A Historical Review of Modern Physics

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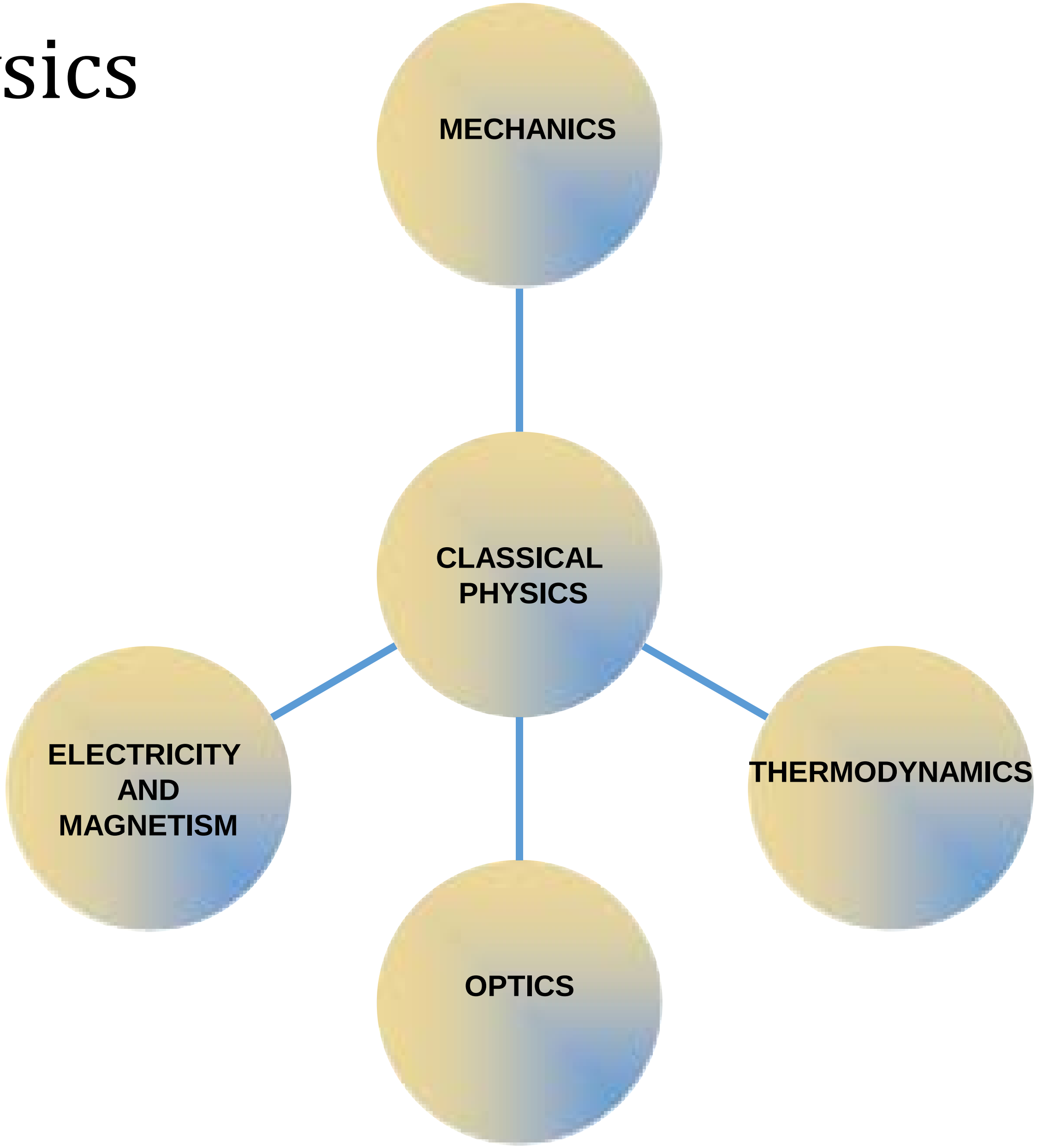
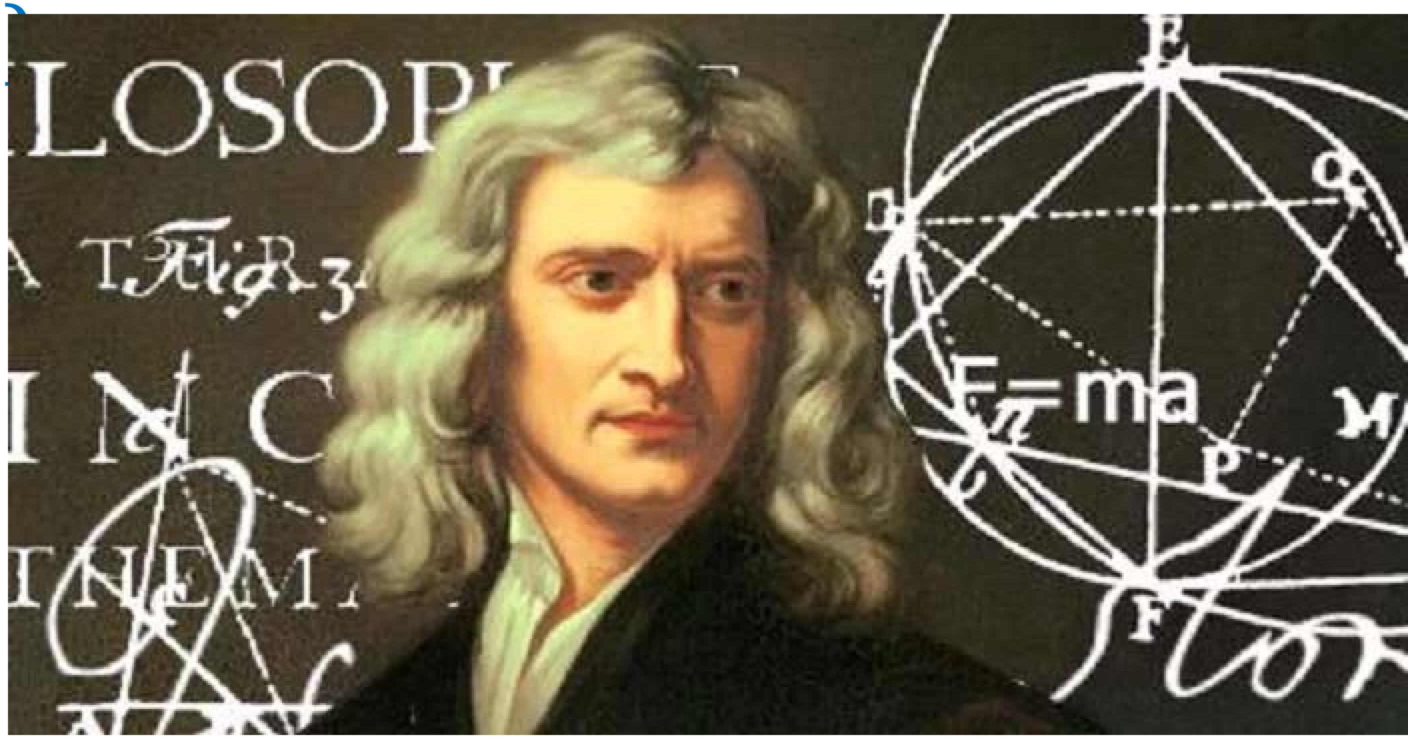
Classical Physics



Isaac Newton (1642-1727)



Three laws describing the relationship between mass and acceleration.

- **Newton's first law** (*law of inertia*): An object in motion with a constant velocity will continue in motion unless acted upon by some net external force.

- **Newton's second law**: Introduces force (F) as responsible for the the change in linear momentum (p):

$$\vec{F} = m\vec{a} \quad \text{or} \quad \vec{F} = \frac{d\vec{p}}{dt}$$

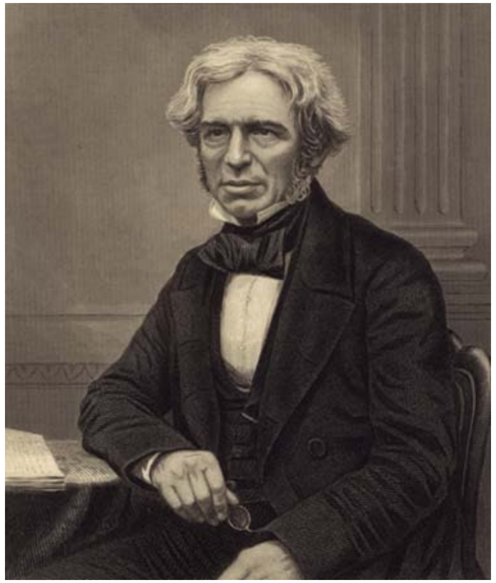
- • **Newton's third law** (*law of action and reaction*): The force exerted by body 1 on body 2 is equal in magnitude and opposite in direction to the force that body 2 exerts on body 1.

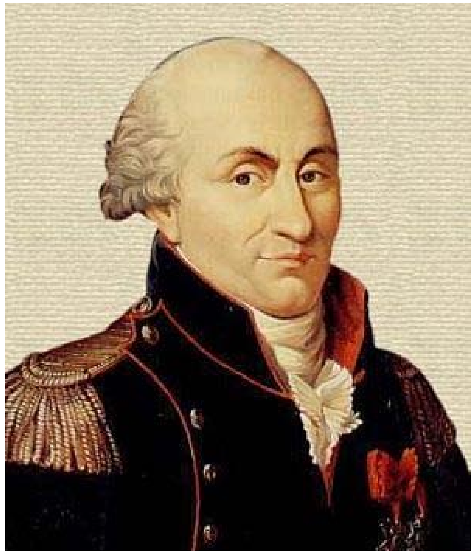
$$\vec{F}_{21} = -\vec{F}_{12}$$

Electromagnetism

Contributions made by:

- Coulomb (1736-1806)
- Oersted (1777-1851)
- Young (1773-1829)
- Ampère (1775-1836)
- Faraday (1791-1867)
- Henry (1797-1878)
- Maxwell (1831-1879)
- Hertz (1857-1894)

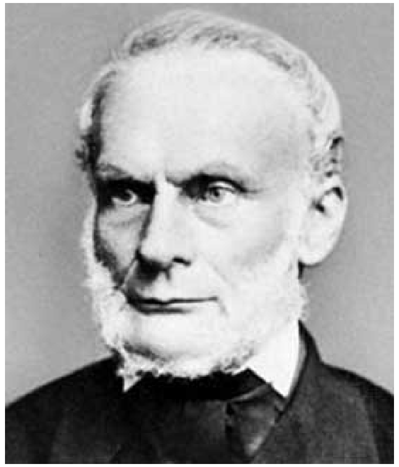




Thermodynamics

Contributions made by:

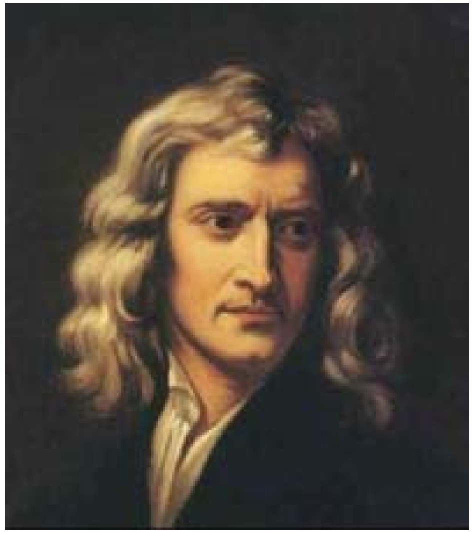
- Benjamin Thompson (1753-1814) (Count Rumford)
- Sadi Carnot (1796-1832)
- James Joule (1818-1889)
- Rudolf Clausius (1822-1888)
- William Thompson (1824-1907) (Lord Kelvin)



Optics

Contributions made by:

- Isaac Newton (1642-1742)
- Christian Huygens (1629 -1695)
- Thomas Young (1773 -1829)
- Augustin Fresnel (1788 – 1829)

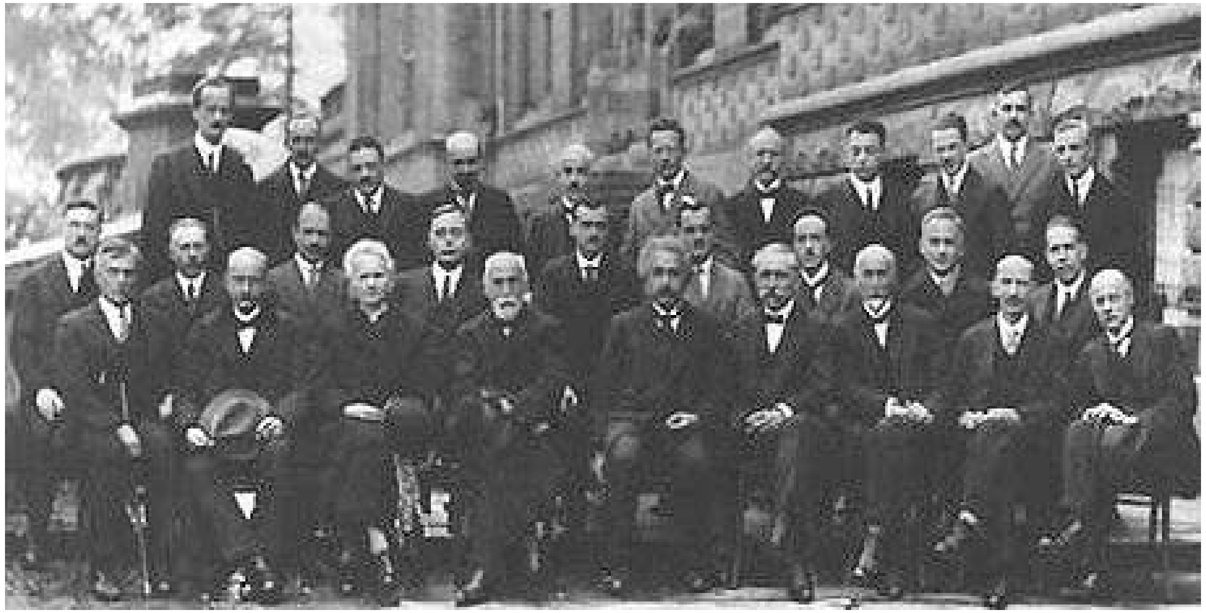


Modern Physics

- Physics changed drastically in the early 1900’s
- New discoveries — *Relativity* and *Quantum Mechanics*

- **Relativity**
  - Changed the way we think about space and time

- **Quantum mechanics**
  - Changed our conceptions of matter.



1900:

- Max Planck proposed theory about black-body radiation

1905:

- Albert Einstein wrote the paper, "*On a Heuristic Viewpoint Concerning the Production and Transformation of Light*“; proposed the idea of energy quanta dealing with the photoelectric effect.

1913:

- Neils Bohr proposed atomic structure theory

1918:

- Max Planck won Nobel prize in physics

1921:

- Won the Nobel Prize in Physics for his discovery and explanation of the law of the photoelectric effect.

1922:

- Neils Bohr won Nobel Prize in physics
- Stern-Gerlach Experiment (Verified the space quantization theory)

1924:

- Louis De Broglie published his doctoral thesis, “*Recherches sur la théorie des quanta*”, which introduced his theory of electron waves.

1925:

- Heisenberg developed the Heisenberg Uncertainty principle
- Wolfgang Pauli developed the fourth quantum number- the spin number

1929:

Louis De Broglie won the Nobel Prize in Physics for hypothesis.

1932:

- Werner Heisenberg won Nobel Prize in physics

1933:

- Otto Stern measures the magnetic moment of the proton
- Schrodinger wins Nobel prize for his Schrodinger Equation

1936:

Publishes paper on Wave Mechanics and Schrödinger's Equation

1940:

Pauli proves Spin-Statistic Theorem

1943:

- Otto Stern receives Nobel prize in Physics

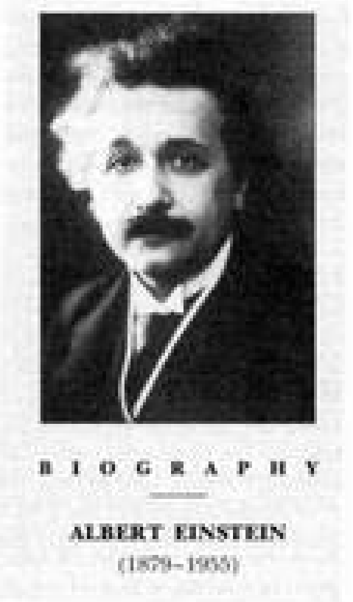
1944:

- Wolfgang Pauli won Nobel Prize in physics

Albert Einstein

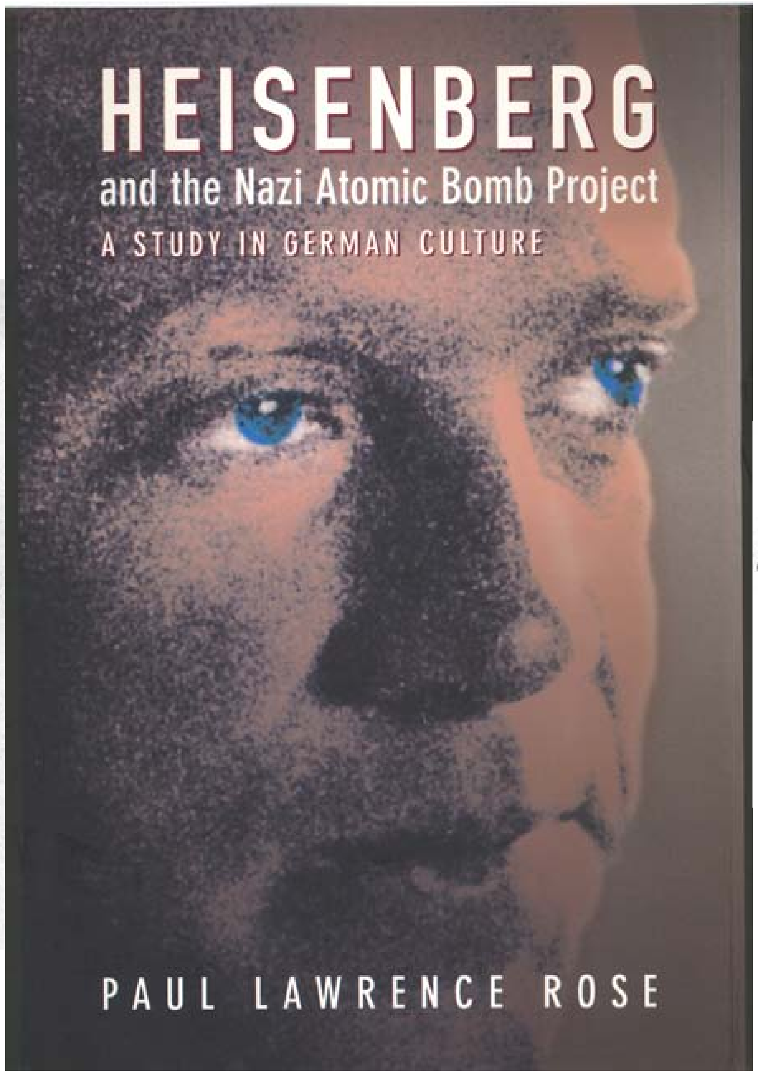
Relativity: History

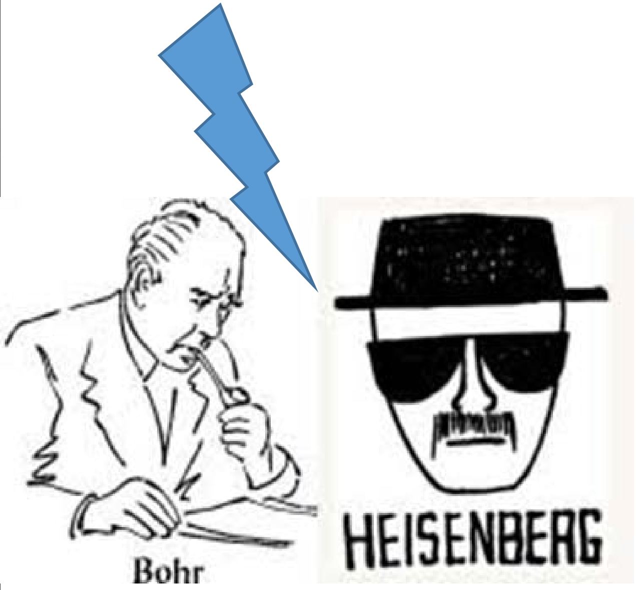
- 1879: Born in Ulm, Germany.
- 1901: Worked at Swiss patent office.
  - Unable to obtain an academic position.
- 1905: Published 4 famous papers.
  - Paper on photoelectric effect (Nobel prize).
  - Paper on Brownian motion.
  - 2 papers on Special Relativity.
  - Only 26 years old at the time!!
- 1915: General Theory of Relativity published.
- 1933: Einstein left Nazi-occupied Germany.
  - Spent remainder of time at Institute of Advanced Study in Princeton, NJ.
  - Attempted to develop unified theory of gravity and electromagnetism (unsuccessful).



- Won the Nobel Prize in Physics in 1921 for his discovery and explanation of the law of the photoelectric effect
- Widely regarded as one of the greatest physicists of all time
- Formulated the theory of relativity and made significant contributions to quantum mechanics and statistical mechanics
- Also famous for formulating $E = mc^2$

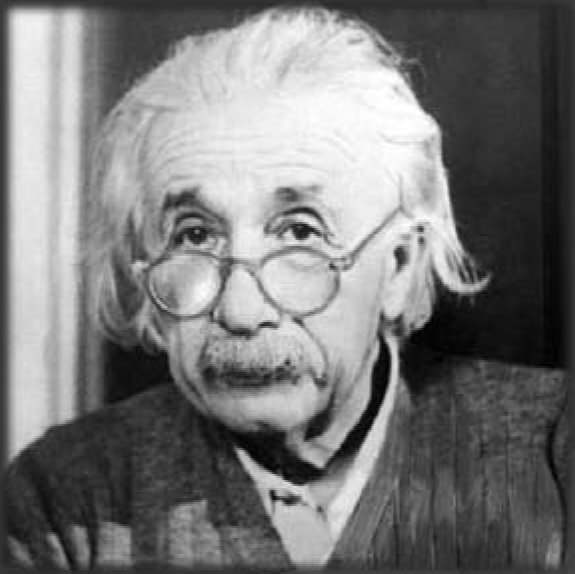
Nazi Atomic Bomb Project



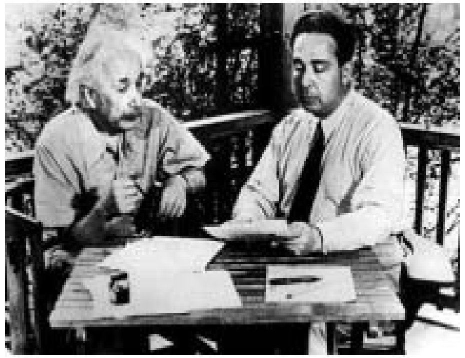


World War II and the Manhattan Project

- In 1939, a group of Hungarian scientists that included emigre physicist Leó Szilárd attempted to alert Washington of ongoing Nazi atomic bomb research. The group's warnings were discounted. Einstein and Szilárd, along with other refugees such as Edward Teller and Eugene Wigner, "regarded it as their responsibility to alert Americans to the possibility that German scientists might win the race to build an atomic bomb, and to warn that Hitler would be more than willing to resort to such a weapon.": In the summer of 1939, a few months before the beginning of World War II in Europe, Einstein was persuaded to lend his prestige by writing a letter with Szilárd to President Franklin D. Roosevelt to alert him of the possibility. The letter also recommended that the U.S. government pay attention to and become directly involved in uranium research and associated chain reaction research.



*August, 1939 Leo Szilard and Albert Einstein write a letter to President Roosevelt outlining the dangers of a German bomb project.

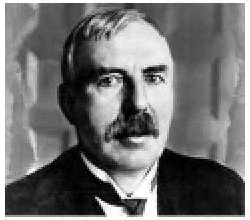


This led to…

The Manhattan Project

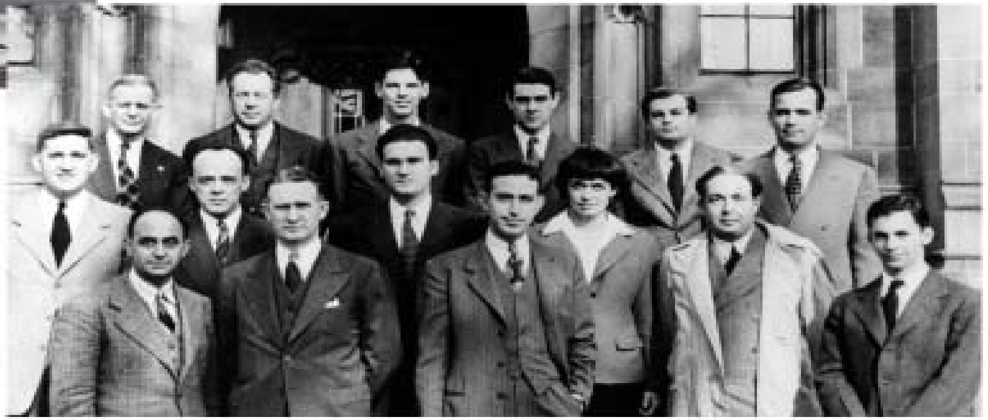
*1939 **J. Robert Oppenheimer** foresees the possibility of the atomic bomb upon hearing about the theory of fission.

*1932 Atom first experimentally split by **John Cockcroft** and **E. T. S. Walton** of Great Britain at **Ernest Rutherford's** Cavendish Laboratory at Cambridge University.


*1934 **Enrico Fermi** unknowingly causes the first laboratory contained nuclear fission reaction.





*Started in late 1941 with the goal of developing an atomic bomb before Germany

*In Truman's presidency, the purpose expanded to forcing Japan's surrender and having control over postwar policy

Comparision of Atom Bomb Attacks with other Bombing Raids

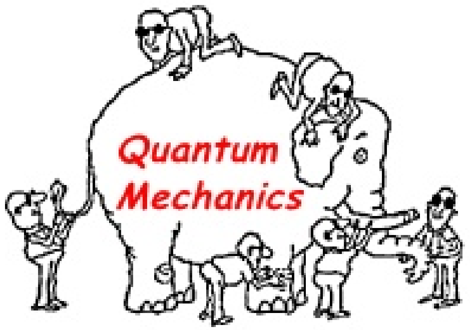
Data from the US Strategic Bombing Survey, Japanese official counts, and U.S. government / military documents assessing the damage caused by these weapons.

Target	**Hiroshima**	**Nagasaki**
Dead/Missing	70,000-80,000	35,000-40,000
Wounded	70,000	40,000
Population Density	35,000 per sq mile	65,000 per sq mile
Total Casualties	140,000-150,000	75,000-80,000
Area Destroyed	4.7 sq mile	1.8 sq mile
Attacking Platform	1 B-29	1 B-29
Weapon(s)	'Tall Boy' 15 kT (15,000 tons of TNT)	'Fat Man' 21 kT (21,000 tons of TNT)

Bohr-Einstein Debate 1927

Solvay conference

The Copenhagen Interpretation



Heisenberg's uncertainty principle:

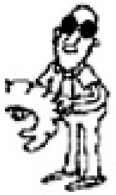
Wave-particle duality, conjugate variables, e.g., $\boldsymbol{x}$ and $\boldsymbol{p}$, $\boldsymbol{E}$ and $\boldsymbol{t}$;
The impossibility of simultaneous conjugate measurements

Born's statistical interpretation:

The meaning of the wave function ψ as probability: $P = \psi\ \psi^*$;
Quantum mechanics predicts only the *average* behavior of a system.

Bohr's complementarity:

The "wholeness" of the system and the measurement apparatus;
Complementary nature of wave-particle duality: a particle OR a wave;
The uncertainty principle is property of nature, not of measurement.



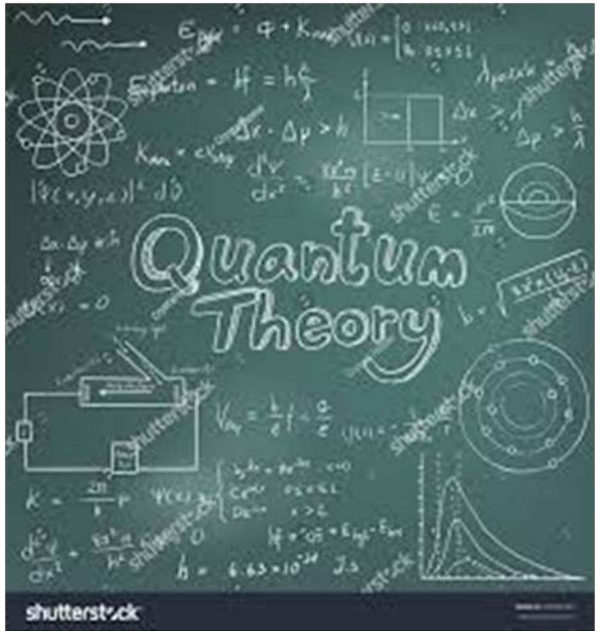
Heisenberg's "knowledge" interpretation:

Identification of ψ with knowledge of an ***observer***;
ψ collapse and non-locality reflect changing knowledge of observer.

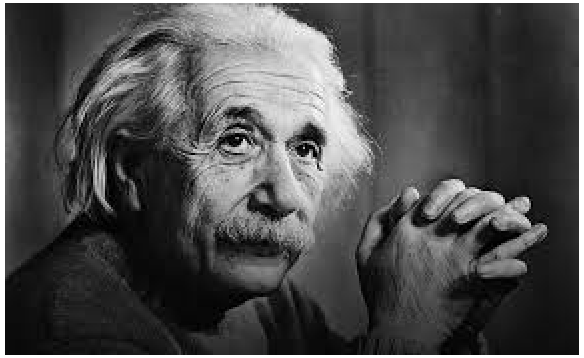
Heisenberg's positivism:

"Don't-ask/Don't tell" about the meaning or reality behind formalism;
Focus exclusively on observables and measurements.

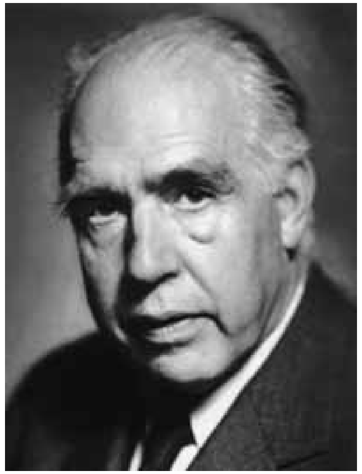
- The quantum mechanical world is VERY different!
  - Physics is not deterministic, but events occur with a probability determined by quantum mechanics.



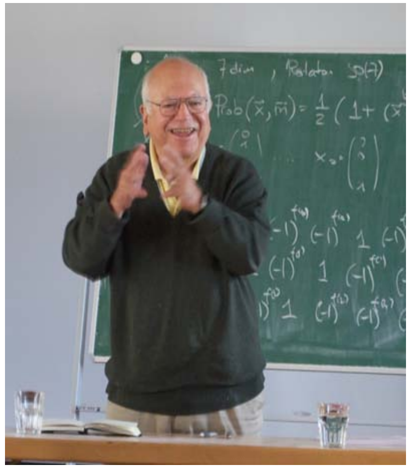
Some Quantum Quotes



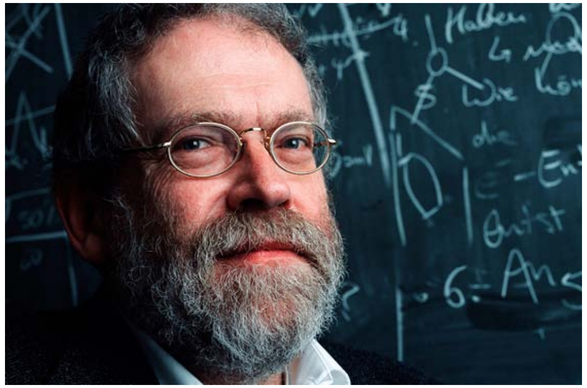
God does not play dice with the universe. – *A. Einstein*



It is not the job of scientists to prescribe to God how He should run the world. – *N. Bohr*

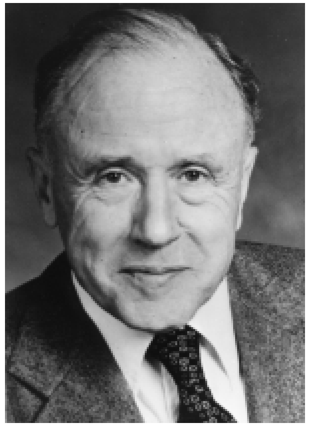


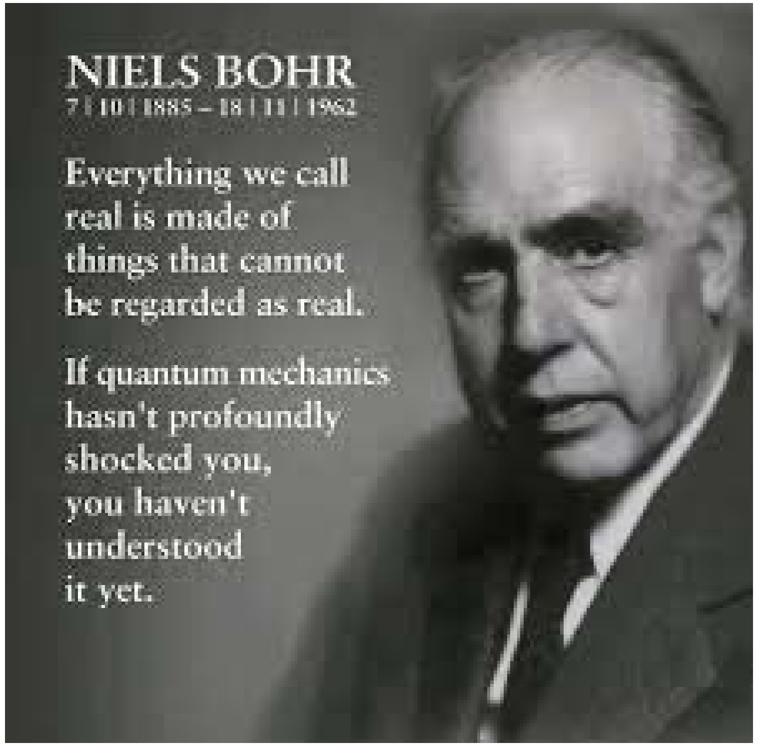
Einstein said that if quantum mechanics is right, then the world is crazy … Well, Einstein was right. The world is crazy. – *D. Greenberger*



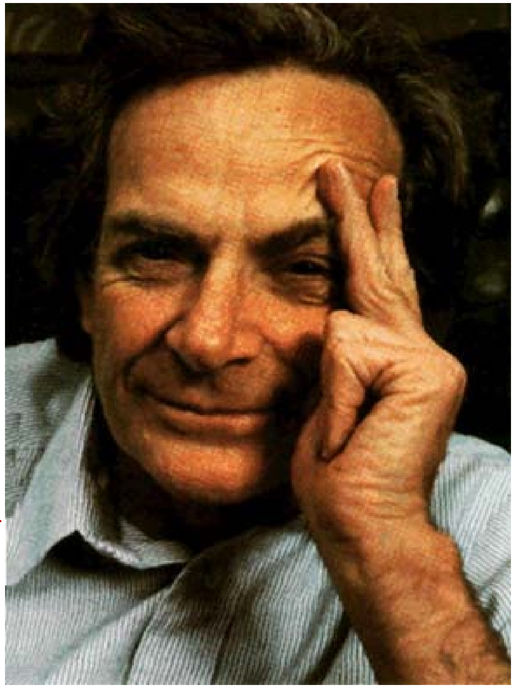
Most physicists are very naive; most still believe in real waves or real particles. – *A. Zeilinger*

Quantum phenomena are neither waves nor particles, but are intrinsically undefined until the moment they are measured. -- J. Wheeler





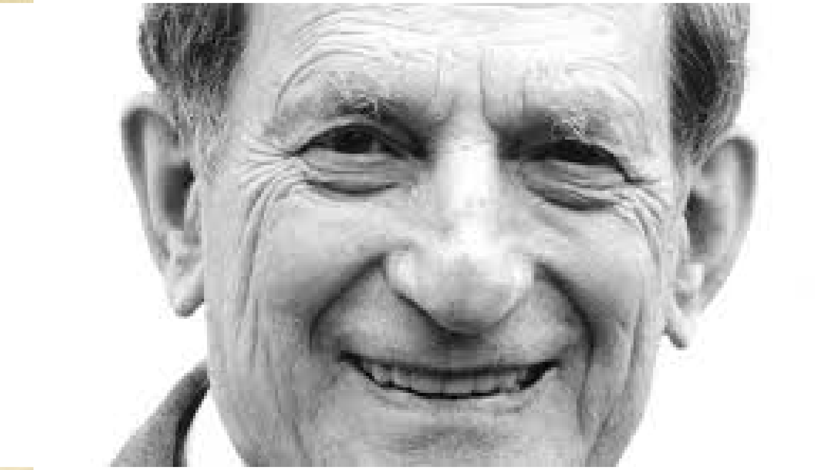
"... I think I can safely say that nobody understands Quantum Mechanics." ---R. Feynman



All of these QM quotes are taken from "Quantum Philosophy" by *John Horgan* in the July 1992 issue of Scientific American, pages 94-102.

Bohm’s 1952 papers, a history

- David Bohm’s 1952, a rediscovery of Louis de Broglie’s quantum theory established in 1927[5]
- Einstein and the origin of the pilot-wave (as an EM wave)[5]
  - Max Born treated the wave equation as a guiding wave
  - De Broglie’s poor response to an objection raised by Wolfgang Pauli in 1927 shuts many doors
- Hilary Putnam, and Heisenberg’s negative reception of Bohmian mechanics[5]
- Leavens, Cushing, and Daumer elaborate on the ease of description of some quantum phenomena by Bohmian mechanics[6]
- “… one purpose of Bohm’s 1952 papers was to show that trajectories are possible and that, therefore, part of the Copenhagen dogma (completeness and, hence, the alleged impossibility of such trajectories) is false. That it certainly did.”[7]

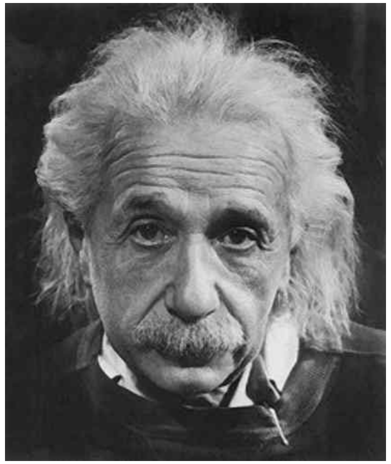


MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. EINSTEIN, B. PODOLSKY AND N. ROSEN, *Institute for Advanced Study, Princeton, New Jersey*
(Received March 25, 1935)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.



Quantum State: [0][0] & [1][1]

John Bell (1964)

Any possible "completion" to quantum mechanics will violate local realism just the same

EINSTEIN ATTACKS QUANTUM THEORY

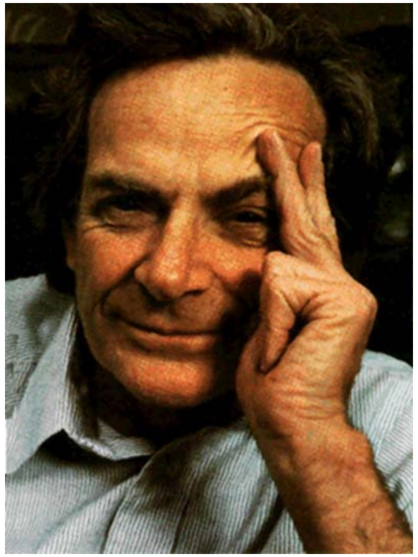
Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

Classical versus Quantum

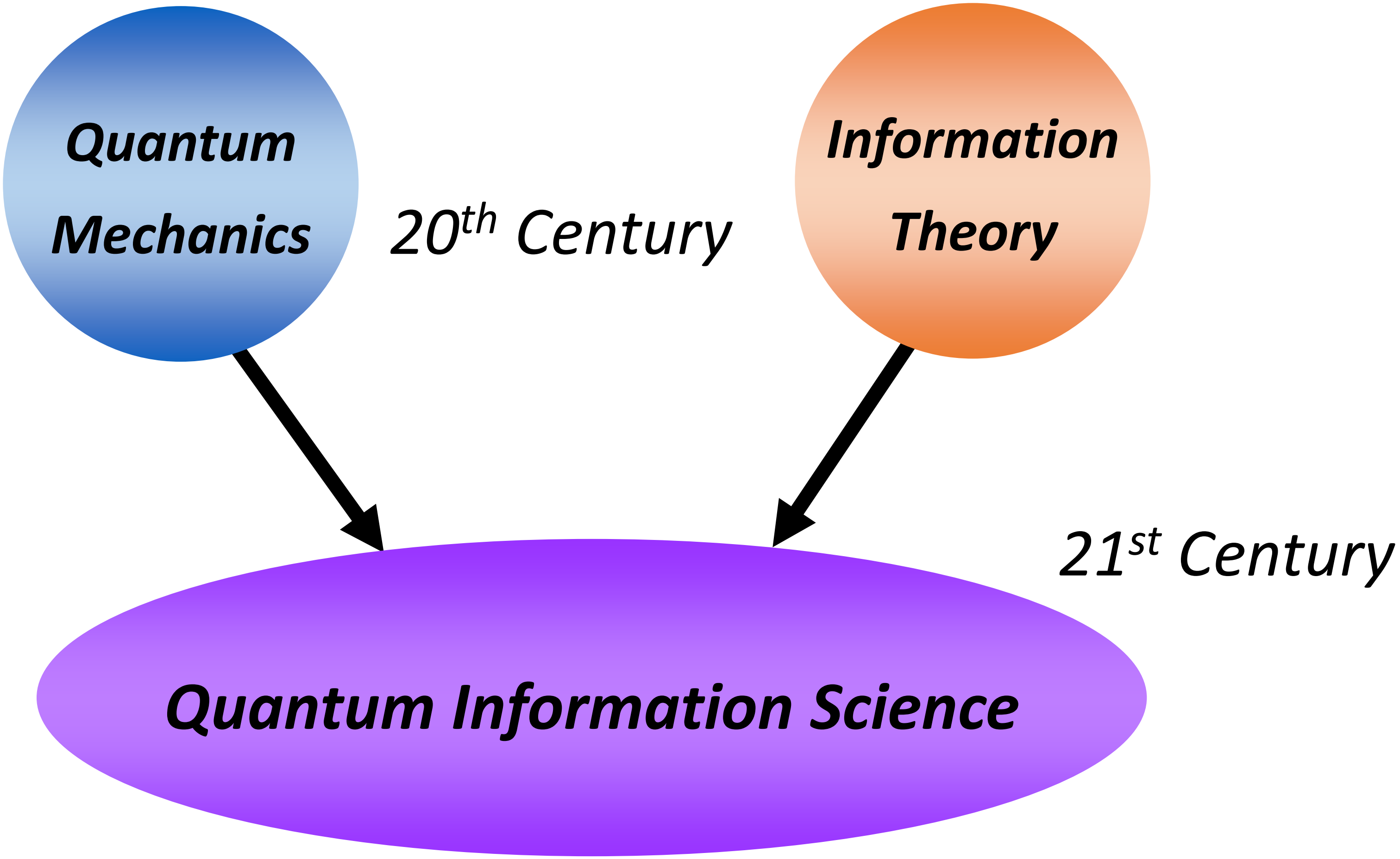
Classical	Quantum
Phase space	**Hilbert space**
Continuity	**Events, ”Clicks”**
Newton’s laws	**Schrödinger + Projection**
Local Realism	**Violation of Local Realism**
Determinism	**Randomness**

- ***Does this mean that the classical world is substantially different from the quantum world?***
- ***When and how do physical systems stop to behave quantumly and begin to behave classically?***

A new science for the 21st Century?



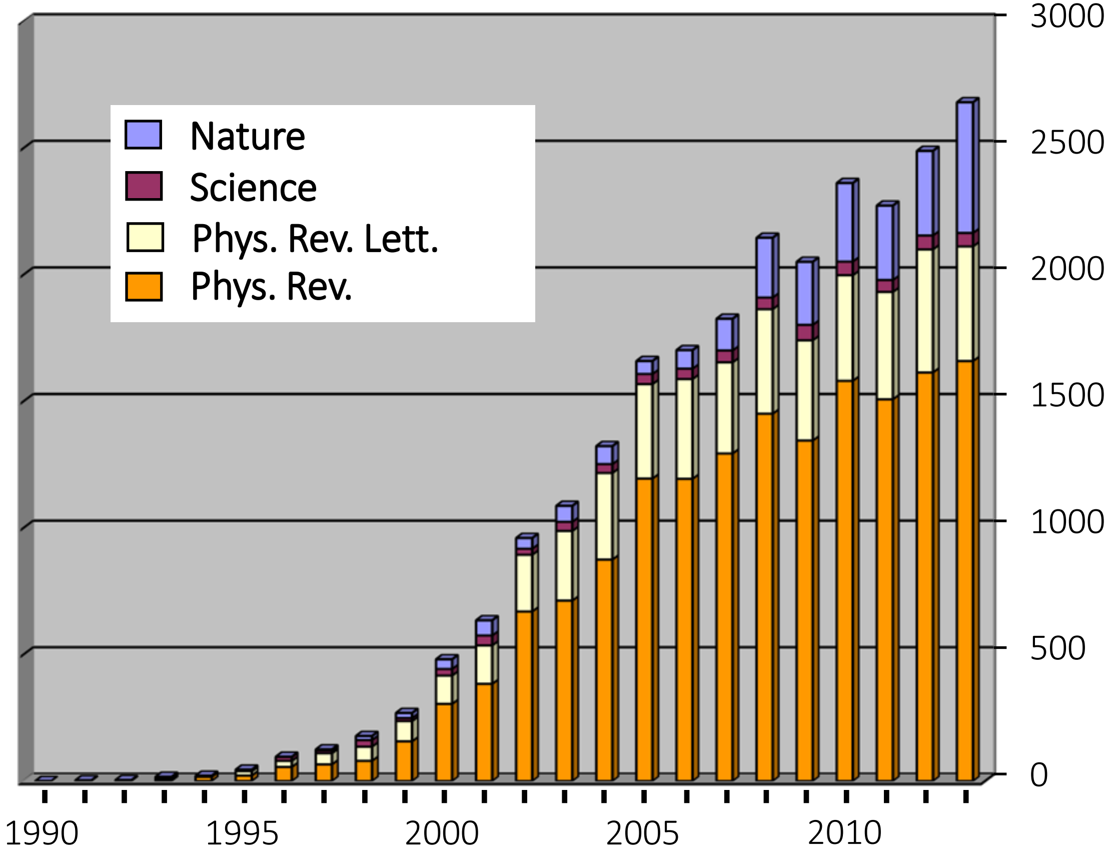
First idea of quantum computing- 1982



Physics
Chemistry
Computer Science

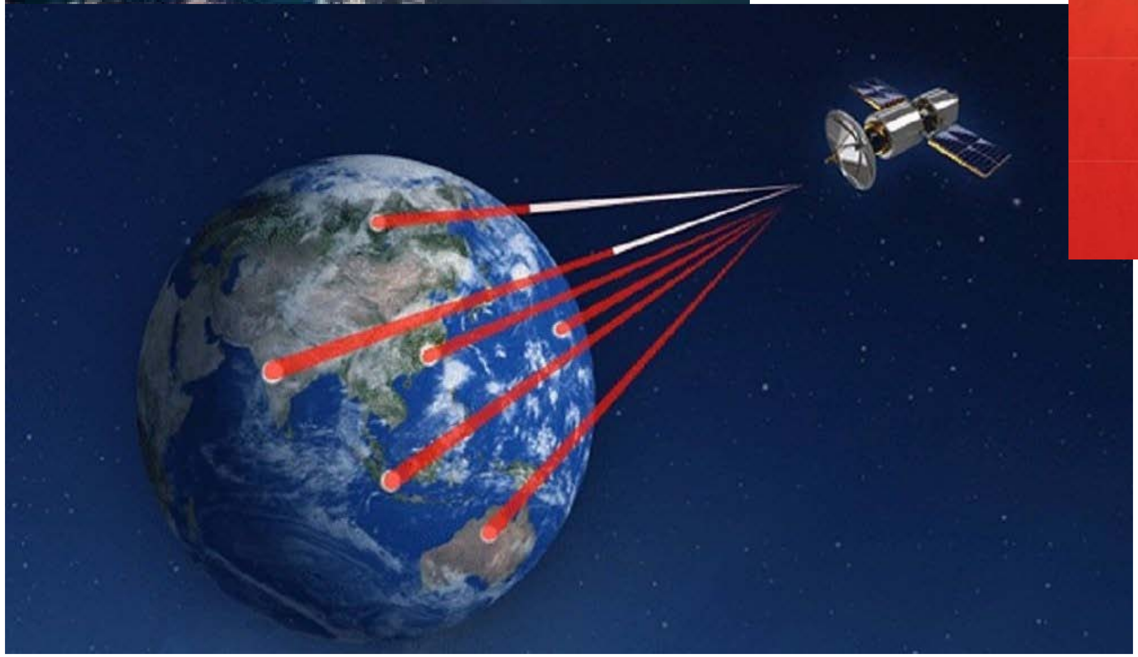
Electrical Engineering
Mathematics
Information Theory

 # articles mentioning "Quantum Information" or "Quantum Computing"



Super-secure Quantum Communication between China and Austria

China Super-Project: Quantum Internet until 2021



New Quantum Technologies

Quantum Computer

Sensing

Communications

Internet

Security

Energy

Imaging

Artificial Intelligence

Cryptography

Game and Media

Medicine

Big data analysis

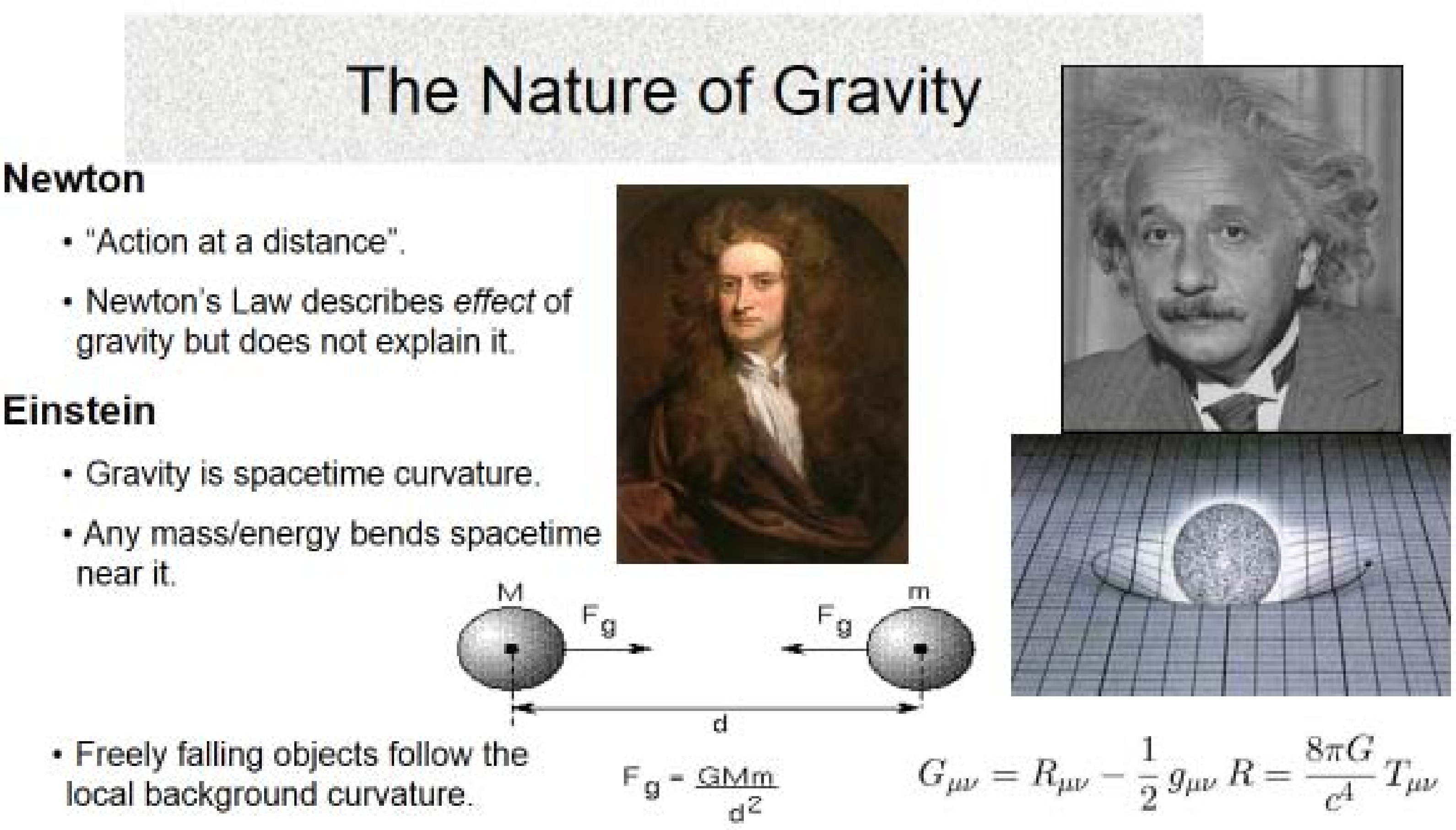
Information Storage

Space Science

Atomic Clocks

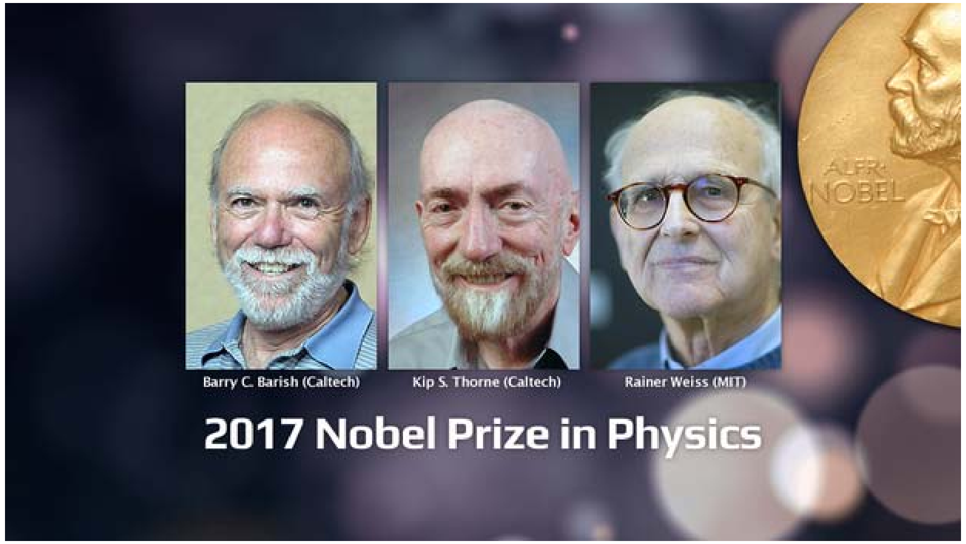
Psychology

General Relativity vs Classical Physics



Listening to the cosmos via Gravitational Waves

- Gravitational waves are one of the most interesting predictions of general relativity, and provide an unprecedented probe of extreme gravity environments in the Universe.
- There are many potential sources of gravitational waves for our detectors, ranging from binary star systems to supermassive black hole mergers to cosmic string cusps.
- Our first direct gravitational wave detection via Advanced LIGO interferometer.
- Now, we stand to learn a great deal about systems that are inaccessible to electromagnetic telescopes.



Gravitational waves: differences from EM

Electromagnetism:

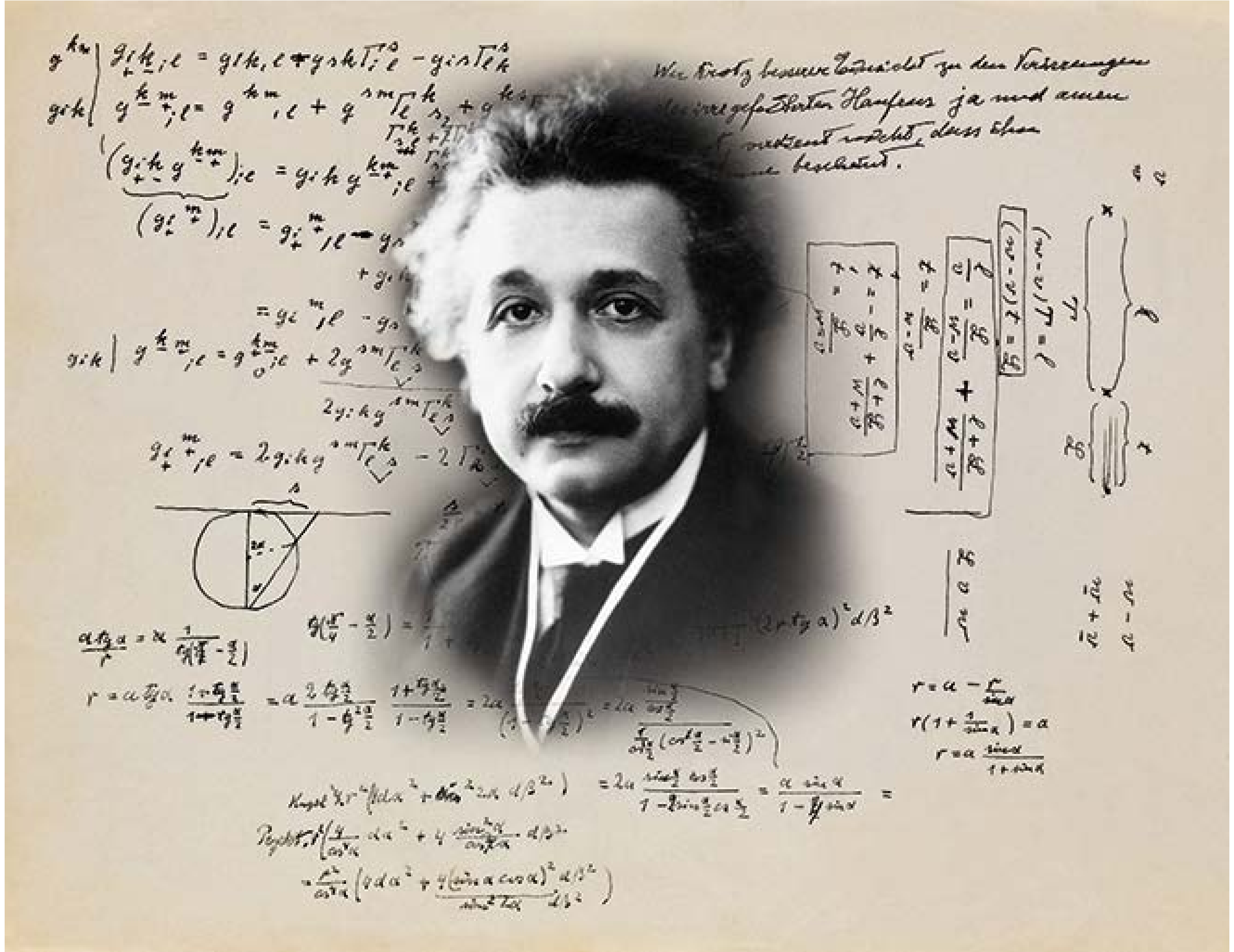
- A strong force, but with opposing charges (+ and -)
- Fields built up incoherently from microscopic charge separations
  » Wavelengths larger than the source
- Waves are easy to detect, but easily blocked
  » Show the surfaces of energetic bodies
- Used to construct *images* of celestial objects

Gravity:

- A weak force, but with only one charge (mass)
- Fields built up coherently from bulk accumulation of matter
  » Wavelengths smaller than the source
- Waves are hard to detect, but pass undisturbed through anything
  » Reveal the bulk motion of dense matter
- Can be though of as *sounds* emitted by those objects

→ A fundamentally different way of observing the Cosmos!

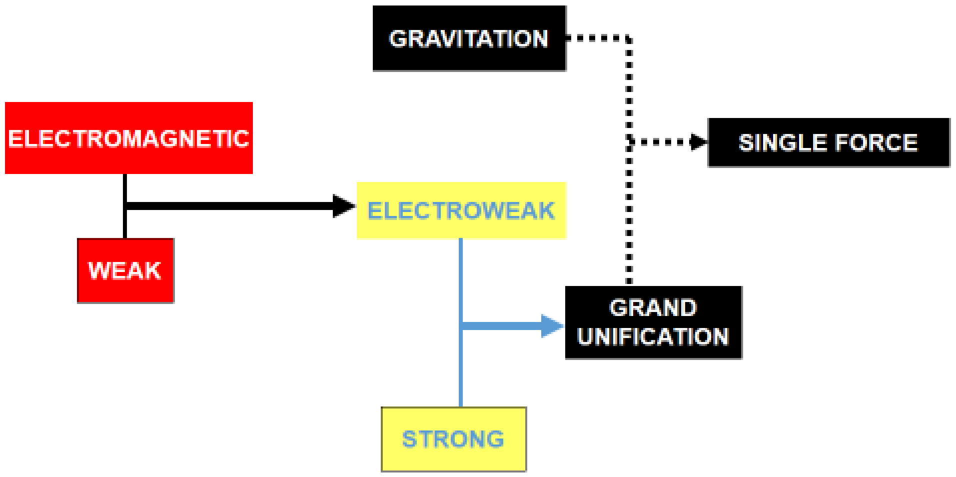
Einstein Unification Theory
(unsuccessful)



Unification of Forces

- Maxwell unified the electric and magnetic forces as fundamentally the same force; now referred to as the **electromagnetic force**
- In the 1970's Glashow, Weinberg, and Salem proposed the equivalence of the electromagnetic and the weak forces (at high energy); now referred to as the **electroweak interaction**

Goal: Unification of All Forces into a Single Force



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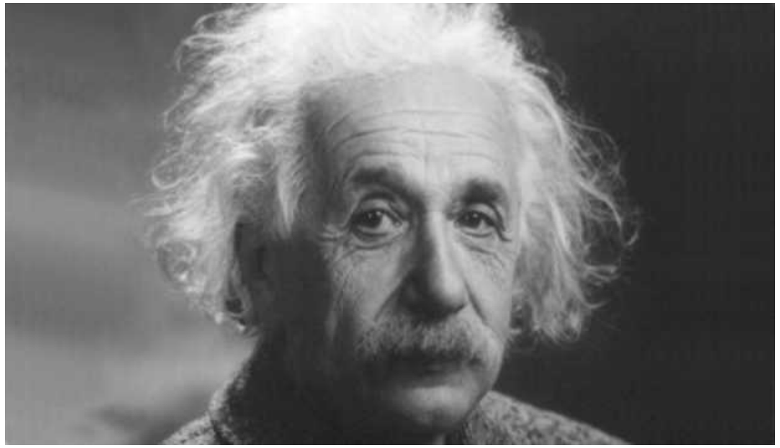
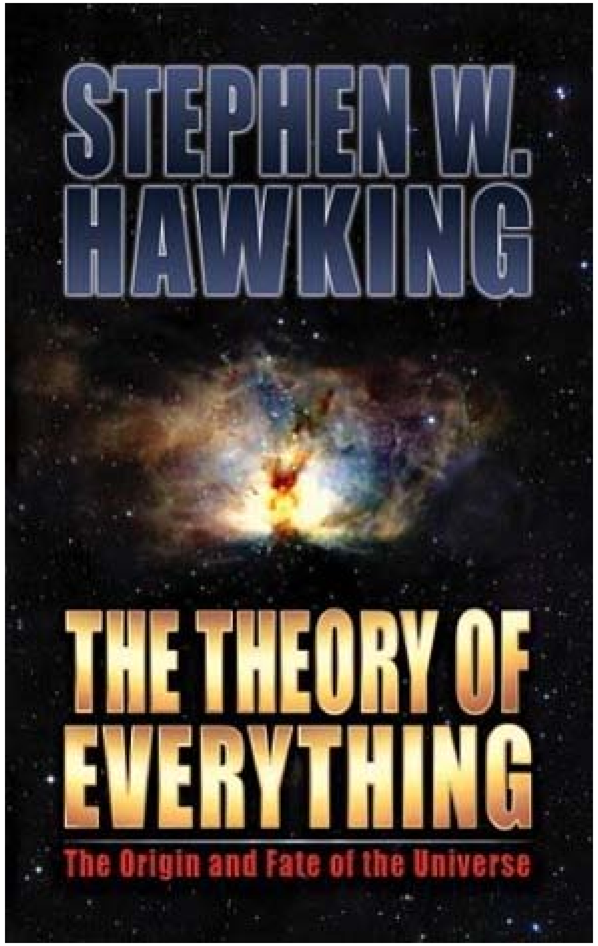




Stephen Hawking- Once believed that it was inevitable, now he believes it is improbable

What is a Theory of Everything

- The unification of General Relativity and Quantum Mechanics
- Relationship between the four fundamental forces
- Explains properties of fundamental particles

Strongest possibilities for a ToE

- String Theory/M-Theory
- Loop Quantum Gravity

Difficulties

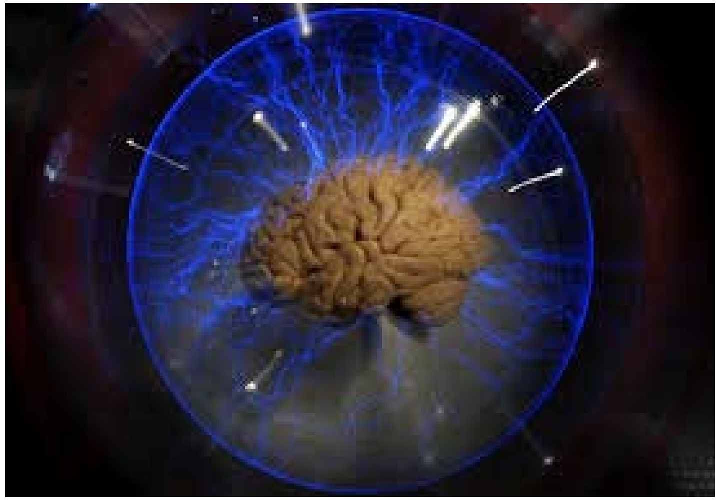
- Super-symmetry was expected to be discovered by now
- The large number of dimensions are have never been detected
- It doesn’t make any precise predictions
- Difficulty of Testing Theories

Benefits of a Theory of Everything

- Simplification of concepts allows deeper understanding
- Better understanding of cosmology, black holes, and The Big Bang
- Better understanding of time/spacetime

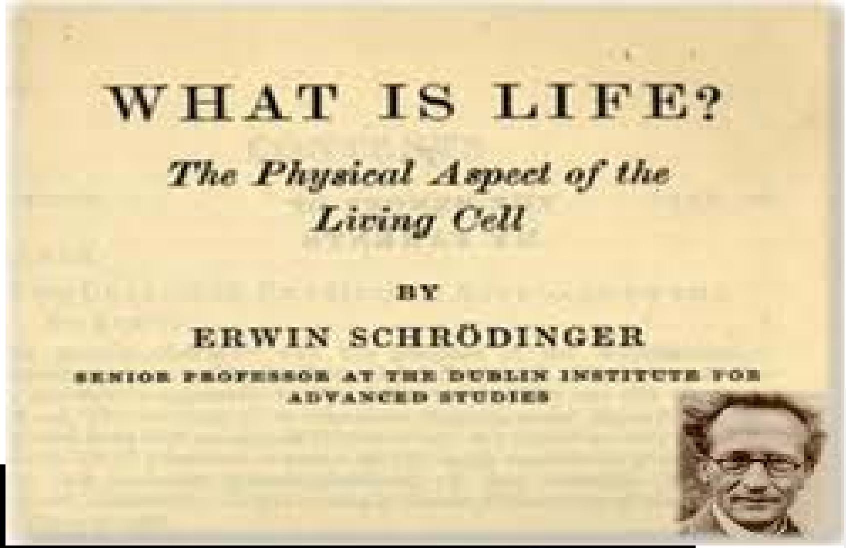
Big Questions of Science

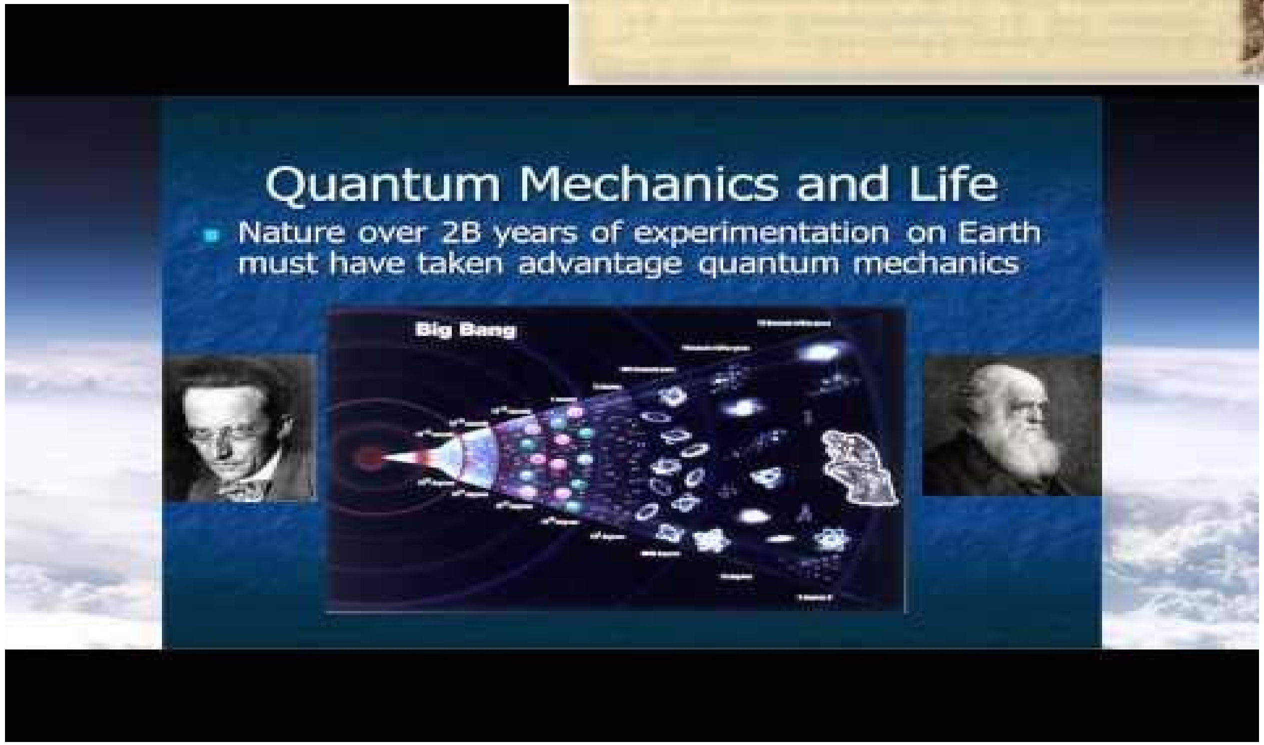
Life and Consciousness



Can Modern Physics help to explain Life and Consciousness?

Quantum Theory in Biology?





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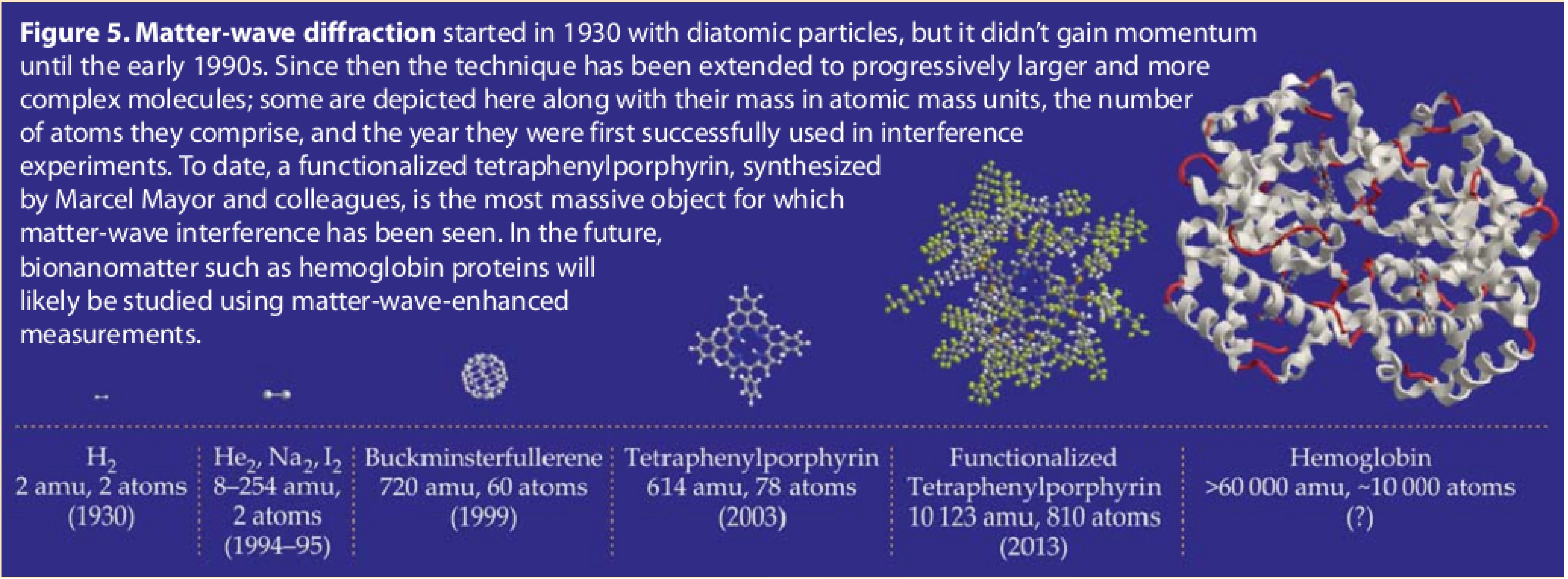
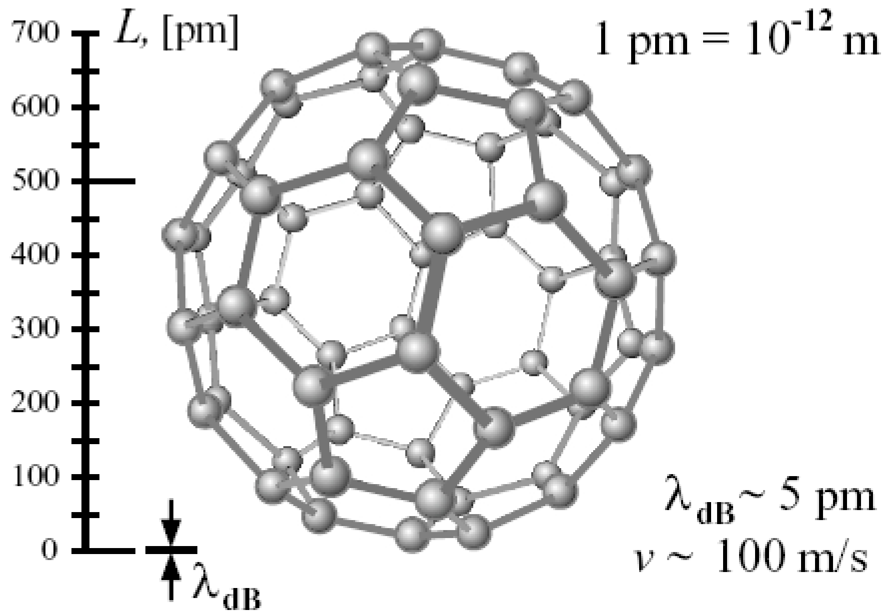


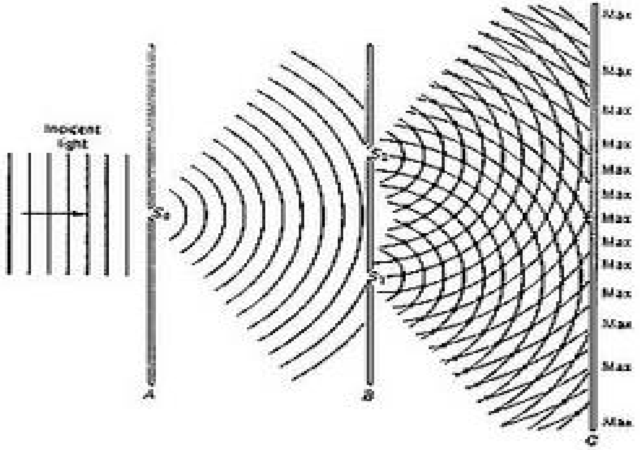
de Broglie

$$\lambda = \frac{h}{mv}$$



Markus Arndt

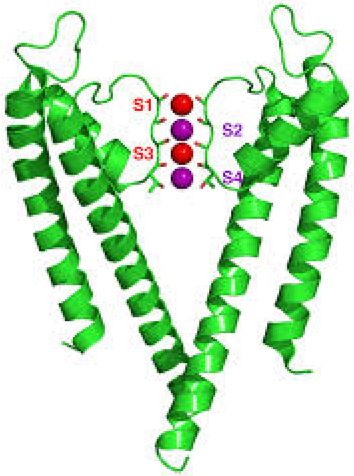
Anton Zeilinger



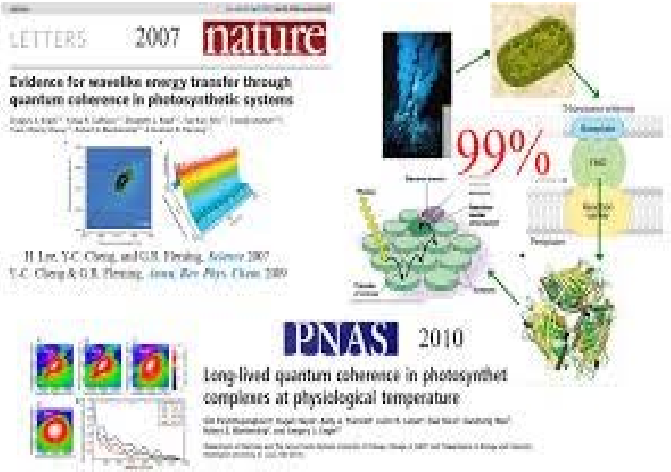
Single Photon Detectors in the Eye

Olfaction

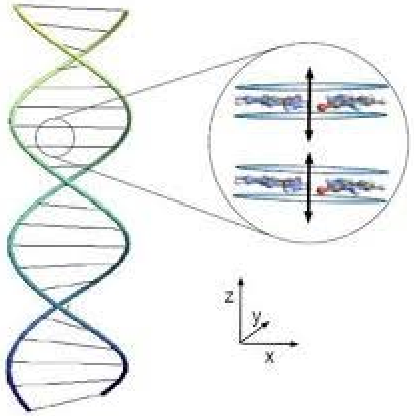
Hearing



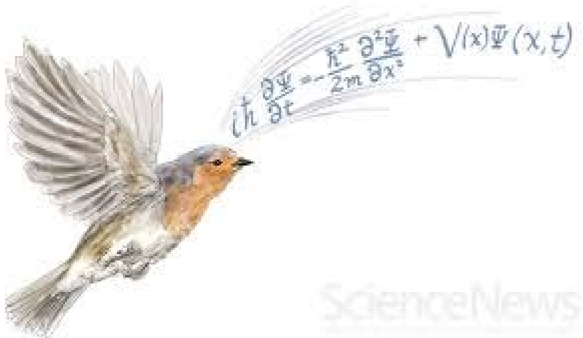
Ion Channels



Photosynthesis



Quantum Effects in DNA



Migratory Birds

A Theory of Everything?

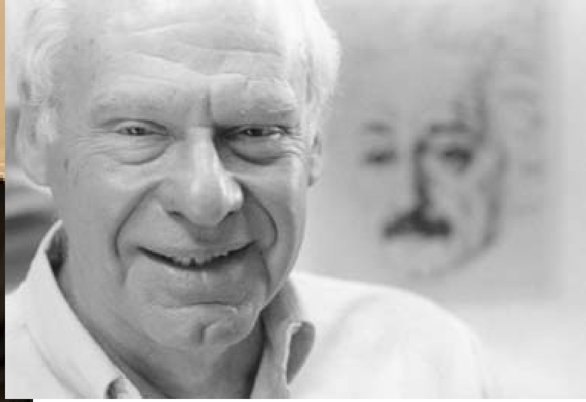
Nature 433, 257-259 (20 January **2005**)

Leonard Susskind

Edward Witten

Gerard t'Hooft

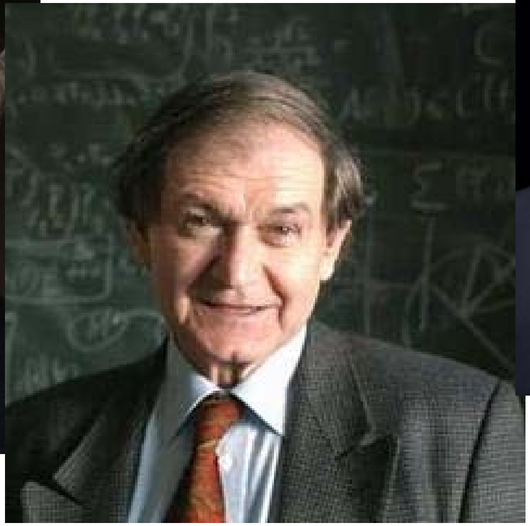
Lee Smolin



John Stachel

Carlo Rovelli

George Ellis



Roger Penrose

Steven Weinberg

Lisa Randall

The Role of Foundational Physics in Future Sciences??!!