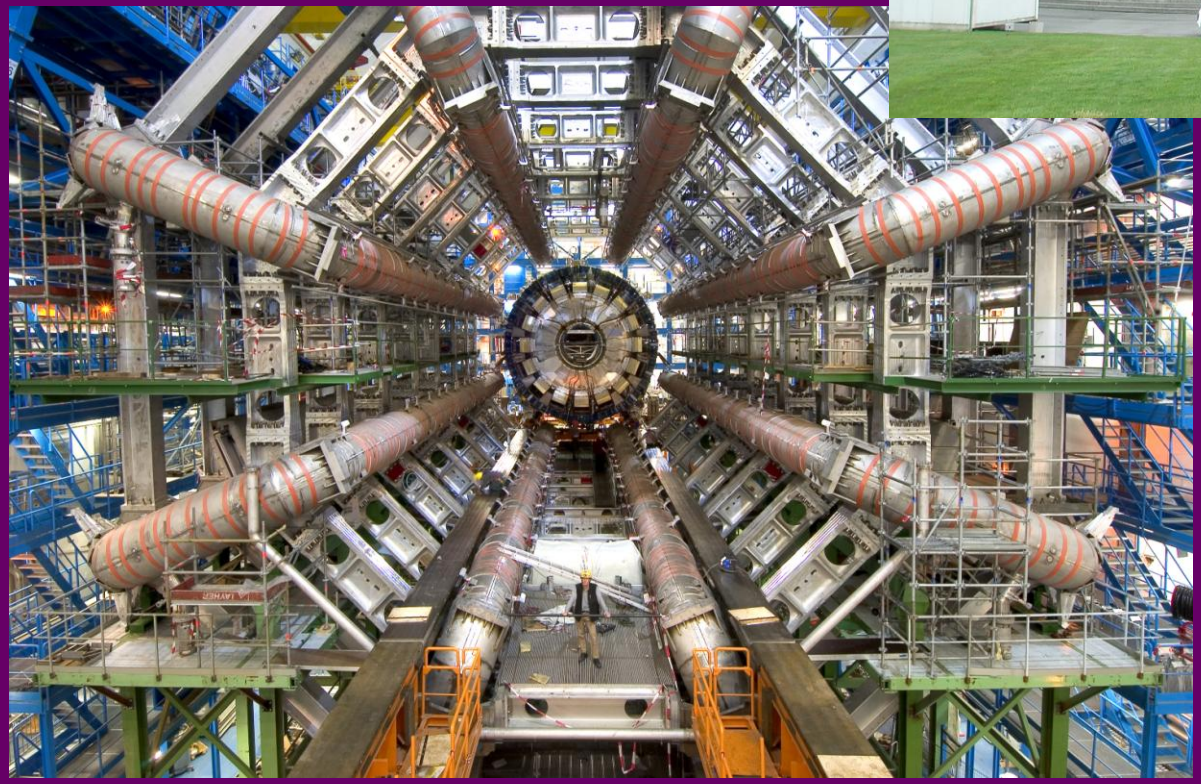


Photo courtesy of Image Editor on Flickr.

Detector under construction at LHC

STS.003 The Rise of Modern Science
Fall 2010