Quantum Theory Matters

with thanks to John Clarke Slater (1900–1976),

Per-Olov Löwdin (1916–2000), and the many members of

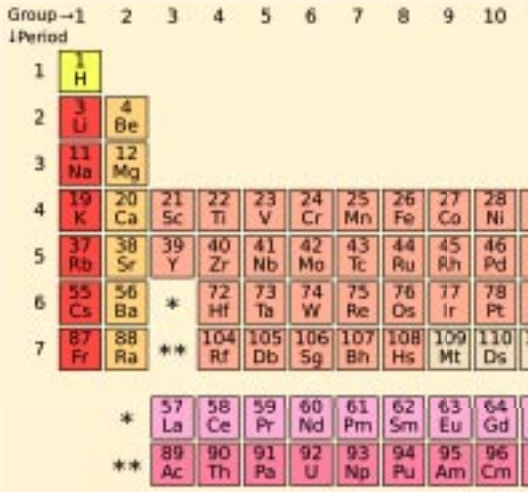
QTP (Gainesville, FL, USA) and KKUU (Uppsala, Sweden)

Nelson H. F. Beebe

Research Professor
University of Utah
Department of Mathematics, 110 LCB
155 S 1400 E RM 233
Salt Lake City, UT 84112-0090
USA

Email: beebe@math.utah.edu, beebe@acm.org, beebe@computer.org (Internet)
WWW URL: http://www.math.utah.edu/~beebe
Telephone: +1 801 581 5254
FAX: +1 801 581 4148

The periodic table of elements



All from H (1) to U (92), *except* Tc (43) and P

Correcting a common misconception

Scientific Theory: *not* a wild @$$#% guess, but rather a *mathematical framework* that allows *actual calculation* for known systems, and *prediction* for unknown ones.

Scientific method

Theories should be based on *minimal s* preconceived dogmas, no matter how w Archimedes, Socrates, Hypatia, Galileo, Lavoisier, . . .]

Open publication and free discussion of experimental results, so that others can and *reproduce them*.

Know who pays for the work, and judge have public support. History shows tha many times over.

If it ain't repeatable, it ain't science!

Conservation principles of physical science

energy (Lavoisier, Davy, Faraday)
linear / angular / spin momentum
(elementary particle) symmetry
(elementary particle) parity
baryon number
. . .

However, there are rare exceptions:

Nobel Prize in Physics for 1957 *to* **Chen Ning Yang and Tsung-Dao (T.D.) Lee** *"for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles"*

Impact of quantum theory on othe

biology,
chemistry,
computer science,
cosmology,
genetics,
geophysics,
medicine,
paleontology,
physics,
. . . , and even
Utah history, plus
billions of consumer products.

Some geography and significant cities

Map of Europe with these 14 cities marked:

Arosa, Switzerland
Berlin
Bern
Cambridge
Göteborg (Gothenburg)
Göttingen
Helgoland
København (Copenhagen)
Leipzig
München (Munich)
Paris
Roma (Rome)
Wien (Vienna)
Zürich.

Some geography and significant cit

Map of US and Southern Canada with these

Chalk River, ON
Berkeley, CA
Chicago
Hanford, WA
Los Alamos, NM
Delta, UT (only beryllium mine in US; critical elements in nuclear technology)
Boron, Kern County, CA (1/2 world so open pit mine)
Moab, UT
New York City (Columbia University)
Oak City, UT
Pasadena, CA
Wendover, UT

Some important big numbers in science

12 g of pure ^{12}C contains *Avogadro's number* of atoms, $\mathbf{6.022\,141\,29(27) \times 10^{23}}$.

The Universe contains about $\mathbf{10^{80}}$ elementary particles.

One *light year* is 9 460 730 472 580 800 m (exactly), or roughly $\mathbf{10^{16}}$ **m**, or 10^{13} km.

The Earth–Moon distance varies from 356, 000 km to 407, 000 km, or about **1.3 light-seconds**.

The median Earth–Sun distance is nearly the same as *one astronomical unit (AU)* , defined to be 149 597 870 700 m (exactly), or about 150 million km, or 150 Gm, or **8.3 light-minutes**.

1 light-year = 63 241 AU.

Solar system diameter is about **60 AU**.

Forces in nature found up to 1900

gravity (known back to Nicolaus Coper
Brahe (1546–1601), Galileo Galilei (156
(1571–1630), and Isaac Newton (1642–

electricity and magnetism (quantitative
(1644–1710), Hans-Christian Ørsted (1
(1791–1867), James Clerk Maxwell (18

Notice that they all come *after* the discovery by Christopher Columbus (1451–1506).

Our current mathematical descriptions are d Maxwell.

E&M *much* stronger than gravity: for two e

Both fall off as $1/r^2$ (like inverse area of sp

However Newton's gravity force is instantan

E&M force propagates at the speed of light

Albert Einstein in Bern, Switzerland, reconc

Forces in nature found after 1900

Nuclear forces that hold a cluster of like-charged particles together:

weak nuclear force,

strong nuclear force (10^{13} times larger than weak force).

Neither has much significance for day-to-day human experience, but we, and the Universe, are here because of them!

Both are *extremely* short range: about 1 to 2.5 fm (10^{-15}m); for comparison, atomic nucleus is about 1.75 fm (H) to 15 fm (U), and atomic radius is about 23 000 fm (H) to 145 000fm (U).

Nobel Prize in Physics for 1979 *to* **Sheldon Lee Glashow, Abdus Salam and Steven Weinberg** *"for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current"*

The rest of this talk

We now look at some high points in science to date.

1891–1897

Anglo-Irish physicist George Johnstone Stoney (1826-1911) names the fundamental unit of electricity an *electron* in 1891.
J. J. (Joseph John) Thomson (1856–1940) and his Cambridge team find it experimentally in 1897.

> **Nobel Prize in Physics for 1906** *to* **Joseph John Thomson** *"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases"*

> **Nobel Prize in Physics for 1923** *to* **Robert Andrews Millikan** *"for his work on the elementary charge of electricity and on the photoelectric effect"*

1895

Wilhelm Conrad Röntgen (1845–1923) disco
Würzburg, Germany.

> **Nobel Prize in Physics for 1901 (f**
> **Röntgen** *"in recognition of the extrao*
> *dered by the discovery of the remarkal*
> *after him"*

1896

Henri Becquerel (1852–1908), Marie Skłodowska-Curie (1867–1934), and Pierre Curie (1859–1906) discover radioactivity in Paris, France.

> **Nobel Prize in Physics for 1903** *to* **Antoine Henri Becquerel, Pierre Curie and Marie Curie, née Skłodowska** *"in recognition of the extraordinary services he [HB] has rendered by his discovery of spontaneous radioactivity and in recognition of the extraordinary services they [PC & MC] have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel"*

Radioactivity depends on particular chemical element and isotope (then unknown).
Half life: time after which half of the reactants have become products.
Thus, in ten generations: 10^{-3} left; twenty: 10^{-6} left, thirty: 10^{-9} left.
Decay of certain isotopes allows accurate dating in medicine, anthropology, and paleontology (Frank Brown and Thure Ceurling are famous Utah experts in that area).

1900

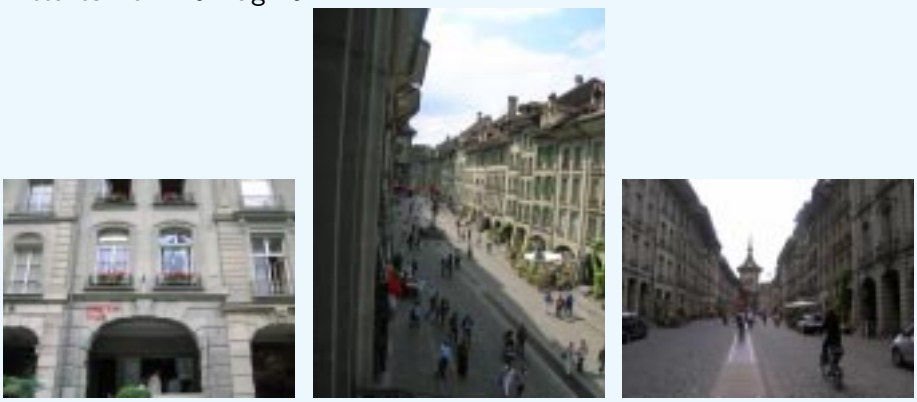
Max Planck (1858–1947) in Berlin, German
energy of light proportional to frequency: E
constant $h = 6.626176(36) \times 10^{-27}$ erg sec.
A. D. Stone: ***h* is the signature of all thin**
An *erg* is **tiny**: 41 868 000 ergs = 1 cal raises
1°C. [etymology: Greek $\epsilon\rho\gamma o$ is English *wor*
1 *food calorie* = 1000 cal $\approx 4 \times 10^{10}$ ergs.
Planck accurately predicted *Avogadro's num*
atom, and the *charge on the proton*.

> **Nobel Prize in Physics for 1918** *t*
> **Planck** *"in recognition of the services*
> *ment of Physics by his discovery of e*

In 1948, the *Kaiser Wilhelm Society* is renar
and ditto its Institutes (akin to US National

Einstein in Bern

Pictures from 20-Aug-2011:



1905: Einstein's Annus Mir

18-Mar-1905: photoelectric effect.

11-May-1905: Brownian motion (giving existence of atoms, and putting probab later tried very hard to avoid!).

30-Jun-1905: *Special Relativity* and *Pri* has constant velocity in all inertial fram *contraction*, *time dilation*, prediction of (wrong by $2\times$), and *bending of light in* mathematics, and no literature referenc

19-Aug-1905: new determination of mo thesis).

27-Sep-1905: $E = mc^2$ (3 pages!)
The velocity of light is $c = 299\,792\,460$ now define the standard meter in terms 1894 by Paul Drude (1864–1906), from

1905 (continued)

Nobel Prize in Physics for 1921 (awarded in 1922) *to* **Albert Einstein** *"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect"*

In December 1922, Einstein was lecturing in Japan, and there was a diplomatic flap in Stockholm when both Swiss and German Ambassadors to Sweden showed up to accept the Prize on behalf of Einstein.

Einstein's second 1905 paper on Brownian motion and theoretical prediction of atoms was found to be in close agreement with experiments by Jean Perrin.

Nobel Prize in Physics for 1926 *to* **Jean Baptiste Perrin** *"for his work on the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium"*

1911

Nobel Prize in Chemistry for 19 Skłodowska *"in recognition of her s of chemistry by the discovery of the nium, by the isolation of radium and compounds of this remarkable elemen*

Marie is thus *first person to win two Nobel* because of a semi-secret love affair with unh a former student of Pierre Curie. [Pierre had carriage in 1906.]

Heike Kamerlingh Onnes in Leiden, The Net *superconductivity*. Its theoretical explanatio (1957).

1913

Niels Bohr (1885–1962) (Cambridge, Manchester, and Copenhagen) publishes three ground-breaking papers that are the peak of *'old quantum mechanics'*, all under the main title *On the Constitution of Atoms and Molecules*, and subtitled

> *The binding of electrons by positive nuclei* (July 1913);
>
> *Systems containing only a single nucleus* (September 1913);
>
> *Systems containing several nuclei* (October 1913).

They are inspired by Planck's *quantum*, and provide the first successful description, and high-accuracy *prediction*, of the spectra of one-electron systems, with electrons moving in quantized fixed *orbits* about the nucleus.

> **Nobel Prize in Physics for 1922** *to* **Niels Henrik David Bohr**
> *"for his services in the investigation of the structure of atoms and of the radiation emanating from them"*

1914–1918: Wo

On 28-Jul-1914, Germany and Austria-Hung
Europe, following assassination of Archduke
28-June-1914 in Sarajevo.

Almost none of the four-and-half-year long w
territory: Poland, Belgium, France, and Rus

The USA does not join until 6-Apr-1917.

Russian Revolution in October/November 1

The war ends on Armistice Day, 11am 11-N
year-and-a-half of peace settlements that are
by US President Woodrow Wilson, British P
George, French Prime Minister Georges Cler
Minister Vittorio Emanuele Orlando, cripple
for the next terrible war in 1939. [The US p
much better!]

Mention Ho Chi Minh in Paris and Boston.

1914

Inspired by Frederick Soddy's popular writings on radioactivity, Herbert George (H. G.) Wells (1866–1946) publishes the book *The World Set Free* about an invention that speeds up radioactive decay of radium, allowing production of what he called *atomic bombs*, the first known use of that phrase in print.

[In 1897–1898, Wells had written the book *The War of the Worlds*, about the hostile invasion of Earth by Martians. A 1938 radio dramatization of that book by Orson Welles caused widespread panic in the US.]

1915

Albert Einstein's work in (peaceful) Berlin fr
to his papers on the field equations of *Gene*
Special Relativity to handle acceleration.

The equations are ten coupled differential eq
mathematics that is unfamiliar, then and no
small areas of pure mathematics.

The field equations reduce to Newton's thre
('small' mass) limit.

Newton's Laws work fine for satellites and r
are $\ll c$, so Special Relativity and General R

> *Matter tells space how to curve, and sp*
> *move.*

1915 (continued)

Einstein (like most physicists and astronomers) believes in 1915 that the Universe is static. Einstein's field equation solutions are found to be unstable for a static Universe, so Einstein adds a fudge term, which he calls the 'cosmological constant' (Λ). He later retracts it, calling it his *Greatest Blunder*: however, he was wrong to remove it (see events of late 1924).
On 22-Dec-1915, Karl Schwarzschild (1873–1916) reports to Einstein an exact solution of the General Relativity field equations.

1916

Karl Schwarzschild publishes paper on a crit
Schwarzschild radius, at which a massive bo
collapse and becomes a *'black hole'*, a term
Wheeler in 1967.
Schwarzschild dies on 11-May-1916 on Russ
gas exposure.

Nobel Prize in Chemistry for 191
synthesis of ammonia from its elemen

Ammonium nitrate fertilizers from Haber's p
lives from starvation, but can be used for ex
Fritz Haber (1868–1934) also develops poisc
close friend of Albert Einstein.

1914–1924

Work by many in Denmark, England, and Germany on why Bohr's atomic model does not work for two or more electrons.
Niels Bohr and Wolfgang Pauli (1900–1958) develop the *Aufbauprinzip* (building-up principle, or *Aufbau principle*) to explain the periodic table of elements.
Niels Bohr develops the *Correspondence Principle* relating classical and quantum mechanical behavior, and guiding the future philosophical development of quantum mechanics.

1919

Ernest Rutherford in Manchester, UK, demo
artificially-induced radioactivity by bombard
alpha particles (more in slides for 1920 and

$$^{14}\mathrm{N} + \alpha \rightarrow {}^{17}\mathrm{O}^{+}$$

At the time, the proton was not yet known,
On 9-Nov-1919, the New York Times report
observations confirm Einstein's General The

> *Lights All Askew in the Heavens: Men*
> *Agog over Results of Eclipse Observati*
> *Triumphs. Stars Not Where They Seem*
> *be, but Nobody Need Worry. A Book f*
> *in All the World Could Comprehend it,*
> *Daring Publishers Accepted It.*

1920

Nobel Prize in Chemistry for 1908 *to* **Ernest Rutherford** *"for his investigations into the disintegration of the elements, and the chemistry of radioactive substances"*

New Zealander Rutherford (1861–1937) did his Ph.D. under J. J. Thomson at Cambridge (1895–1898).

Rutherford and Frederick Soddy (1877–1956) work together at McGill University in Montréal (1898–1907), and Rutherford then moves to Manchester, UK. [Eyring anecdote.]

Rutherford names the second elementary particle (after the 1891 *electron*) the *proton*, and finds it experimentally in atomic collisions of nitrogen.

His Bakerian Lecture on 1-Jul-1920 predicts a third elementary particle, the *neutron* (confirmed in 1932). That lecture does not use the term *neutron*; he first published that word five months later.

Rutherford becomes *Sir Ernest* in 1914, and *Baron Rutherford of Nelson* in 1925.

1923

Arthur H. Compton (1892–1962) at Washin
MO, publishes experimental results that pro
radiation behaves as *particles of zero mass*,
Thus, light exhibits *wave–particle duality*, a
light, called *photons*, a name introduced in
Gilbert N. Lewis.

Nobel Prize in Physics for 1927 *t*
"for his discovery of the effect named

The controversy over whether light consists
to the late 1600s, with Isaac Newton favorir
Descartes, Robert Hooke, and Christiaan Hu

1924

Enrico Fermi (1901–1954) in Rome publishes December 1924 paper on *Fermi–Dirac statistics*, and almost discovers Pauli's *Exclusion Principle* (1925).

Fermi is the most-cited pioneer physicist: 1.2× Einstein, and his name is attached to many important concepts in physics, to about half the particles in the Universe (fermions), and to element 100 (fermium).

Wolfgang Pauli (1900–1958) in Zürich predicts electron and nuclear spin.

Electron spin is proposed independently, and confirmed experimentally, by George Uhlenbeck (1900–1988) and Samuel Goudsmit (1902–1978) in November 1925.

Nuclear spin is confirmed experimentally by S. Goudsmit and E. Back in 1927, in papers received 8-Apr-1927 and 1-Dec-1927

No Nobel Prize to U & G, however!

1924 (conti

Einstein translates to German two papers fr
(1894–1974) in Dacca, East Bengal, India, a
is the origin of *Bose–Einstein statistics*. Bos
the other half of the particles in the Univers
by Paul Dirac.

Nobel Prize in Physics for 2001 *to*
Ketterle and Carl E. Wieman *"fo*
Einstein condensation in dilute gases o
fundamental studies of the properties

Prince, later Duke, Louis de Broglie (1892–1
duality in his 1924 doctoral thesis.

Nobel Prize in Physics for 1929 *to*
Raymond de Broglie *"for his disco*
electrons"

1924–1925

23-Dec-1924 and 2-Jan-1925: Astronomer Edwin Hubble (1889–1954) reports that Universe is *expanding* in New York Times story and American Astronomical Society meeting; thus, Einstein's cosmological constant Λ is needed!

[No Nobel Prize, because astronomy is not covered by Nobel's will; that rule of the Nobel Committee is changed after Hubble's death.]

1929: Hubble publishes Redshift distance law.

1925–19

Georges Lemaître (1894–1966) in Louvain, B
expanding Universe, derives Hubble's Law, r
Hubble's constant, but publishes in little-rea

1925–1926

Werner Heisenberg (1901–1976) publishes three papers on matrix mechanics, the beginning of the *'new quantum theory'*:

1st received 29-Jul-1925 (after visions on Helgoland recovering from severe allergies);

2nd received 27-Sep-1925;

3rd received 16-Nov-1925.

Nobel Prize in Physics for 1932 *to* **Werner Karl Heisenberg** *"for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen"*

Albert Einstein says: "Heisenberg has laid a big quantum egg. In Göttingen they believe in it (I don't). ... A veritable witches' multiplication table ... exceedingly clever and because of its great complexity, safe against refutation."

1925

In February 1925, Wolfgang Pauli publishes
governs build-up of atoms: *no two fermions*
spin, such as electrons and protons) can occ
at the same time.

Nobel Prize in Physics for 1945 *to*
discovery of the Exclusion Principle, al

1926

Austrian Erwin Schrödinger (1887–1961) at Univerität Zürich, while on a ski holiday in Arosa, Switzerland, in December 1925 discovers *wave mechanics*:

Quantization as an eigenvalue problem (4 papers): 1st paper received 27-Jan-1926, 4th on 21-Jun-1926 (140 pages total).
Wave-mechanics equation *much* easier for traditional physicists to understand than matrix mechanics, and dominates the field ever since.
18-Mar-1926: Schrödinger demonstrates equivalence of matrix mechanics and wave mechanics.

Nobel Prize in Physics for 1933 *to* **Erwin Schrödinger and Paul Adrien Maurice Dirac** *"for the discovery of new productive forms of atomic theory"*

In December 1928, Max Born (1882–1970) in Göttingen interprets Schrödinger wavefunction's 'square' $|\Psi\Psi^*|$ as a *probability*, causing his close friend Albert Einstein much grief and anguish.

1927

Nobel Prize in Physics for 1954 *to* **Bothe** *"for his fundamental research pecially for his statistical interpretatio and for the coincidence method and hi [WB]"*

Werner Heisenberg's paper on *Unschärferela* English, the **Uncertainty Principle**) receive

$$\Delta x \Delta p \geq h/(2\pi) \quad \text{positio}$$
$$\Delta E \Delta t \geq h/(2\pi) \quad \text{energy-}$$

Drastically different from expectations of Ne
However, h is tiny, so we do not see its limit
certainly not on cosmological scales.

1928

George Gamow (1904–1968) is first to apply quantum mechanics to nucleus, and that year, discusses nuclear disintegration, and proposes liquid-drop model of nuclear structure. Also describes (1) quantum nature of alpha decay, (2) theory of the hot initial state of the Universe, (3) existence of cosmic microwave background radiation, (4) clue to the genetic code in biology. Gamow never got the Nobel Prize, but he often got there first in research.
Oppenheimer, and Gamow, and Gurney & Condon, independently discover phenomenon of 'quantum tunneling', which explains alpha decay (atom → new-atom + He^{++}), and is critical for modern electronics design.
Oppenheimer leads by 5 months with paper received 28-Mar-1928.
Paul Dirac (1902–1984) at Cambridge extends Schrödinger's wave equation with Einstein's Relativity to produce *relativistic quantum mechanics*, albeit only for single particle (papers: 2-Jan-1928, 2-Feb-1928). His equations predict a *positive electron*, later called a *positron*.

1930

Dirac book *Principles of Quantum Mechani* action' notation: $\hbar = h/(2\pi)$.
4-Dec-1930: Pauli writes letter *"Dear Radio* to Tübingen conference participants, propos which he calls a *neutron*, (later renamed *ne* carry away energy in beta decay (p ↔ n, so (electron or positron)),

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + e^- + \bar{\nu}$$
$$^{23}_{12}\mathrm{Mg} \rightarrow {}^{23}_{11}\mathrm{Na} + e^+ +$$

and preserve the *Principle of Conservation o* Neutrino is confirmed in 1953 by Frederick

Nobel Prize in Physics for 1995 *to* **erick Reines** *"for the discovery of th the detection of the neutrino (FR)"*

1931

5-Dec-1931: Harold Urey (1893–1981) reports discovery of heavy isotope of deuterium, D = $^2_1$H. D is stable & about 0.02% of all hydrogen on Earth.

Nobel Prize in Chemistry for 1934 *to* **Harold Clayton Urey** *"for his discovery of heavy hydrogen"*

Wikipedia: "Tritium [T = $^3_1$H] was first produced in 1934 from deuterium, another isotope of hydrogen, by Ernest Rutherford, working with Mark Oliphant and Paul Harteck. Rutherford was unable to isolate the tritium, a job that was left to Luis Alvarez and Robert Cornog, who correctly deduced that the substance was radioactive [half life ≈ 12 years]. Willard F. Libby discovered that tritium could be used for dating water, and therefore wine."

Nobel Prize in Chemistry for 1960 *to* **Willard Frank Libby** *"for his method to use carbon-14 for age determination in archaeology, geology, geophysics, and other branches of science"*

1932 (Miracle year in

Three huge developments in nuclear physics

James Chadwick (1891–1974) at Camb (possible existence: 27-Feb-1932; confi

Frédéric Joliot-Curie (1900–1958) and Paris produce first artificially induced n charged-particle bombardment.

Carl Anderson (1905–1991) at Caltech, positron.

Free electron and proton are stable indefinit than 10^{26} years, and 10^{29} years, respectively years old).

Neutrons are stable inside the nucleus, but a half life of about 15 minutes to a proton, ar antineutrino: $\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e} + \bar{\nu}_e$.

1932 (continued)

Nobel Prize in Chemistry for 1935 *to* **Frédéric Joliot and Irène Joliot-Curie** *"in recognition of their synthesis of new radioactive elements"*

Thus, 5 members of the Curie family shared 3 Nobel Prizes!

Nobel Prize in Physics for 1935 *to* **James Chadwick** *"or the discovery of the neutron"*

Nobel Prize in Physics for 1936 *to* **Victor Franz Hess and Carl David Anderson** *"for his discovery of cosmic radiation (VHF) and for his discovery of the positron (CDA)"*

U of Utah Physics & Astronomy *Cosmic Ray Project* is a world leader in that area.

1933

30-Jan-1933 Adolf Hitler becomes Chancello Third Reich will last a thousand years.

Persecution of Jews and other ethnic minori many such flee (e.g., Einstein to IAS, Prince

12-Sep-1933: New York Herald-Tribune repo *'The energy produced by the breaking down of thing, Any one who expects a source of p of these atoms is* **talking moonshine**.*'*

Also on 12-Sep-1933: After reading a Londo Rutherford's *'talking moonshine'* comment, becomes the first to conceive of the possibil

In March 1934, Szilard files a British patent chain reaction, the first in that new area of

Discuss chain reaction.

1934

Enrico Fermi and his group in Rome begin experiments to bombard all available elements with neutrons, discovering more than 60 new radioactive nuclei.

> **Nobel Prize in Physics for 1938** *to* **Enrico Fermi** *"for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons"*

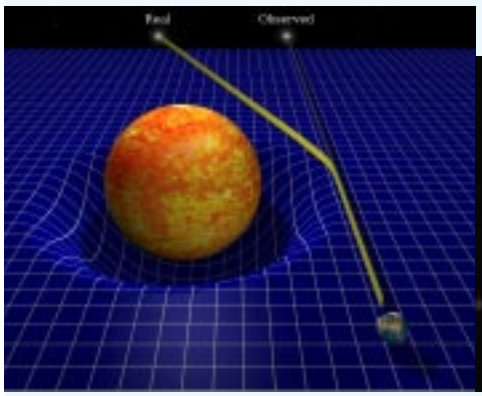
Fermi and his family leave Nobel celebration in Stockholm in December 1938 for the UK and then the US, never to return to Italy.

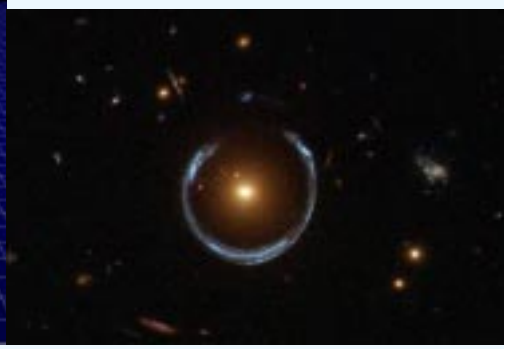
1935

25-Mar-1935: Albert Einstein, Boris Podolsk
submit paper *Can quantum mechanical desc*
considered complete? to *Physical Review* jo
The EPR paper is one of most cited in all o
downloaded from APS archives.

1936

Einstein predicts gravitational lensing effect; confirmed experimentally in 1979.





1938

On 13-July-1938, nuclear physicist Lise Meit
Germany via The Netherlands to Stockholm
grudgingly, and barely, supported by Manne

> **Nobel Prize in Physics for 1924** *to*
> **bahn** *"for his discoveries and research*
> *troscopy"*

> **Nobel Prize in Physics for 1981** *t*
> **Arthur Leonard Schawlow, and K**
> *contribution to the development of las*
> *and for his contribution to the develop*
> *tron spectroscopy (KMS)"*

Manne's (1886–1978) son is Kai (1918–200
also physicists.

1938 (continued)

Hans Bethe (1906–2005) in two papers received 7-Sep-1938 and 15-Dec-1938 publishes quantitative description of energy production in stars, leading to models of stellar evolution: white/brown/black dwarfs, red giants, neutron stars, quasars, pulsars, and black holes, and ultimately, answering the deep question: *Where do the 90 other chemical elements come from, if stars contain mostly H and He?*

Nobel Prize in Physics for 1967 *to* **Hans Albrecht Bethe** *"for his contributions to the theory of nuclear reactions, especially his discoveries concerning the energy production in stars"*

1938 (conti

Otto Hahn (1879–1968) and Fritz Strassma papers received 22-Dec-1938 on unexpected neutron bombardment of uranium. On 24-D Lise Meitner (1878–1968) and her nephew O (1904–1979) explain this as *nuclear fission*, liquid-drop model (often miscredited to Niel back to Bohr's group in Copenhagen, Denm

Nobel Prize in Chemistry for 1944 Hahn *"for his discovery of the fission*

Sadly, neither Strassmann nor Meitner share too. Despite decades of close collaboration after 1945, Hahn shamefully discredits her c Lewin Sime's papers and books.

1939: Physics heats up!

2-Jan-1939: Enrico Fermi arrives at Columbia University in NYC.

16-Jan-1939: Niels Bohr and Leon Rosenfeld arrive in NYC; fission news is supposed to be suppressed until H&S and M&F papers are published, but Rosenfeld is not told that, so he spills the beans, and within two weeks, uranium fission is reproduced at a few US labs. First public story in New York Times on 29-Jan-1939.

Early 1939: Enrico Fermi and his Columbia group, and another group at the University of Minnesota, show that the rare uranium-235 isotope is the fissile component of natural uranium, which is mostly composed of uranium-238 (99.3% U-238 and 0.7% U-235).

April 1939: Nazi Germany starts *Uranverein* (Uranium club).

28-Jun-1939: Niels Bohr and John Wheeler (1911–2008) publish quantitative liquid drop model of nuclear fission and predict that U-235 and Pu-239 are the fissile isotopes.

Summer 1939: Werner Heisenberg lectures in Ann Arbor, MI, but refuses urging by friends and colleagues to remain in the US.

1939 (conti

2-Aug-1939: Albert Einstein signs letter, wr Eugene Wigner (1902–1995) and Edward Te President, warning of danger of German nuc Roosevelt does not see letter until 11-Oct-1

1-Sep-1939: World War II begins when Nazi

1941

September 1941: Enrico Fermi suggests to Edward Teller that a fission bomb might be used to ignite deuterium sufficiently to produce a fusion weapon.

6-Dec-1941: US President Franklin Roosevelt authorizes nuclear research project.

7-Dec-1941: Japan attacks Pearl Harbor, and US enters World War II.

1942

September 1942: General Leslie Groves initi
construct an atomic bomb: ultimately, 140,0
top-secret project in Oak Ridge, TN, Hanfo

Mention Oak City, UT, 14 miles east of Delta.

Enrico Fermi group of 43 under the Universi
demonstrate first working nuclear pile. The
Field to Argonne, IL (later named Argonne
reproduced in large scale in Hanford, WA fo
of synthetic element 94, plutonium.

First American use of nuclear power for com
17-Jul-1955 in Arco, ID.

Nuclear fission power now provides 13% of v
for France, over 70%. It produces **zero** CO_2
radioactive-waste disposal problem.

Despite 70 years of effort, *controlled nuclear*
may be mankind's only hope of long-term su

1945

12-Apr-1945: Franklin Roosevelt dies in Warm Springs, GA. VP Harry Truman becomes President that day, and is shortly thereafter informed of Manhattan Project, of which he knew *nothing* until then.

16-Jul-1945: First atomic bomb test at Trinity, NM.

6-Aug-1945: U-235 Little Boy bomb dropped on Hiroshima, Japan. Bomber crews trained at Wendover, UT.

9-Aug-1945: Pu-239 Fat Man bomb dropped on Nagasaki, Japan.

2-Sep-1945: Japan surrenders unconditionally, and WW II ends.

World Wars I and II had huge loss of life on all sides, but technology won World War II: (1) cryptography and cryptanalysis in UK and US (notably, Alan Turing, Bletchley Park), (2) radar in UK and US, (3) atomic weapons (US).

Wartime computations needed for (1) and (3), and for artillery tables, spurred development of electronic computers, but British *Official Secrets Act* hid much of UK work for 50+ years.

1945

Sam Goudsmit leads *Alsos* team to capture
are interned first in Belgium, and then at *Fa*

Physicist Luis Alvarez (1911–1988) is scient
Son Walter and father Luis in 1977–1980 fir
in Gubbio, Italy (home of TV mystery series
channel 9.2). That leads to discovery in 197
Yucatan in Gulf of Mexico; the meteor impa
and most life on Earth, in the Cretaceous–T
about 66 Mya.

Nobel Prize in Physics for 1968 *to* **L**
decisive contributions to elementary p
the discovery of a large number of re
ble through his development of the t
bubble chamber and data analysis"

1945–1991

Iron Curtain and the Cold War between Western Allies and the USSR and its 'allies', notably, the People's Republic of China.
Hot wars, including Korean War (1950–1953) and Vietnam War (1955–1975), numerous minor wars and coups in Latin America, Asia, and Africa, and Hungarian uprising in 1956.
Significant threat of nuclear war and *nuclear winter*.

1948

Alpha-beta-gamma ($\alpha\beta\gamma$: Alfer, 'Bethe', Ga
chemical elements: details later shown to be
and Turner (2008) describe its influence.
Gamow adds Bethe as a joke, but Bethe do
gets remembered and cited!

Late 1940s and early 1950s

Bethe/Feynman/Tomonaga/Schwinger: quantum electrodynamics (QED).
Richard P. Feynman (1918–1988), Julian Schwinger (1918–1994), Sin-Itiro Tomonaga (1906–1979).

> **Nobel Prize in Physics for 1965** *to* **Sin-Itiro Tomonaga, Julian Schwinger and Richard P. Feynman** *"for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"*

Freeman Dyson (1923–) in 1948–1949 combines F/S/T work into consistent theory.
Some predictions of QED now agree with experiment to **ten decimal digits**, surpassing any previous theories in the history of humankind.

1949

28-Mar-1949: British astrophysicist Fred Ho
of a static Universe model, coins the term *B*
backward-in-time of Hubble's expanding Un
29-Aug-1949: USSR explodes its first atomi

1950

Fermi Paradox: Where are they? [extraterrestrials]
Lunch-time question by Enrico Fermi to Emil Konopinski (1911–1990), Edward Teller, and Herbert York (1921–2009) later spawns SETI (*Search for Extraterrestrial Intelligence*) project.

1950–19

During the Manhattan Project work at Los
Teller vigorously campaigns for work on *'the*
ultimate size is unlimited, unlike that of an
1-Feb-1950: President Harry Truman issues
directed the Atomic Energy Commission to
of atomic weapons, including the so-called s
1-Nov-1952: first hydrogen bomb test by U
Teller, Stan Ulam (1909–1984), John von N
12-Aug-1953: first hydrogen bomb test by U

1964

In London, UK, Peter Higgs (1929–) and six others predict a new super-fundamental particle.
Higgs boson is found at CERN in the Large Hadron Collider on 4-Jul-2012.

Nobel Prize in Physics for 2013 *to* **Peter Higgs and François Englert** *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

1964 (conti

Nobel Prize in Physics for 1964
Nicolay Gennadiyevich Basov and
Prokhorov *"for fundamental work in*
tronics, which has led to the construc
plifiers based on the maser-laser princ

Lasers used in CDs and DVDs, much experi
long-distance communication in optical fiber
interplanetary distance measurements.
Tom Stockham (1933–2004) founds Sounds
commercial digital recordings.
"In 1974 he [Stockham] investigated President
tapes. It was he who discovered that the 18 mi
accidental, as Nixon's secretary Rosemary Wood
discern several distinct erasures and even determ
Nixon resigned 9-Aug-1974, preceded by VP

1986

Nobel Prize in Physics for 1986 *to* **Ernst Ruska, Gerd Binnig, and Heinrich Rohrer** *"for his fundamental work in electron optics, and for the design of the first electron microscope (ER) and for their design of the scanning tunneling microscope (GB & HR)"*

Scanning tunneling microscope (STM) (1981) and its successor, the atomic force microscrope (AFM) (1986, with Calvin Quate (1923–), from Baker, NV, (5 miles west of Utah border and Great Basin National Park) and Professor Emeritus at Stanford University, and Christoph Gerber (Basel)), make possible imaging of single atoms.

2011

Nobel Prize in Physics for 2011 *to*
Schmidt, and Adam G. Riess *"for*
erating expansion of the Universe thro
supernovae"

Possible explanations of acceleration: dark m
Fritz Zwicky, 1933) and dark energy (US an
The mystery of the Universe continues!

Wrap up: Spinoffs of physical science

DNA and modern molecular biology, genetics, and pharmaceutics.

Global-Positioning System (GPS): needs corrections from both Special and General Relativity.

Electronics and transistor, replacing vacuum tubes ('valves' in the UK).

Nobel Prize in Physics for 1956 *to* **William Bradford Shockley, John Bardeen and Walter Houser Brattain** *"for their researches on semiconductors and their discovery of the transistor effect"*

2nd (and later) generation computers, including CPUs, storage devices, and local networks.

ARPAnet (started with SRI, UC/Berkeley, UC/Los Angeles, University of Utah, and UC/Santa Barbara), and the Internet.

Wrap up: Spinoffs of

Explanation of superconductivity.

Nobel Prize in Physics for 197
Neil Cooper and John Robert
developed theory of supercondu
BCS-theory"

Hope for high-temperature superconduc
energy transmission.

Mobile phones, tablets, laptops, and co

Prediction, and manufacture, of post-u
now).

Quantum cryptography and quantum c

Lasers and masers and accurate commu

Wrap up: Spinoffs of physical science (continued)

LCD/LED displays for TVs, computers, mobile devices.

> **Nobel Prize in Physics for 2014** *to* **Isamu Akasaki, Hiroshi Amano and Shuji Nakamura** *"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*

Accurate timing and accurate standards of length.

Medical imaging (X-ray, NMR, EPR, . . .).

> **Nobel Prize in Chemistry for 2014** *to* **Eric Betzig, Stefan W. Hell and William E. Moerner** *"for the development of super-resolved fluorescence microscopy"*

Probably: space program, satellites, astronauts on the moon, . . .

Literature res

Autobiographies, biographies, books, origina
recorded in bibliography archives at

`http://www.math.utah.edu/pub/`
`http://www.math.utah.edu/pub/`

The start of each tells how to mirror the col

Nobel Prize citations used in these slides are

`http://www.nobelprize.org/nob`
`http://www.nobelprize.org/nob`

Final words from the masters

If we are going to stick to those damned quantum jumps, then I regret that I ever had anything to do with the quantum theory!
Erwin Schrödinger (1926)

If anybody says he can think about quantum theory without getting giddy, it merely shows that he hasn't understood the first thing about it! Niels Bohr (1927)

I have thought a hundred times as much about the quantum problems as I have about general relativity theory.
Albert Einstein (1940s)

All the fifty years of conscious brooding have brought me no closer to the answer to the question: "what are light quanta?" Of course today every rascal thinks he knows the answer, but he is deluding himself. Albert Einstein (1951)