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Quantum Theory - Understanding and Dealing

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https://www.photonenkondensation.de

1 The Beginnings of Quantum Theory
2 Quantum Logic ignites a Physics Revolution
3 From Copenhagen Interpretation to a Constructivistic Interpretation of Quantum Theory
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1. Berlin, October 7, 1900

Max Planck discovers Quantum Theory.

It is Sunday afternoon. Heinrich Rubens, together with his wife, visits the family Planck. He reports consolidated data on measurements of heat radiation in the far infrared spectrum at the Physikalisch-Technische Reichsanstalt in Berlin. At this time, world-wide the most advanced laboratory for these measurements.

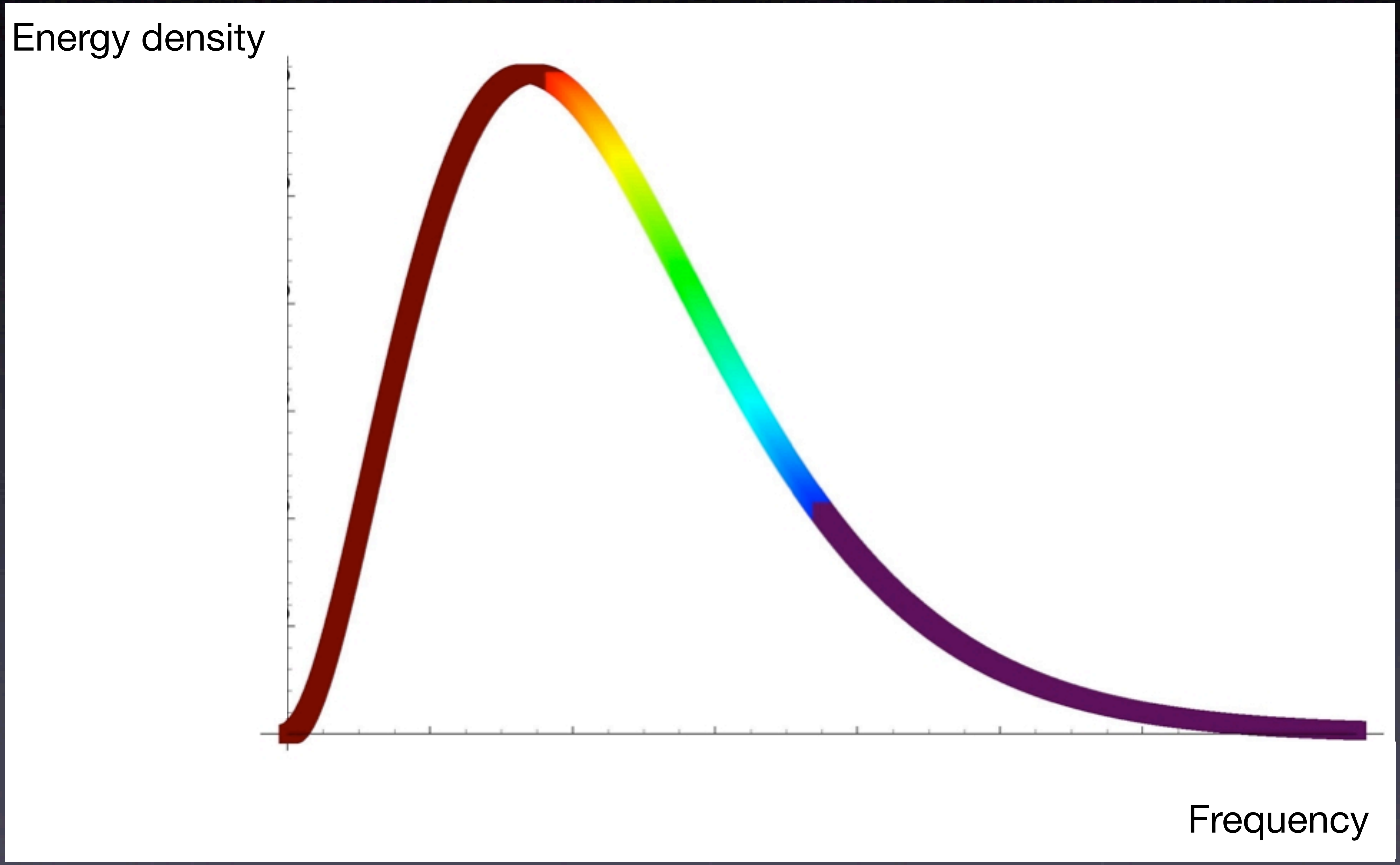
This night Planck interpolated between Wilhelm Wien's classical radiation law from 1896 and the latest experimental data.
As a result, he got his radiation formula. He communicated it to Rubens on a postcard.
In a session of the Deutsche Physikalische Gesellschaft in Berlin, October 19, 1900, Planck published his formula.
The following night, Rubens proofed experimentally the validity of Planck's formula for the whole heat radiation spectrum.
In December 14, 1900, again during a DPG session in Berlin, Planck presented a mathematical derivation to his formula.

“Shortly summarized, I can describe the whole deed as an act of desperation. It is my very nature to be peaceful disliking questionable adventures. But a theoretical explanation of the radiation law had to be found at any cost, whatever it takes. The two fundamental laws of thermodynamics seemed to me the only premises to be hold under all circumstances. Beyond that I was prepared to sacrifice whatever of my previous physical convictions.“
(Letter of Planck to R. W. Wood, October 7, 1931. Translation E. M.)

In Planck’s radiation formula a completely unanticipated element emerges:
a smallest energy quantum of electromagnetic radiation of definite frequency ν,

$$E_\nu = \mathbf{h}\nu$$

h: Planck’s constant



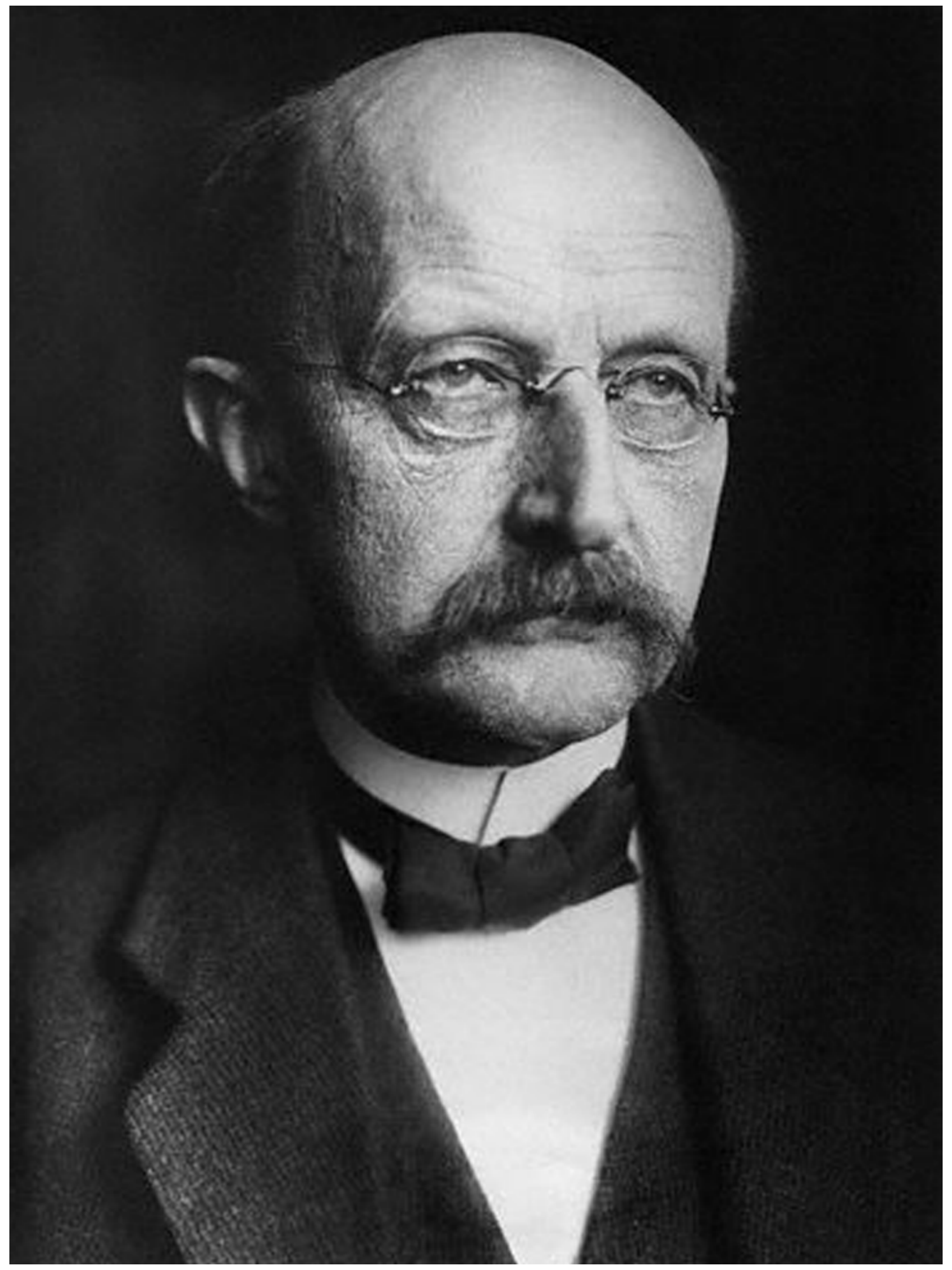
Energy distribution of heat radiation

1905, Albert Einstein uses Planck's concept of a light quantum (Lichtquanten-Hypothese) to present an explanation of the **photoelectric effect**.

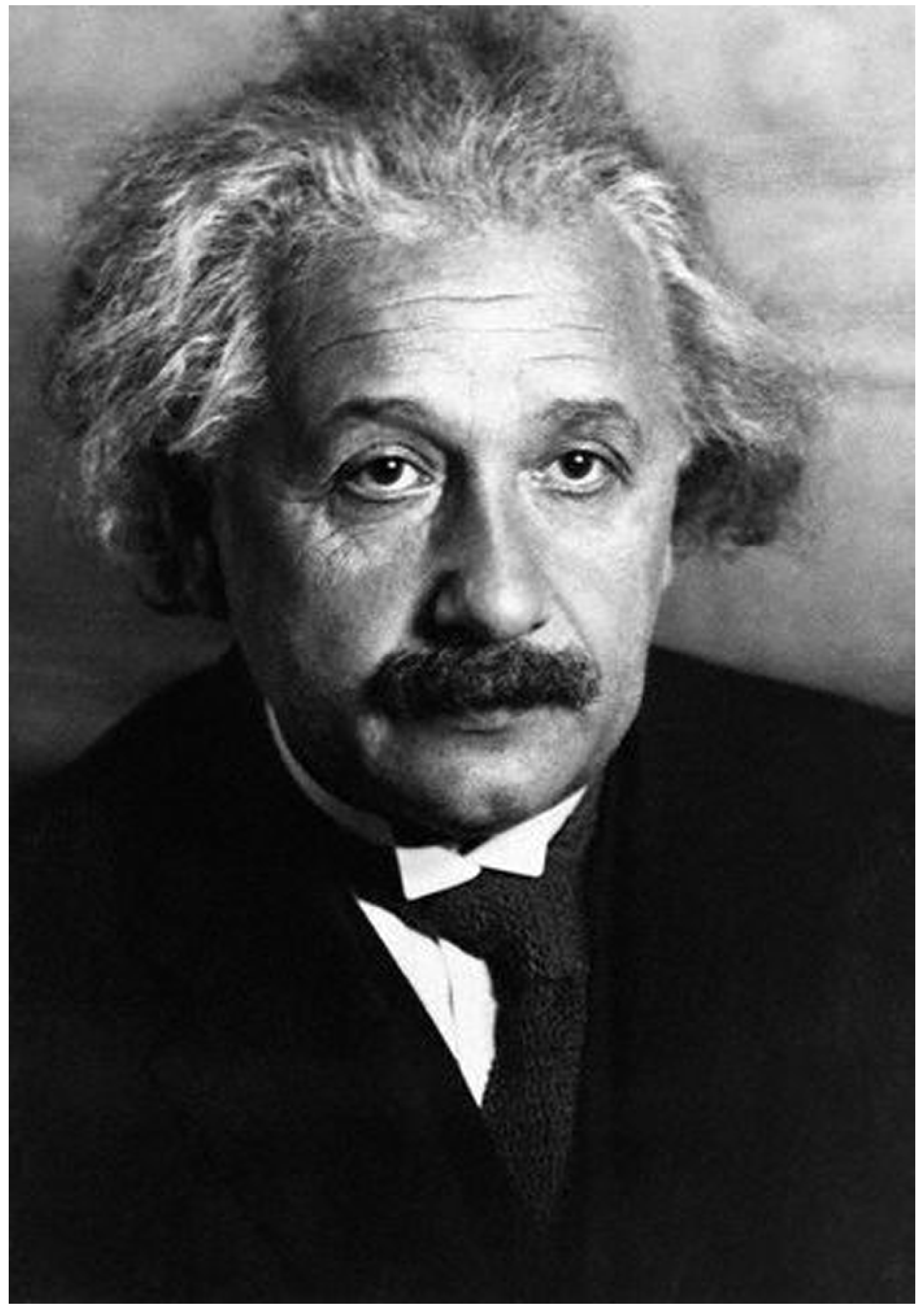
When ultraviolet light shines on some metallic surface, electrons are liberated therefrom.
In case of red light the material is simply heated without releasing electrons.
Light of sufficient high frequency pushes the electrons, comparable to a beam of very small billiard balls.

Einstein's reasoning: A light quantum, a photon, behaves like a particle.
On the other hand, the wave nature of light had been perfectly established in physics since the work of Christiaan Huygens in the 17th century.

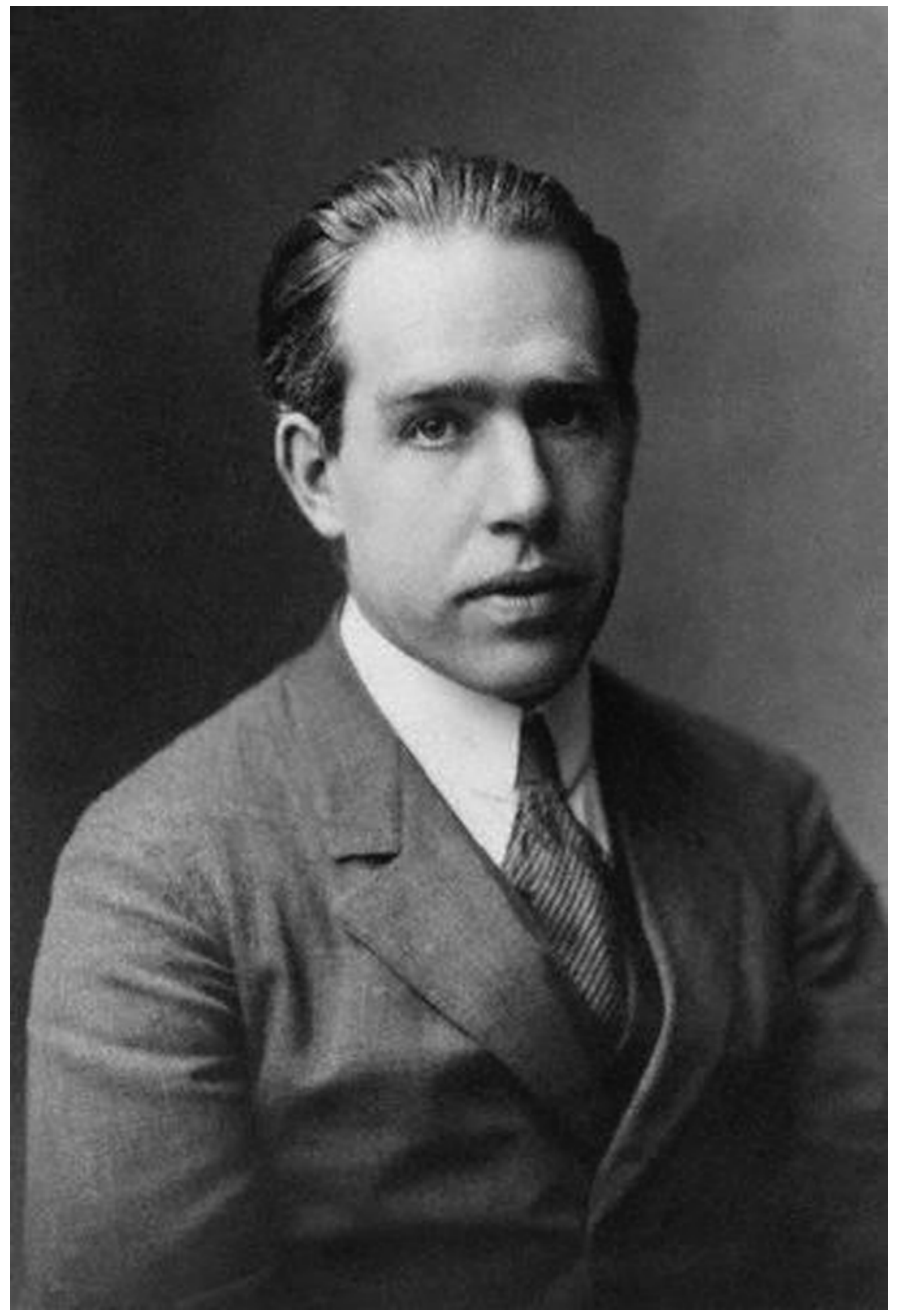
Therefore quantum theory implies a paradoxical setting:
A photon has genuinely wave properties and as well particle properties.



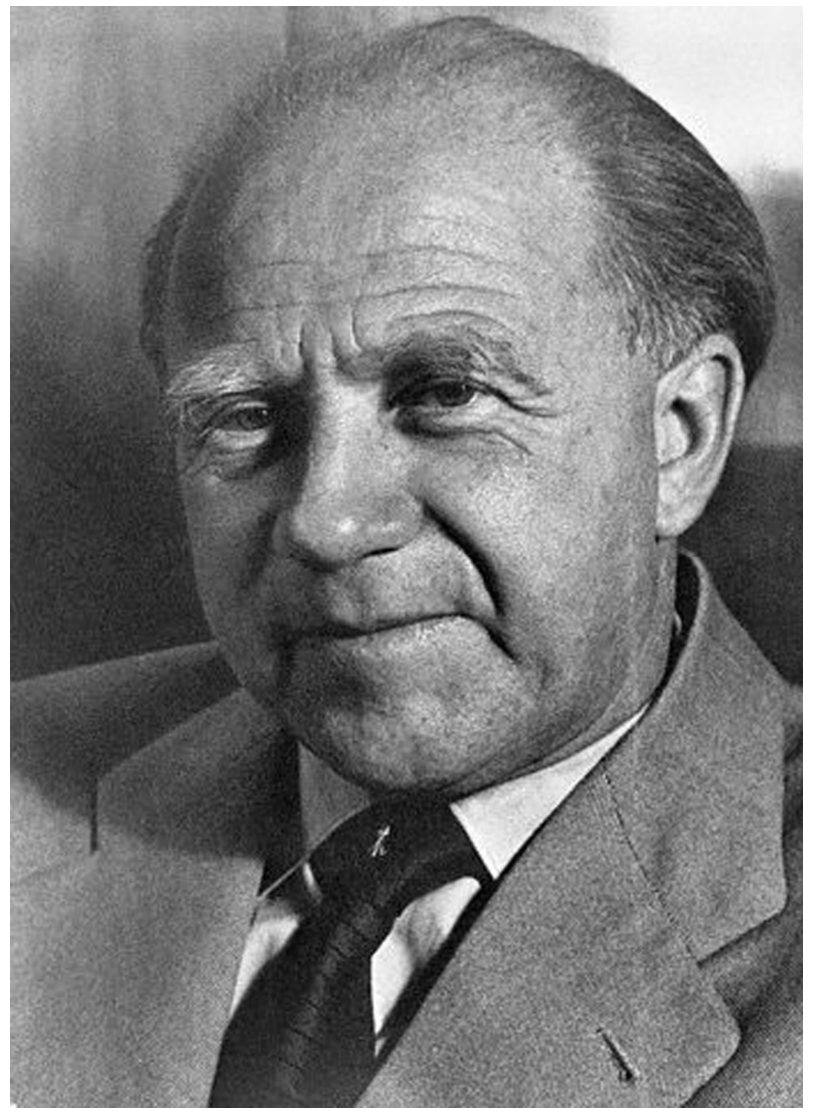
Max Planck 1858-1947



Albert Einstein 1879-1955



Niels Bohr 1885-1962



Werner Heisenberg
1901-1976

Wolfgang Pauli
1900-1958

Growing evidence confirmed the existence of an energy quantum:

- Franck-Hertz impact experiments (1913)
  between slow electrons (in a cathode-ray tube) and gas molecules
  absorbing energy in certain portions.

- Bohr’s model of atoms (1913),
  a nucleus with electrons circulating in specific orbits only. Refined by:

- Bohr-Sommerfeld atom model (1915/1916).
  Spectral analysis of chemical elements; periodic table of the elements.

Louis de Broglie, 1923:
The wave-particle dualism is a general pattern.
Not only for photons, but as well for electrons (electron microscopy, 1927), protons etc.

2. Quantum Logic ignites a Physics Revolution

Werner Heisenberg, June 1925: Quantum Mechanics.

Heisenberg introduces matrix mechanics.
Classical trajectories are obsolet. Observable quantities (frequencies, spectral intensities) are used.
The spatial view (Anschaulichkeit) in physics is no longer a conception a priori.

There is a **Heisenberg commutation relation** between the momentum operator **P** and the position operator **Q**.
Operators of observables are mathematical tools to describe specific physical measurements.

$$\mathbf{PQ - QP = -i\,(h/2\pi)\,Id}$$

This relation forms the heart of quantum mechanics and quantum theory.

This Heisenberg commutation relation implies the Heisenberg uncertainty relation (1927):

$$\Delta q \, \Delta p \geq h/4\pi$$

Δq: spatial uncertainty; Δp: momentum uncertainty

Unlike to classical physics, a quantum object can not be localized sharply.

The Heisenberg commutation relation intertwines the particle picture and the wave picture.
It is the basic equation of quantum mechanics expressing the non-commutativity of
the observable operators. At first measuring the momentum, and thereafter the position,
i.e. applying **QP**, is different from first measuring the position, and then the momentum,
i.e. applying **PQ**.

$$\mathbf{PQ} \neq \mathbf{QP}$$

In quantum mechanics, the succession of the measurements matters, unlike to classical Newtonian mechanics.

Quantum mechanics treats the particle picture and the wave picture at the same footing.
Both pictures have an equal status, equal right.
A quantum object has wave properties **as well as** particle properties.

So quantum theory follows a complete different logic compared to classical physics.
It is the **“As well as logic“** that rules quantum theory.
In contrast to classical “Either or logic“ ruling classical physics.

Looking at the graph of Planck’s formula of heat radiation, the intertwining of particle picture
and wave picture can be identified:
High frequency photons (small wave length) approximately behave like particles being quite well localized.
Low frequency photons (long wave length) approximately behave like waves.

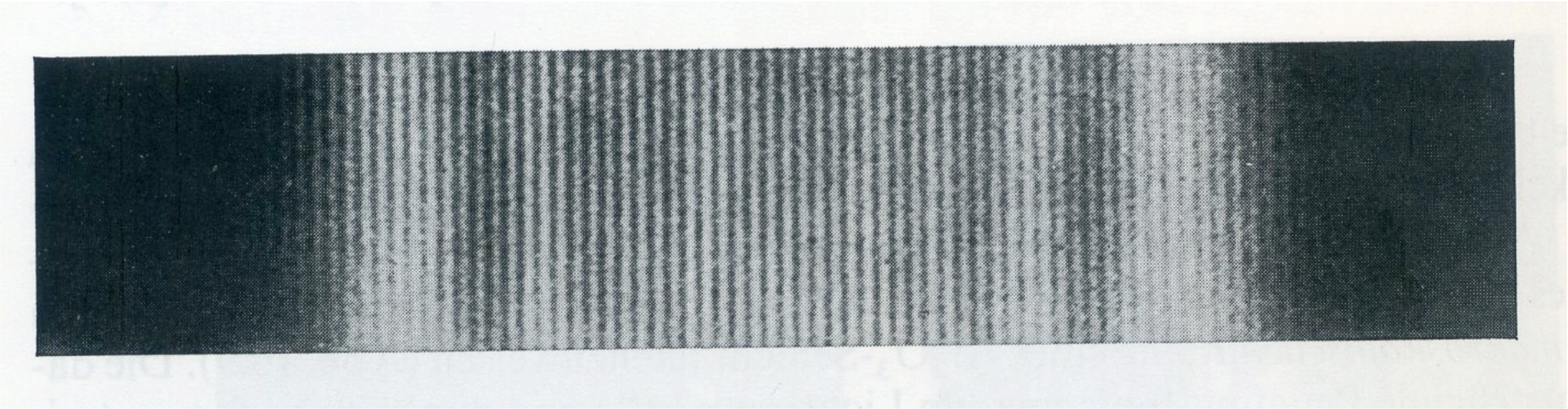
The quantum logic **as well as** reflects a **dialectic form**.

Take the particle picture represented by the observable operator **Q as a thesis**.
Take the wave picture represented by the observable **P as a hetero-thesis**.
The **synthesis** is the holding of the tension between the thesis and the hetero-thesis.
Thesis and hetero-thesis form two counterparts.

This synthesis creates a meta-level with respect to the level of thesis and hetero-thesis.
Physically, the level of thesis and hetero-thesis is the level of space and time.
The meta-level of the synthesis is an abstract level where the spatial view no longer holds.
Mathematically, it is formed by a Hilbert-space where the observable operators operate upon it.

It is an ingenious mathematical apparatus which is necessary to formulate quantum theory.
The general mathematical term for a quantum system is a non-commutative operator algebra
(**John v. Neumann, 1932, 1936**).

3. From Copenhagen Interpretation to a Constructivistic Interpretation of QT



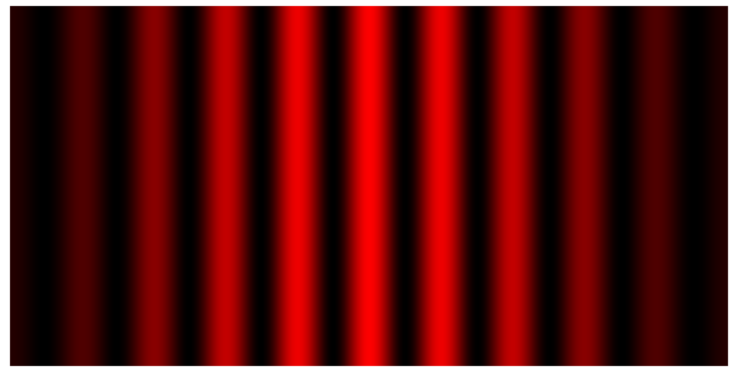
Bergmann-Schaefer: Optik, p. 1020

Electron interference with
Möllenstedt-Biprism
University of Tübingen, 1956

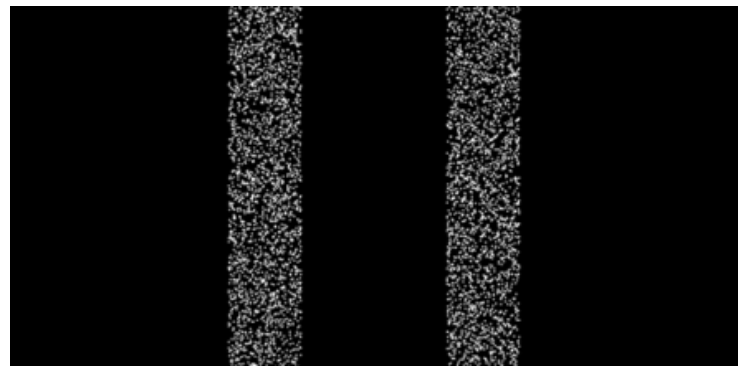
G. Möllenstedt, H. Düker:
Zeitschrift für Physik 44 (1956), p. 377

Double Split Experiment

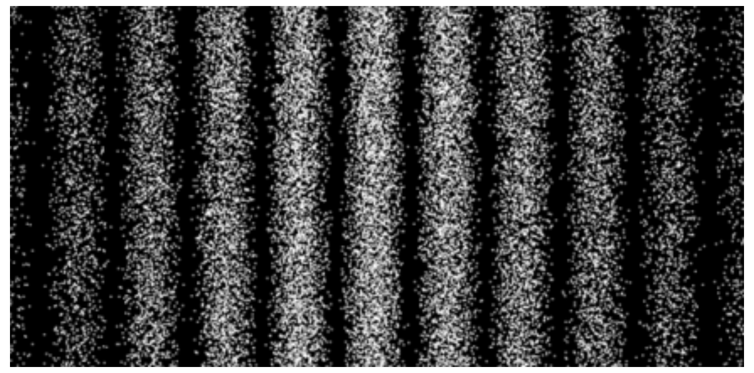
wikipedia.org/wiki/
Welle-Teilchen-Dualismus



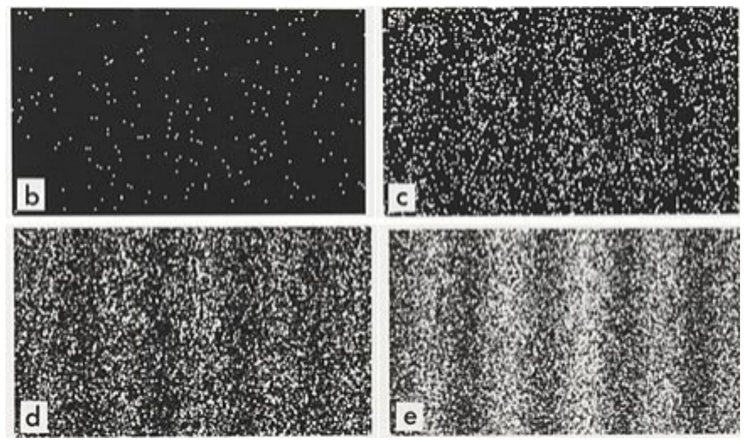
Diffraction pattern:
classical wave



Distribution of classical particles



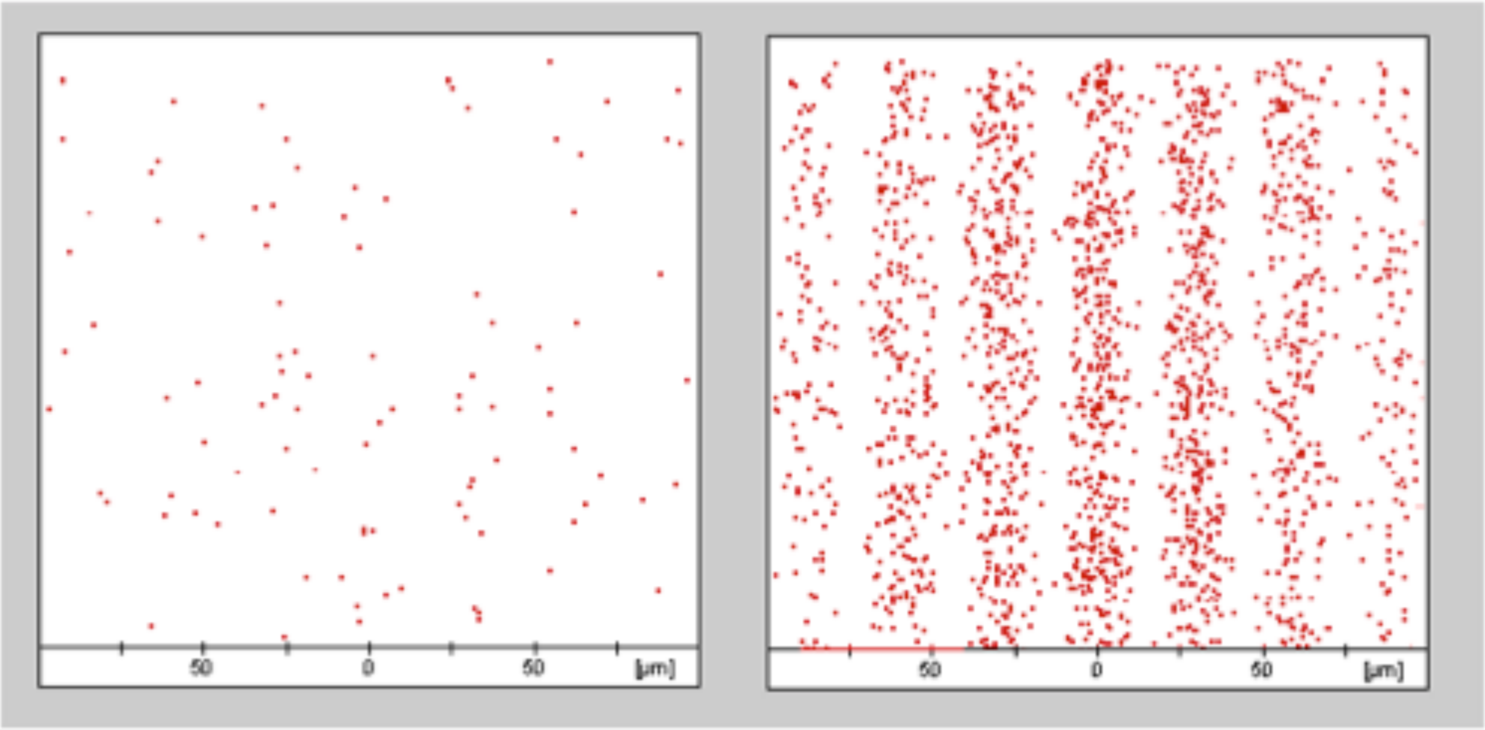
Diffraction pattern:
quantum objects



Single electron build-up of interference pattern, experimental data:
Akira Tonomura, Hitachi

Eberhard Müller, QT

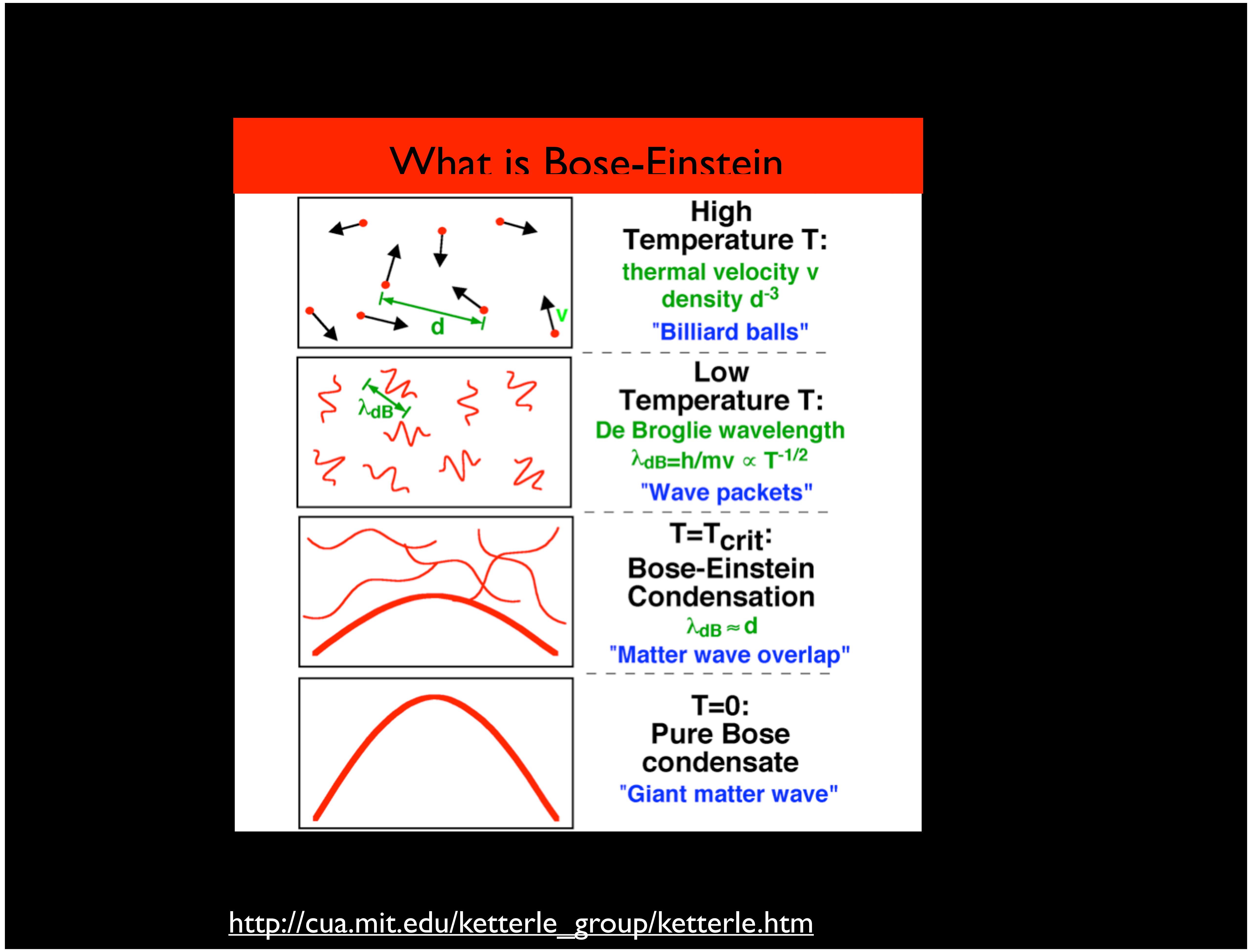
Double Split Experiment
with photons



The intensity of the light source is extremely reduced in order to identify single photons.
The spatial localization of a single photon is random. The classical notion of a trajectory does not apply.
A large number of photons build up an interference pattern. This is characteristic for a wave.

An example of a continuous transition from the particle picture to the wave picture.

The graphics displays quantum correlations and their effect during a Bose-Einstein condensaton.



The random behavior of single quantum objects as photons, or electrons, or protons let **Max Born 1927** invent a **statistical interpretation of quantum theory**.
Niels Bohr, Werner Heisenberg, Wolfgang Pauli deepened this view which is known as **Copenhagen Interpretation of Quantum Theory**.

Albert Einstein, Max Planck, Max von Laue, Erwin Schrödinger criticized the statistical interpretation of quantum theory. Einstein's verdict is famous: God does not play dice.

According to the Copenhagen Interpretation of QT, a measurement in a quantum system makes the ψ-function collapse. The quantum wave function ψ represents the physical information of a system. It is the superposition of all relevant states. **The measurement process is an irreversible process**.

Constructivistic Interpretation of QT. What is an Object?

A statistical interpretation refers to a statistical ensemble. But what about single objects in quantum physics?
Since the second half of the 20th century, we see an increasing number of experiments with single atoms, single electrons, single photons. Is there an individual interpretation of QT?

Any quantum system is an entangled system. The wave functions of the elements of a quantum system are superposed, they overlap, they are correlated. All potential objects of the system, all parts of the system are mutually correlated.
The total system of quantum objects under consideration forms a wholeness, a unity.
In such a system **there does not exist a priori a separable, isolated subset**.

We are left with a severe question: What is a single object being part of a quantum system? What is a quantum object?
The radical answer: **We have to construct the desired object**.

We have to set a definition cut within the “quantum universe“ of our system thereby neglecting a part of the correlations involved. Defining is making. The experimentalist sets the definition cut by arranging the experimental setting. In doing so, he defines the desired quantum object. And, at the same time, the environment of the object.

The definition cut means focussing. Strictly speaking, it is fictitious. The definition cut rules the coupling between the quantum object and the rest of the world (resp. the relevant environment).
A quantum object is conceivable only as an open system.

Neglecting specific correlations within the total quantum system under consideration means neglecting information. This increases the entropy. Hence, the definition cut causes an irreversible time evolution for the quantum object.

Hans Primas (1928 - 2014):

In a holistic world objects have to be invented; in a theoretical description objects are created by abstracting from the Einstein-Podolsky-Rosen correlation between the object and its environment. The properties of the invented objects can be discovered experimentally, by experiments which neglect some existing correlations as irrelevant.

The exploration of nature leads to inventions and discoveries.
Discoverers have a fixed point of view, inventors create new contexts.

Hans Primas, Chemistry, Quantum Mechanics and Reductionism. Perspectives in Theoretical Chemistry. Foreword by Paul Feyerabend. Springer-Verlag Berlin, Heidelberg New York, p. 353.

4. Paradigmatic Examples for Definition Cuts

4.1 Nuclear Magnetic Resonance

We consider a quantum system consisting of (nuclear) spins and photons (electromagnetic field).
The energy operator (Hamiltonian) of the total system rules a reversible time evolution.

$$H = H_{Spins} + H_{Photons} + \lambda H_{Interaction} \qquad \lambda\text{: coupling parameter}$$

Now we identify the **subsystem of spins** within the total mixed system in a specific way.
It will be our definition cut. It is a mathematical idealization by means of a **weak coupling limit**.
For this we rescale the time:

$$t \longrightarrow \tau = \lambda^2 t$$

In the limit $t \longrightarrow \infty$, $\lambda \longrightarrow 0$ such that τ remains a finite time, we get the irreversible **Bloch equations of NMR**.
They provide the time evolution of the spin system.

J. Pulè, The Bloch Equations. Communications of Mathematical Physics 38 (1974), p. 241

4.2 Decorrelating: From two coherent light rays to two separate, single rays

Max Planck:
… my favorite student Max v. Laue did convince me in a couple of discussions
that ***the entropy of two coherent light rays is smaller than the sum of the entropy of the single rays****.*

This is an extreme example to proceed a definition cut.

M. Planck, Zur Geschichte der Auffindung des physikalischen Wirkungsquantums. Vorträge und Erinnerungen,
in Wissenschaftliche Buchgesellschaft Darmstadt, 1933/1965, p. 27.

4.3 Primas' Theory Reduction

Chemistry can be reduced to the basic of quantum electrodynamics (QED).

The notion of a "chemical atom" is not a fundamental notion of QED. On this fundamental level, electrons, protons, neutrons are Dirac quantum fields. We need a **definition procedure to construct the notion of a chemical atom**. This is done by the **Born-Oppenheimer approximation**. The Dirac fields, going to form a nucleus of an "atom", are approximated as localized classical objects that follow a classical time evolution, while the electrons are treated as quantum objects. So we get the usual notion of a chemical atom in the sense of the Bohr-Sommerfeld model.

This is the crucial clue to establish chemistry reducing it to QED.

H. Primas, Chemistry, Quantum Mechanics and Reductionism, see quotation above, p. 279 ff.

5. Conclusions

Quantum theory provides a completely new approach to thinking physics. A new approach to physical intuition.
The core of this revolution is the quantum logic “as well as“.
It delivers a mathematical foundation of the dialectic form of thesis, heterothesis, synthesis.

This new logical approach and the constructivistic procedure might be used as tools in non-physical areas.

Consider a subtext within a text. The subtext has an environment, a context. The grammatical rules can be used to define a specific coupling between the subtext and the context. Thereby the subtext, or even single words, get their specific meaning. Different couplings define different subtexts, i. e. different objects.

A similar structure can be observed in the art of photography. A photograph is not just a simple representation of reality. The technique, the perspective, the framing, the way to take a photo constructs an object of its own. It’s a play of coupling, and decoupling.

More general: There are many ways and options to conceive “reality“. Strictly speaking, there is no objective reality.
Realities exist by construction.