Max Planck, Kiel and recent progress in the dynamics of correlated quantum many-body systems

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1. Quantum physics today

2. Max Planck and Kiel

3. Planck and the discovery of elementary quanta

4. Quantum mechanics:
   from the Big Bang to ultracold atoms
1. Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

The basis for modern (quantum) chemistry, material science
Atoms and molecules

Lowest hydrogen orbitals
(analytical results)

DFT result for 3 LUMO frontier orbitals for the most probable PPCBMB adducts, phenyl-C61-butyric acid methyl ester,

Stephen et al., Chemical Communications 2016
Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

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The basis for electronic conduction: from nanotechnology to electrical engineering

M. Bonitz, “Max Planck, Kiel and correlated quantum systems”, Budapest, October 2018
Nanotechnology
Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

The basis for modern (quantum) chemistry, material science

The basis for electronic conduction: from nanotechnology to electrical engineering

The basis for understanding the Universe and its history
Quantum Theory provides strong evidence for the Big Bang theory
Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

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The basis for electronic conduction: from nanotechnology to electrical engineering

The basis for understanding the Universe and its history

It all started December 14 1900, with Max Planck‘s discovery

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2. Max Planck.
Childhood in Kiel, 1858-1867

Born in Kiel, 23. April 1858
Father Julius Wilhelm Planck (1817-1900), law professor in Kiel
Mother Emma Planck, (born Patzig)

Uncle Gottlieb Planck (1824-1907), lawyer
Grandfather Gottlieb Jakob Planck (1751-1833), theologian
Max Planck’s family moves to Munich

**German/Austrian-Danish War**
February-October 1864

for the duchies Holstein, Saxe-Lauenburg, and Schleswig

Reason: passing of the November Constitution, which integrated the Duchy of Schleswig into the Danish kingdom in violation of the London Protocol

**1867**: Planck’s father under protest against Prussia leaves Kiel

Planck retains ties to his hometown

Map: Maximilian Dörrbecker (Chumwa)
Max Planck studies physics

School in Munich: 1867-1874

Studies: 1874-1879, Munich and Berlin
    Helmholtz, Kirchhoff, Weierstraß
    Self-education: Clausius

PhD thesis 1879: on 2nd law of thermodynamics

Privatdozent: 1879-1885, Munich

Continue in Physics?
Continue in Physics?

Advise from Prof. Jolly, in Munich, 1877

„Theoretical Physics is close to completion, ... similar as geometry is long complete.“

„in some „corners“ there might be a few tiny „dust grains“ left to explore and categorize, but the system as a whole is well founded.“

„I do not desire to discover new ground, but only to understand the existing fundamentals of the physical science and, possibly, to deepen them“

Planck, Naturwiss. 13, 52-59 (1925)

M. Bonitz, “Max Planck und die Welt der Quanten”, SHUG 2017
Finally: a position in Kiel

1885: call to Kiel University as extra-ordinarius for Theoretical Physics, Planck: „relief“

1886 Max Planck founeds a family
marries his girlfriend from childhood, Marie Merck

the couple has 4 children:
- 1888: son Karl (–1916)
- 1889: twins Emma (–1919), Grete (–1917),
- 1893: son Erwin (–1945)
Important papers in Kiel: on thermodynamics

- "Über das Prinzip der Vermehrung der Entropie" (3 Arb.)
- "Über die molekulare Konstitution verdünnter Lösungen"
- "Das chemische Gleichgewicht in verdünnten Lösungen"
- "Über die Hypothese der Dissoziation der Salze in sehr verdünnten Lösungen"
- "Über die Dampfspannung verdünnter Lösungen flüchtiger Stoffe"
- "Zur Theorie der Thermoelektrizität in metallischen Leitern"

1887: wins 2nd prize in Göttingen theory challenge
   (supported Helmholtz‘ ideas against W. Weber)

1889: offer to Berlin University (successor of Kirchhoff)
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Theoretical physics around 1875

- Mechanics
- Electrodynamics
  - Electrical and magnetic processes, electromagn. waves, etc.
  - Dynamics of bodies, liquids, and planets, elastic media

- Thermodynamics
  - Heat, gases, heating and cooling machines

Phlogiston

Ether

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Theoretical physics around 1875

Mechanics
- dynamics of bodies, liquids, and planets, elastic media
- Heat, gases, heating and cooling machines

Electrodynamics
- Electrical and magnetic processes, electromagn. waves, etc.
- Spectrum of black-body radiation

Thermodynamics
- EM wave velocity in moving systems
- Ether
- Phlogiston

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Max Planck and black-body radiation

1860: Gustav Kirchhoff formulates model of „black body“: EM waves in resonator in TD equilibrium

1894: Berlin – Experimentalists at PTRA show Planck their new data
– Planck starts to look for a theory

Planck does, what he can best: he computes the Entropy of the EM radiation (a truly „crazy idea“)
New accurate experimental data

Messung von Lummer und Pringsheim (1900)
Planck finds the radiation formula
(DPG, Berlin, 19.10. 1900)

I. Wien-Formel
(große Frequenzen)

\[ U(\beta) = b e^{-a\beta} \]
\[ R = \left( \frac{d^2 S}{dU^2} \right)^{-1} = -aU \]

II. Rayleigh-Jeans-Gesetz
(kleine Frequenzen)

\[ U(\beta) = \frac{d}{\beta}, \quad \beta = 1/kT \]
\[ R = -U^2 / d \]

Kombination:

\[ R = -aU - U^2 / d \]

Integration:

\[ \frac{dS}{dU} = \beta(U) = \frac{1}{a} \ln \left[ 1 + \frac{ad}{U} \right] \]

Auflösen nach U:

\[ U(\beta) = \frac{ad}{e^{a\beta} - 1} \]
Planck finds the radiation formula
(DPG, Berlin, 19.10. 1900)

Planck’s result „interpolates“ between the known limits

perfect agreement with experiment

but: no physical explanation
Planck’s Derivation

\[ \rho(\lambda, T) = \frac{8\pi ch}{\lambda^5} \frac{1}{e^{hc/kT\lambda} - 1} \]

Planck recognizes sum of geometric progression

**Hypothesis:** energy at each wavelength composed of \(N\) identical finite “energy quanta”

\[ U_\nu = N_\nu \cdot \varepsilon_\nu = N_\nu \cdot h\nu \]


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Broad scepticism against Planck’s discovery

- Striking contradiction to radiation laws of classical electrodynamics
- Criticism from Rayleigh, Jeans, Ehrenfest, H.A. Lorentz and many other theoreticians

1911: Nobel prize for Wilhelm Wien,

"for his discoveries regarding the laws governing the radiation of heat"
1918: Nobel prize for Max Planck

„for his work on the establishment and development of the theory of elementary quanta.“

Planck‘s „theoretical conclusion stands in very sharp opposition to our earlier concept of the radiation phenomenon. Experience had to provide powerful confirmation, therefore, before Planck’s radiation theory could be accepted. In the meantime this theory has had unheard-of success.“

„Planck’s radiation theory is, in truth, the most significant lodestar for modern physical research, and it seems that it will be a long time before the treasures will be exhausted which have been unearthed as a result of Planck’s genius.“

A.G. Ekstrand, President of the Royal Swedish Academy of Sciences, 1. June 1920
Tragic personal life

• 1909 death of Planck’s wife Marie

• 1911: Second marriage, to Marga von Hoeßlin son Herrmann (1911-1954)

• witnesses death of all 4 children from first marriage:
  - son Karl: died 1916 in World War I
  - twins Grete and Emma: died 1917 and 1919 when giving birth

World War II: Planck stayed in Nazi Germany (conservative, loyal, patriot)
• 1943, October: during a lecture in Kassel Planck barely survived the bombing of the city
• 1944: Planck’s house in Berlin was bombed, he lost everything
• 1945, 23.1.: son Erwin executed (participant in Hitler assassination attempt)
Planck stays in Germany and defends science and scientists

Planck’s public activities (selection):

- many public lectures about science
- permanent Secretary of Prussian Academy of Sciences (1912/38)
- Rector of Berlin University (1913/14), supported Einstein
- several times president of German Physical Society
- President of Kaiser-Wilhelm-Society (1930/36)

- **1946**: Invited to Newton's 300th birthday celebration, London
- **1945/46** president of the Max Planck Society, laid foundation for revival of German science system after WWII
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Electrical conduction,
Optical properties,
Computer chips

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Quantum effects on cosmic scales?

Big Bang  |  Expansion, cooling, condensation  |  matter today

electrons, quarks, photons  

Expansion, cooling, condensation

Afterglow Light Pattern
400,000 yrs.

Dark Ages

Development of Galaxies, Planets, etc.

Accelerated Expansion

Inflation

Quantum Fluctuations

1st Stars about 400 million yrs.

Big Bang Expansion  
13.7 billion years

a few photons should have survived

Gamov, 1947
Discovery of the cosmic microwave background radiation

1964: Penzias, Wilson

Expansion and cooling 3000K → 2.73K

Cosmic radio signals
annoying noise….
A window to the Universe
13.7 billion years ago!

2006: Physics Nobel prize for Mather and Smooth, COBE satellite (1989-93)
today: Satellites measure anisotropy, mass distribution etc.
       WMAP (2001-10), Planck (2009-13)

Summary and Outlook

„I do not desire to discover new ground, but only to understand the existing fundamentals of the physical science and, possibly, to deepen them“

„…..the most significant lodestar for modern physical research, ... it will be a long time before the treasures will be exhausted which have been unearthed as a result of Planck’s genius.“

Quantum mechanics: Revolution in science, technology
A unique example of scientific discovery and personal integrity
A story that should be kept and told
Extensive program of city Kiel, University and Planck School celebrating Planck’s 150th birthday

4. 10. 2007: Kiel commemorates the 60th anniversary of Planck‘s death

2008, spring: Scientific colloquium and public lectures

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Planck and Quantum mechanics
Public lecture for school children

Kiel City council hall, April 2008

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Planck Celebration in Kiel 2007/2008

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First proposal of a Max-Planck-Museum

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A Museum for Planck and Quantum mechanics


www.theo-physik.uni-kiel.de/~bonitz/planck.html

M. Bonitz, “Max Planck, Kiel and correlated quantum systems”, Budapest, October 2018
A Museum for Planck and Quantum mechanics


www.theo-physik.uni-kiel.de/~bonitz/planck.html → s. flyer

M. Bonitz, “Max Planck, Kiel and correlated quantum systems”, Budapest, October 2018
Planck 2018
Memorial Scientific Symposium

10-11 October 2018. Széchenyi Square 9, Budapest, Hungary

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