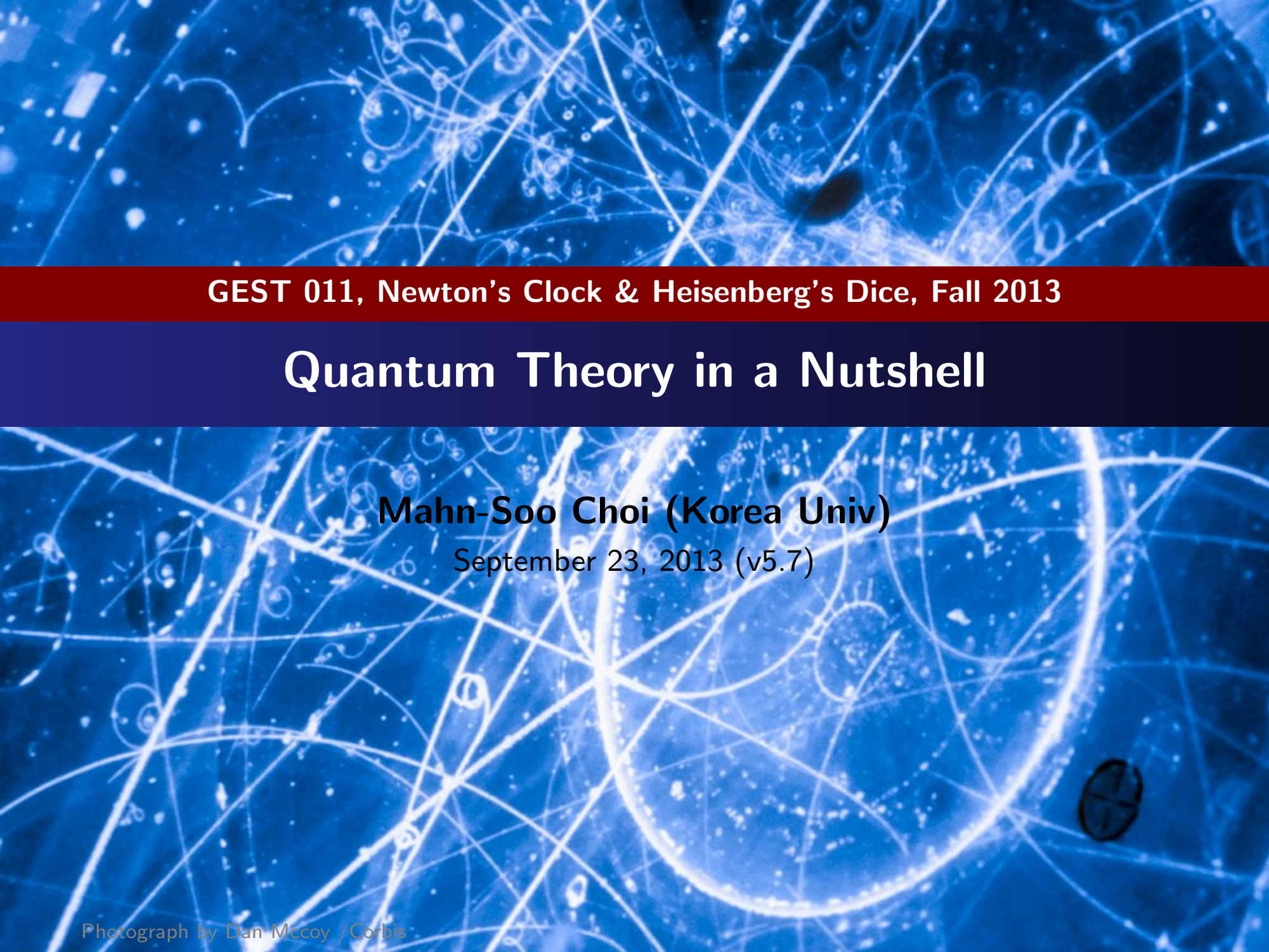


GEST 011, Newton's Clock & Heisenberg's Dice, Fall 2013

# Quantum Theory in a Nutshell

**Mahn-Soo Choi (Korea Univ)**

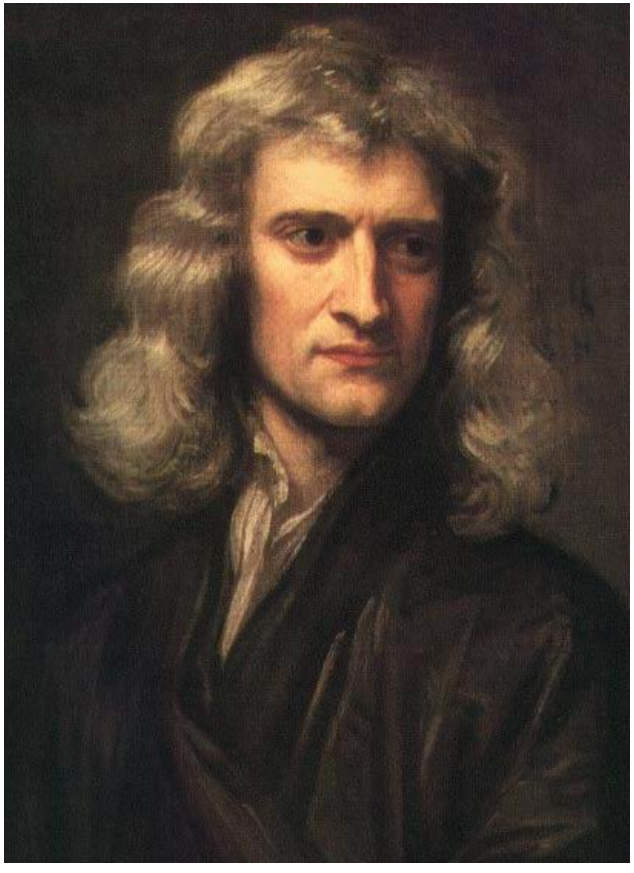
September 23, 2013 (v5.7)

Photograph by Dan Mccoy /Corbis

# State Variables

# State of a Particle in Motion

## Classical Mechanics



Sir Isaac Newton (1643–1727)
http://wikipedia.org/

- Position $\boldsymbol{r}$ & Velocity $\boldsymbol{v}$
- Newton's equation of motion

  (force) = (mass) × (acceleration)

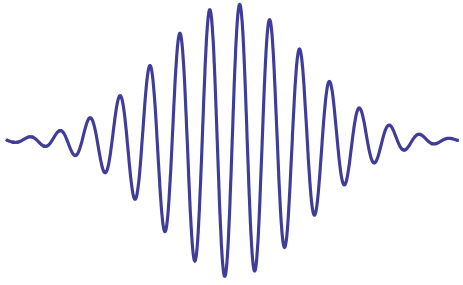
$$\boldsymbol{F} = m\frac{d\boldsymbol{v}}{dt} = m\frac{d^2\boldsymbol{r}}{dt^2}$$

# State of a Particle in Motion

## Quantum Mechanics

Erwin Schrödinger (1887–1961)
http://wikipedia.org/

- Wave function $\psi(x, t)$

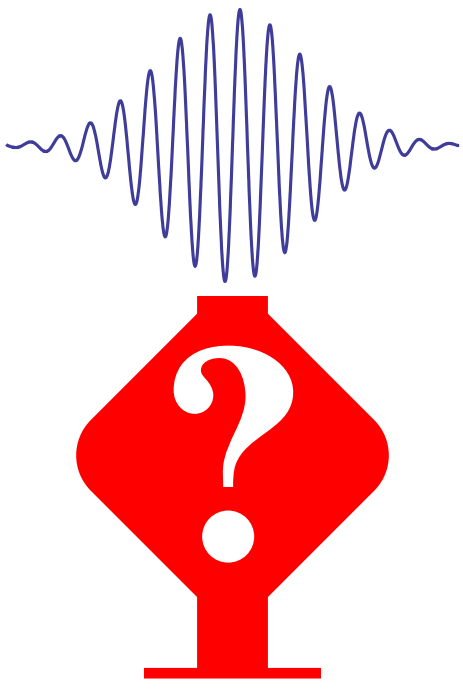


- Schrödinger's equation (1925)

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi(x, t)$$

# What is Wave Function?

$$\Psi(x, t)$$



# Probabilistic Interpretation of $\Psi$

## (Born, Z. Phys. 1926b; Born, Z. Phys. 1926a)

Max Born (1882–1970)

The absolute square of the wave function gives the probability density to find the particle at a position between $x$ and $x + dx$:

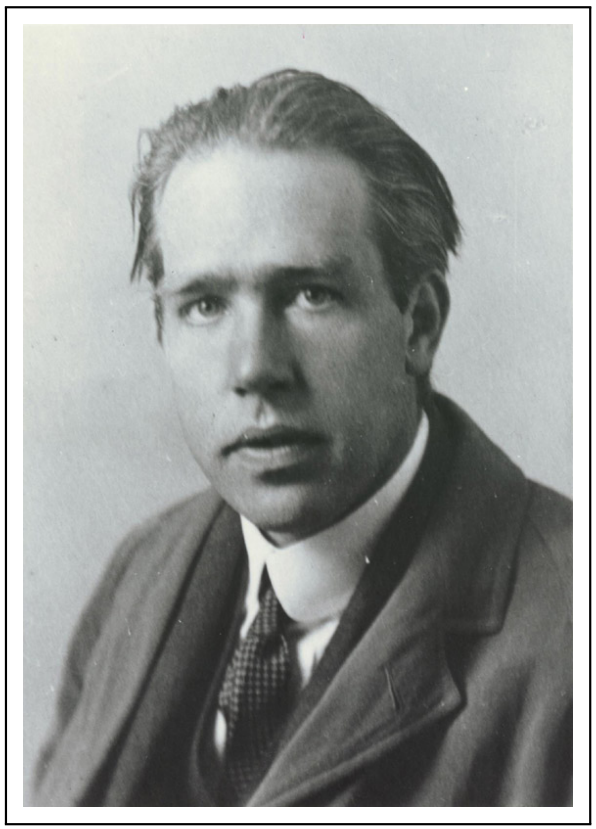
$$(\text{probability}) = |\psi(x, t)|^2 dx$$

Image from http://wikipedia.org/

# The Quantum Principia

## (Fundamental Postulates)

# The Copenhagen School



Niels Bohr (1885–1962)

Werner Heisenberg (1901–1976)

Images courtesy of http://wikipedia.org/

# The Copenhagen Interpretation (1927)

Bohr and Heisenberg chatting
http://wikipedia.org/

- A system is completely described by a wave function. (Heisenberg)
- The description of nature is essentially probabilistic. (Born)
- Measuring devices are essentially classical devices, and measure classical properties.
- After the measurement, the wave function "collapses" into one of the eigenstate of the quantity.

# Fundamental Postulates

## (The Copenhagen Interpretation)

1. The state of a particle in motion is described by the wave function $\psi(x, t)$.
2. The dynamics is governed by Schrödinger's equation of motion

$$i\hbar\frac{\partial}{\partial t}\psi(x, t) = H\psi(x, t)$$

3. Under a given condition, every physical quantity has a unique wave function* $\psi_m(x)$ for each observed value† $m$ of it.
4. After a measurement, the wave function "collapses" into one of the eigenfunctions of the measured quantity.

*Called as eigenfunction

†Called as eigenvalue

# Bohr and Einstein Debate ...?

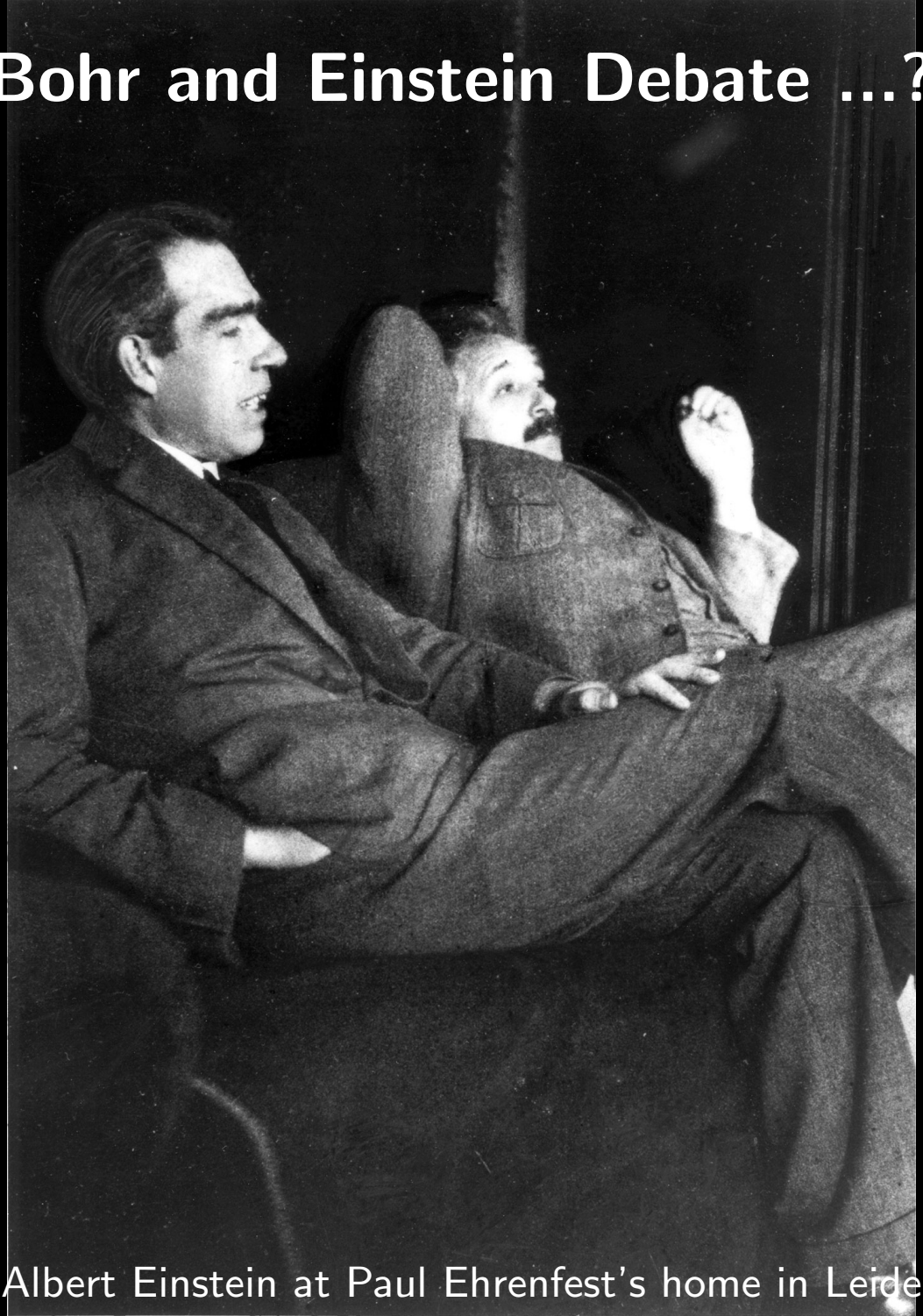


Image from Wikipedia

Niels Bohr with Albert Einstein at Paul Ehrenfest's home in Leiden in Dec 1925.

# The 5th Solvay International Conference (1927)

## (on photons and electrons)

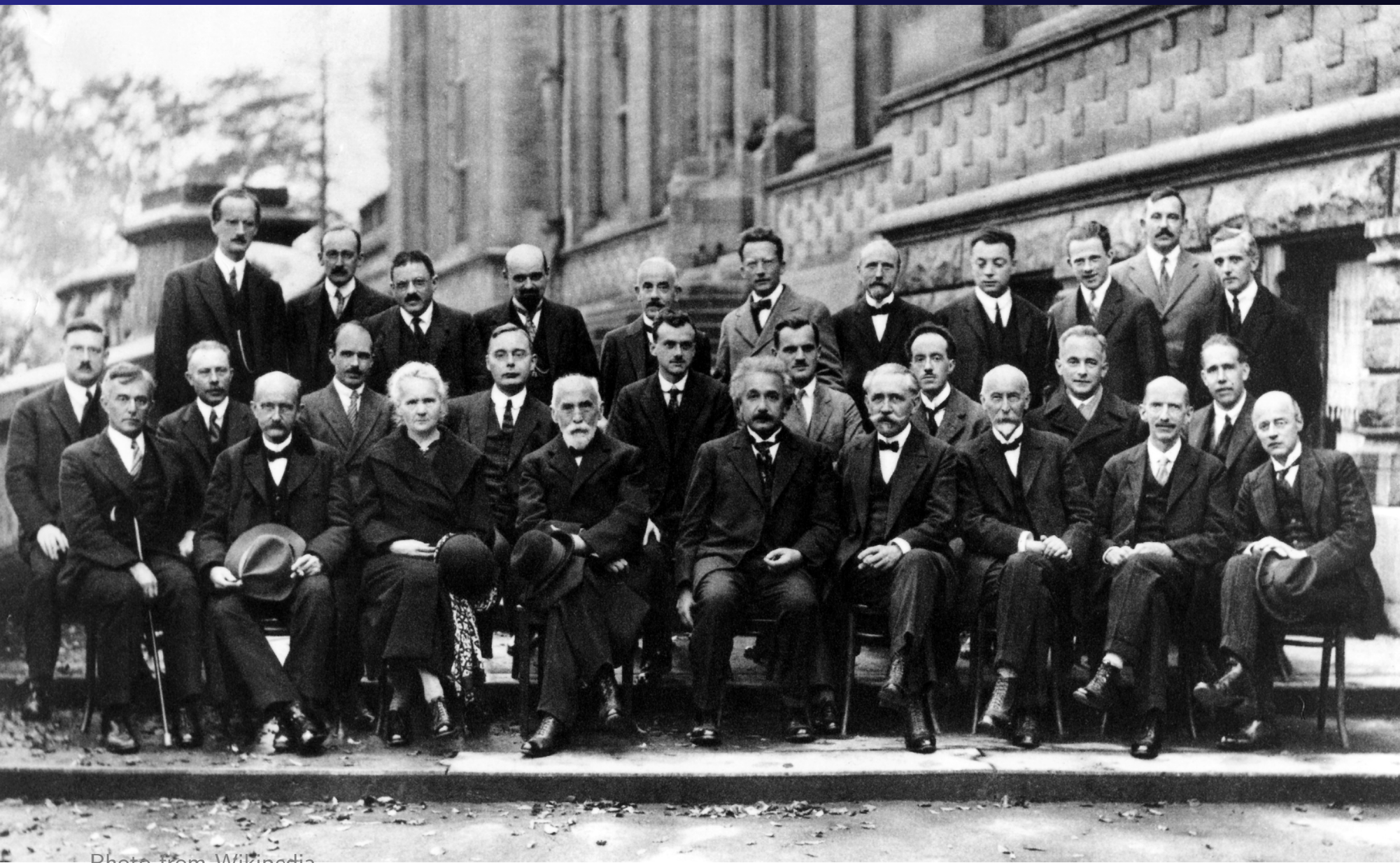
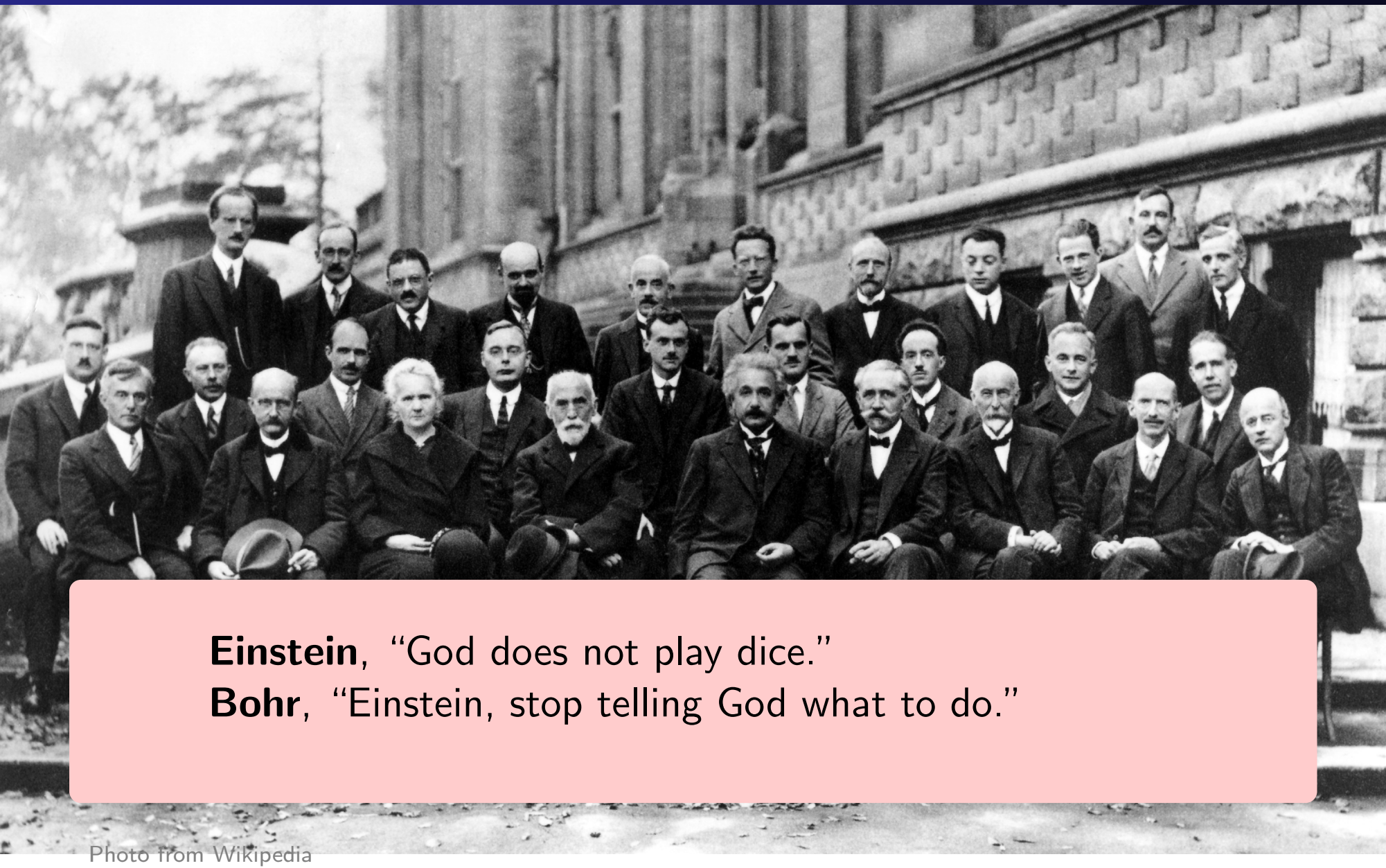


Photo from Wikipedia

# The 5th Solvay International Conference (1927)

**(on photons and electrons)**



**Einstein**, "God does not play dice."
**Bohr**, "Einstein, stop telling God what to do."

Photo from Wikipedia

# References

M. Born, Z. Phys. **38**, 803 (1926).

M. Born, Z. Phys. **37**, 863 (1926).