The Fifth Milestone of Quantum Physics

The tale for the centenary of quantum mechanics

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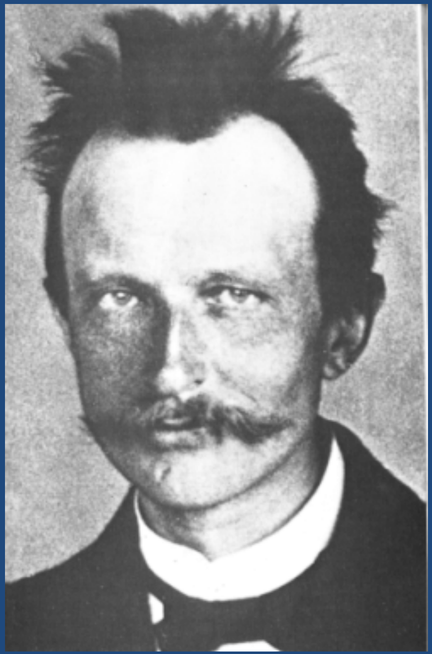
The first milestone – 14th December 1900

Friday, December 14, 1900 – at a meeting of the German Physical Society, Max Planck delivered a presentation entitled "Zur Theorie des Gesetzes der Energieverteilung im Normalspectrum" – "On the Theory of the Law of Energy Distribution in the Normal Spectrum." According to Max von Laue, this event marks the birth of quantum theory



$$u(\nu)\,\mathrm{d}\nu = \frac{A\nu^3}{\exp(B\nu/T) - 1}$$

Not the formula shocked the audience but its justification… *„At this point, we need to specify an expression describing the distribution of energy U(N) among N resonators with frequency v. If we consider U(N) as an infinitely divisible quantity, then the appropriate distribution can be constructed in infinitely many ways. However, we will assume—and this is the most important moment of the entire calculation—that U(N) can be divided into a precisely defined number of finite, equal parts, and we will use the fundamental constant h = 6.55 × 10^{-27} erg·s. Multiplying this constant by the common frequency of the resonators v, we obtain the energy value ε in ergs, and by dividing U(N) by ε, we find the number P of energy elements that should be distributed among the N resonators."*

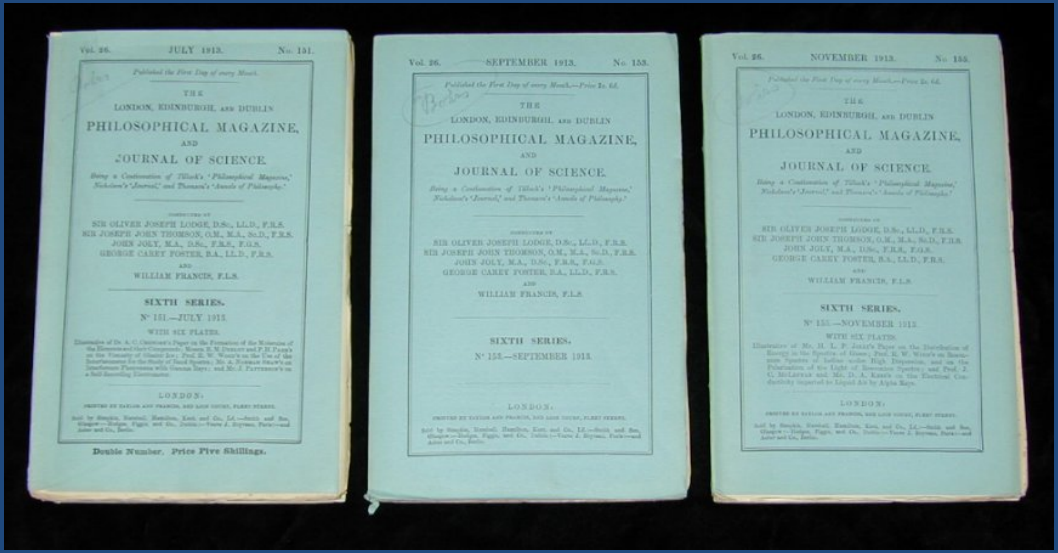
The second milestone –
17th March 1905

The first Einstein's paper belonging to the „marvelous 1905 five", widely known (incorrectly) as the paper on photoelectric effect - in fact this is the paper on photons

Heuristic perspective regarding the generation and transformation of light
Annalen der Physik 17 132 - 146 (1905)

„...it seems to me that the radiation of a perfect black body, luminescence, the production of cathode radiation by ultraviolet light, and other phenomena involving emission and transformation of light can be better understood by assuming that the energy of light is distributed in space in a discontinuous manner...
...energy consists of a finite number of energy quanta, localized in space, which move as indivisible parts and can only be absorbed or emitted entirely."

The third milestone – Bohr’s Trilogy „On constitution of atoms and molecules”, Philosophical Magazine and Journal of Science”, July, September, November 2013



"The energy radiated by a vibrating atomic oscillator with frequency ν during a single emission event is equal to nhν, where n is an integer, and h is the universal constant….Now, let's assume that during the binding of an electron, uniform radiation with frequency ν is emitted, which is equal to half the electron's angular velocity ω on its final orbit. Therefore, according to Planck's theory, the energy emitted during this process is equal to nhν."

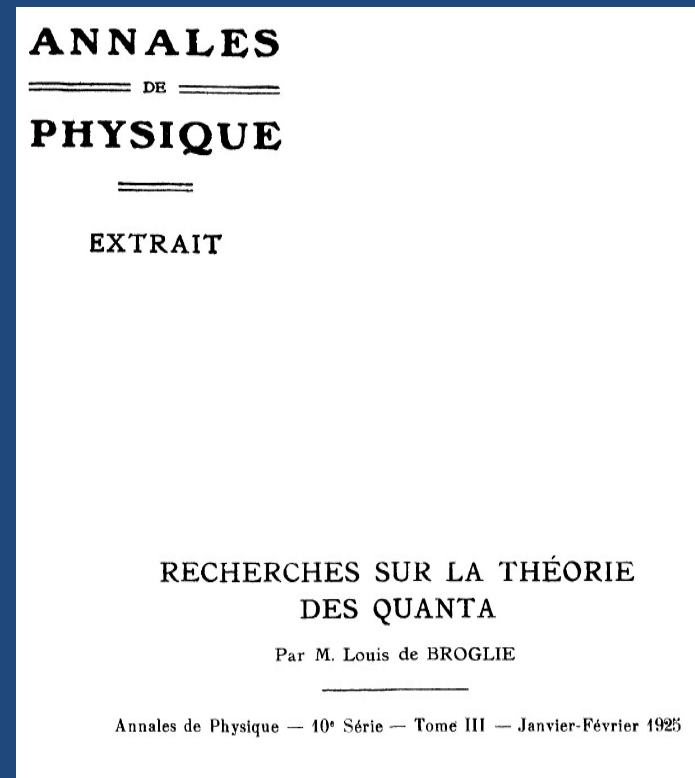
The fourth milestone – 28-th November 2024;

Brave step further than Einstein: matter and waves are dual faces of physical reality

Louis-Victor-Pierre-Raymond,
7-th Duc de Broglie

$$E = h\nu$$

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


ANNALES
DE
PHYSIQUE

EXTRAIT

RECHERCHES SUR LA THÉORIE
DES QUANTA

Par M. Louis de BROGLIE

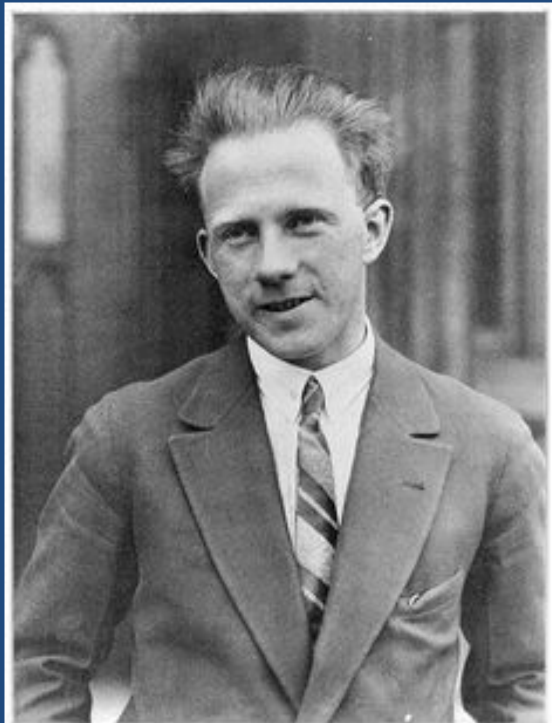
Annales de Physique — 10ᵉ Série — Tome III — Janvier-Février 1925

If matterial objects, e.g., electrons, behave in a wave-like manner then what is suitable wave equation??? Who and whom asked for that?

Six months
of the year 1925

Cast of characters

CHARACTERS



Werner Karl Heisenberg

Age: 24 years old

Athletic blond with blue eyes and charming demeanor,

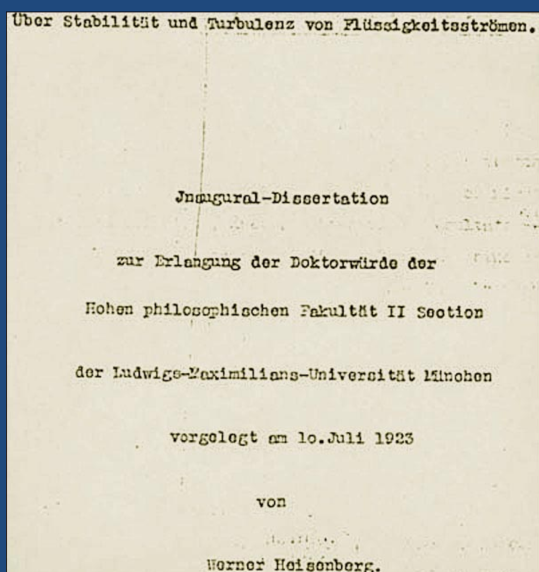
Privatdozent at the Institute of Physics at the University of Göttingen, since autumn 1923 assistant to Max Born, director of the Institute.

Born in Würzburg, descendant of an upper middle class Bavarian family, graduate of Maximilians gymnasium in Munich (classical profile);

studied at the University of Munich from 1921-23 under Arnold Sommerfeld, also earned his doctorate there (1923);

habilitated at the University of Göttingen (1924) under the supervision of Max Born.

He is almost as talented as Pauli, but much more charming in manner. And he plays the piano perfectly (Max Born).



Über Stabilität und Turbulenz von Flüssigkeitsströmen.

Inaugural-Dissertation

zur Erlangung der Doktorwürde der

Hohen philosophischen Fakultät II Section

der Ludwigs-Maximilians-Universität München

vorgelegt am 10. Juli 1923

von

Werner Heisenberg.

CHARACTERS

Max Born

Age: 43 years old

Not in the best of health, suffers from asthma

Director of the Institute of Physics at the University of Göttingen, professor of theoretical physics, head of the Department of Theoretical Physics

Born in Wrocław, studied mathematics in Wrocław, Heidelberg, Zurich, and Göttingen. In Göttingen, earned a doctorate in elasticity theory (1906) under the supervision of Carl Runge (Felix Klein declined); habilitation (on the topic of Special Theory of Relativity), planned under Minkowski, but due to Minkowski's early death, it was completed under V. Voigt in 1909.

From 1909 to 1913, served as a Privatdozent at the University of Göttingen. In 1914, received a professorship in theoretical physics in Berlin; from 1915 to 1918, served in the Imperial Army as an "acoustic localization" officer for artillery purposes. In 1919, he resigned from the Berlin professorship in favor of Max von Laue and moved to Frankfurt. In 1921, with David Hilbert's patronage, he obtained a professorship in Göttingen, jointly with his friend James Franck.

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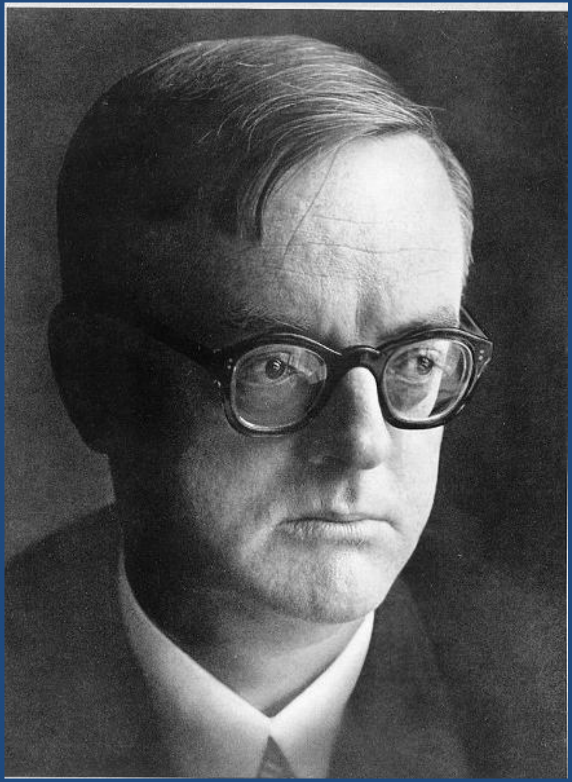
(Ernst) Pascual Jordan



Age: 22 years old

Extremely hardworking, has serious difficulty with communicating – very stutters; since autumn 1924, assistant to Max Born

Hanover native, descendant of a Spanish soldier named Pasqual Jorda, who settled in Hanover during the Napoleonic era; son of a painter – from childhood, encouraged with the help of his mother, Eva Fischer, is interested in mathematics, biology, architecture, and painting, as well as in philosophy, especially Mach's.

Studying in Hanover and Göttingen: mathematics, zoology, chemistry, and physics. In his doctoral thesis, defended in autumn 1924 under the supervision of Max Born, he criticizes Albert Einstein's hypothesis of light quanta.

"Man of all trades" – as a student, he helps Born to write an article on network dynamics for the Encyclopaedia of Mathematical Knowledge; prepares lecture notes from Courant's lectures, his work form the basis of the first volume of Courant and Hilbert's *Methods of Mathematical Physics;* co-authors with James Franck the book *Excitation by Collisions of Quantum Jumps*. Regarded by Born and Heisenberg as a mathematician.

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Arnold Johannes Wilhelm Sommerfeld

Age 57 years

Since 1906, Professor of Theoretical Physics at the University of Munich and Director of the Institute of Theoretical Physics

One of the most important, alongside Planck, Einstein, and Born, professors of theoretical physics in Germany. Teacher and mentor of Pauli and Heisenberg (and earlier Debye, and later Bethe) all being his doctoral students; creator and promoter of the old quantum theory, discoverer of the description of fine structure splitting in the hydrogen atom spectrum.Probably the best German expert in classical theoretical physics. 84 times nominated for the Nobel Prize in physics.

Thanks to Sommerfeld, Heisenberg:

-- Met in 1922 in Göttingen, Bohr and Born

-- Was saved (from Wilhelm Wien) during his doctoral exam

-- Got a position with Born

D R A M A T I S

P E R S O N A E

Wolfgang Ernst Pauli

Age 25 years old

Widely regarded as a genius, simultaneously an *enfant terrible* of German theoretical physics,

Since 1923, a Privatdozent at the University of Hamburg. Closest friend, often confidant, of Heisenberg.

A Viennese, godson of Ernst Mach, a "wonder child." He studied at the University of Munich under Sommerfeld, completing his studies in the shortest allowed time of 3 years. His doctorate (1921) concerns a singly ionized hydrogen molecule. As a senior colleague, he takes care of, on Sommerfeld's recommendation, the newly admitted student Heisenberg. Pauli's article on the theory of relativity, written in 1921 for the Encyclopedia of Mathematical Sciences (237 pages), was considered for many years a standard textbook in Special Relativity. Between 1921 and 1923, he was an assistant to Born for a year and also an assistant to Bohr in Copenhagen for a year (where he discovers the Pauli exclusion principle). He tries to avoid Göttingen – the peace of the old university town bores him excessively.

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Niels Henrik David Bohr

Age 39 years old

"Great guru" of quantum theory.

Since 1916, professor of theoretical physics at the University of Copenhagen,

Creator and from 1921 director of the Institute of Theoretical Physics (Bohr Institute) in Copenhagen,

Nobel Prize laureate for 1922.

Denmark, due to its neutrality during World War I, was a country where physicists from warring sides had the chance to meet (or rather, a country through which they could exchange ideas). Copenhagen remained such a place even after the war ended, especially following the establishment of the Bohr Institute.

Niels Bohr became an undisputed leader and authority for physicists working on quantum theory – he was also such for Heisenberg, from their first meeting in Göttingen in 1922 when young Heisenberg attended the Wolfskehl Lectures. Heisenberg considered Bohr more of a philosopher than a physicist.

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Hendrik Anthony „Hans" Kramers

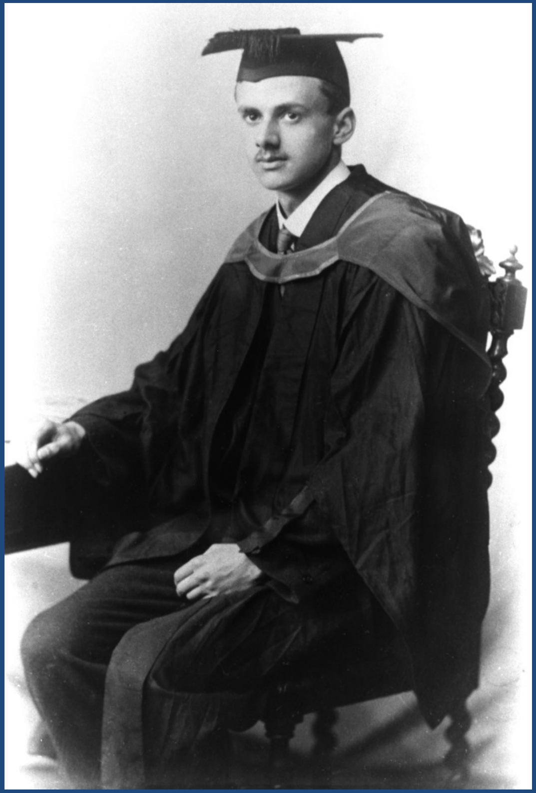
Age 31 years old
Dutch
Assistant to Niels Bohr at the Bohr Institute, skillfully in mathematics and doing long and complicated calculations

A close collaborator of Bohr for many years, in fact his doctoral student, although the formal supervisor of Kramers' doctoral dissertation in Leiden was Paul Ehrenfest. During Heisenberg's visits to Copenhagen (a short one in spring 1924 and a six-month fellowship from the Rockefeller Foundation from autumn 1924 to spring 1925), both worked together on the theory of dispersion — Heisenberg would apply the methods used in his later works.

And two (currently) unaware of their future –
one of whom, Heisenberg (maybe???), knows that it exists; concerning the second he has no idea about his existence.

Erwin Rudolf Josef Alexander Schrödinger

Age 37 years old
professor of theoretical physics at the University of Zurich



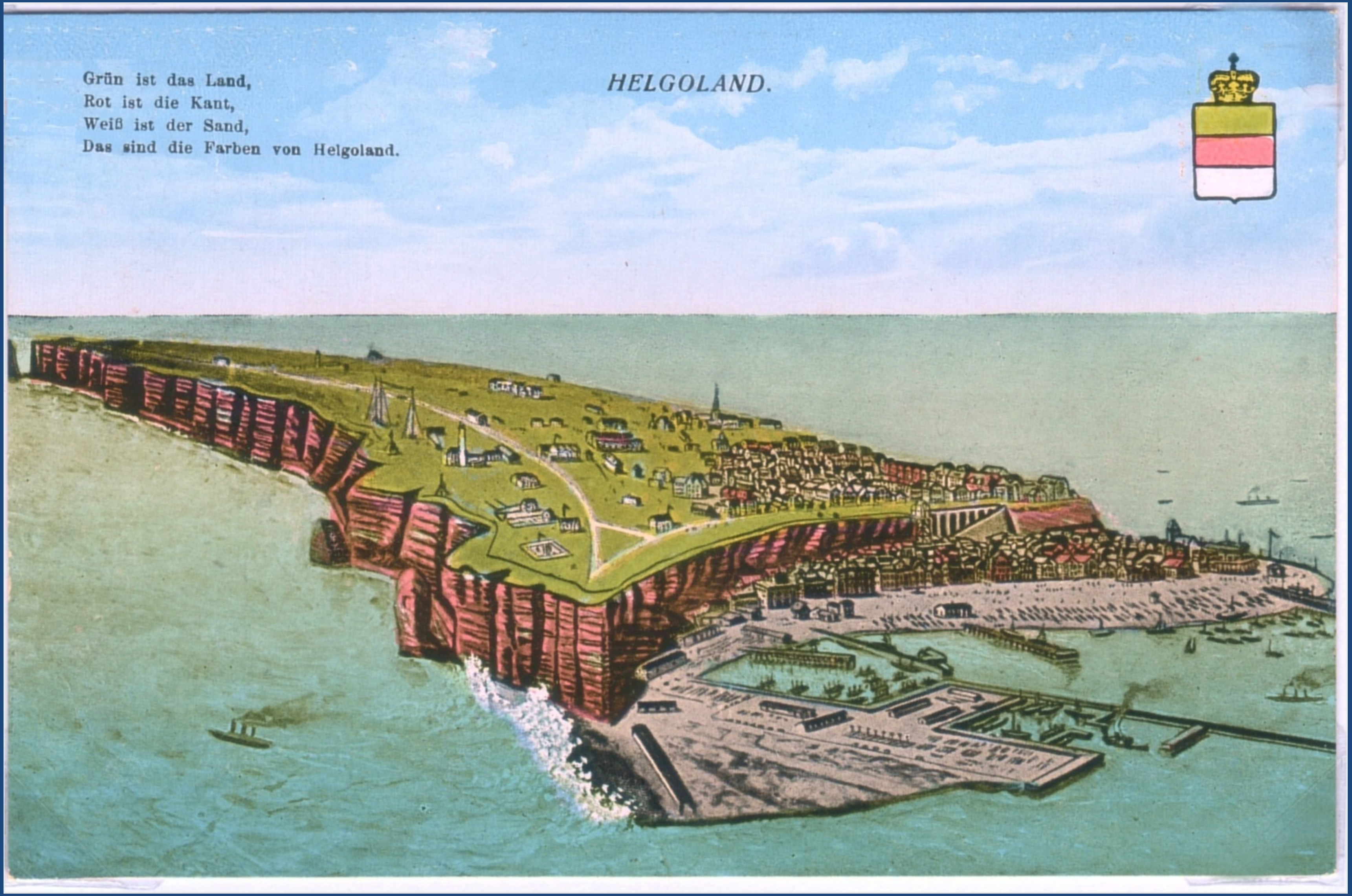
Paul Adrien Maurice Dirac

Age 22 years old
electrical engineer, but also awarded a master's degree in mathematics, doctoral student under Ralph Fowler at Cambridge

Helgoland

After returning from Copenhagen to Göttingen, Heisenberg suffers a severe hay-fever attack. Max Born, himself an allergy sufferer, understands the situation and grants his subordinate two weeks of leave. Heisenberg goes to Helgoland, a place known for its climate that beneficially affects respiratory ailments...


Helgoland
Büsum
Bremerhaven
Hamburg
Bremen
Google earth



Grun ist das Land,
Rot ist der Kant,

Weis ist der Sand,
Das sind die Farben
von Helgoland

Sea breeze, nature free of grass and flower pollens, and the tranquility of Helgoland heal Heisenberg; after a few days, he feels much better and eager to work comes back to his previous calculations. Instead of studying complicated atomic models he considers anharmonic oscillator.

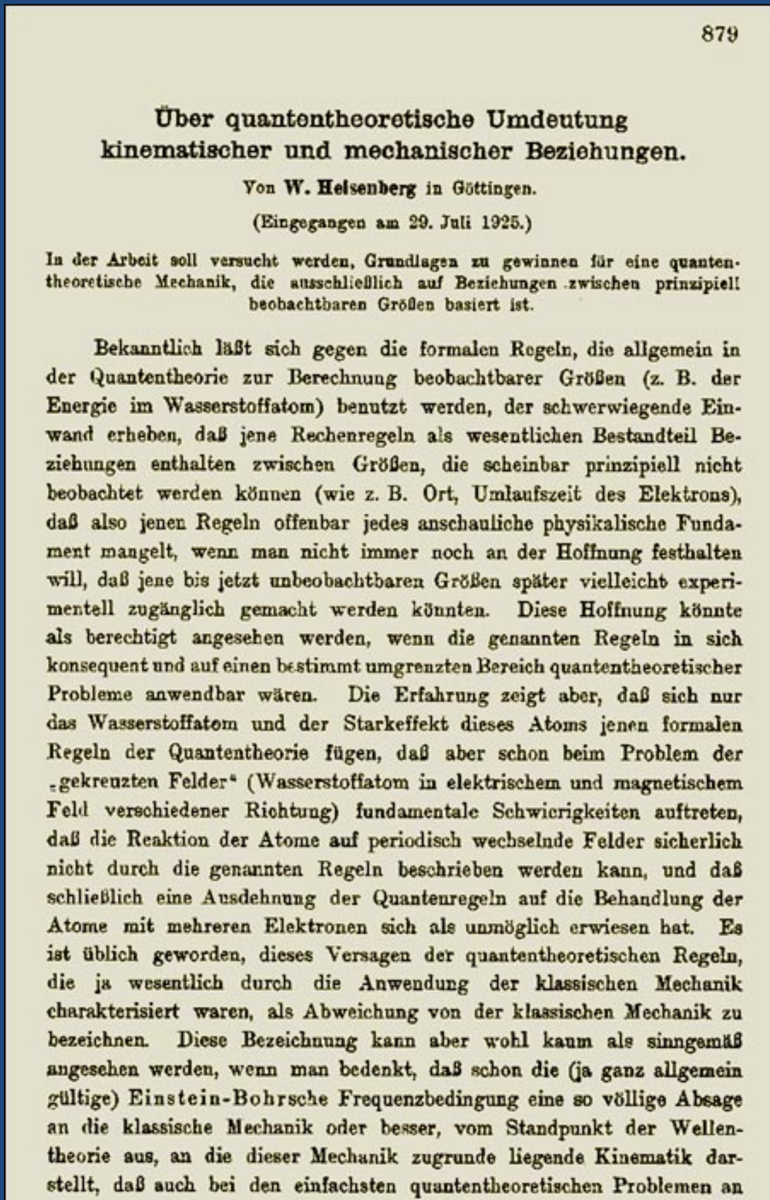
Late at night on July 15, calculations seemed to be complete and confirming his expectations. Heisenberg experienced something that he would later write about:

“As a result, it was almost three o’clock in the morning before the final result of my computations lay before me... ... I was deeply alarmed, I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structure nature had so generously spread out before me. I was far too excited to sleep and so, as a new day dawned, I made for the southern tip of the island, where I had been longing to climb a rock jutting out into the sea. I now did so without too much trouble, and waited for the sun to rise…”

From *Der Teil und das Ganze: Gespräche im Umkreis der Atomphysik*

A new dawn at Helgoland photo:iStock/Iurii Buriak

At 3 a.m. one morning in June 1925, an exhausted, allergy-ridden 23-year old climbed a rock at the edge of a small island off the coas t of Germany in the North Sea.



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Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen.

Von **W. Heisenberg** in Göttingen.

(Eingegangen am 29. Juli 1925.)

In der Arbeit soll versucht werden, Grundlagen zu gewinnen für eine quantentheoretische Mechanik, die ausschließlich auf Beziehungen zwischen prinzipiell beobachtbaren Größen basiert ist.

Bekanntlich läßt sich gegen die formalen Regeln, die allgemein in der Quantentheorie zur Berechnung beobachtbarer Größen (z. B. der Energie im Wasserstoffatom) benutzt werden, der schwerwiegende Einwand erheben, daß jene Rechenregeln als wesentlichen Bestandteil Beziehungen enthalten zwischen Größen, die scheinbar prinzipiell nicht beobachtet werden können (wie z. B. Ort, Umlaufszeit des Elektrons), daß also jenen Regeln offenbar jedes anschauliche physikalische Fundament mangelt, wenn man nicht immer noch an der Hoffnung festhalten will, daß jene bis jetzt unbeobachtbaren Größen später vielleicht experimentell zugänglich gemacht werden könnten. Diese Hoffnung könnte als berechtigt angesehen werden, wenn die genannten Regeln in sich konsequent und auf einen bestimmt umgrenzten Bereich quantentheoretischer Probleme anwendbar wären. Die Erfahrung zeigt aber, daß sich nur das Wasserstoffatom und der Starkeffekt dieses Atoms jenen formalen Regeln der Quantentheorie fügen, daß aber schon beim Problem der „gekreuzten Felder" (Wasserstoffatom in elektrischem und magnetischem Feld verschiedener Richtung) fundamentale Schwierigkeiten auftreten, daß die Reaktion der Atome auf periodisch wechselnde Felder sicherlich nicht durch die genannten Regeln beschrieben werden kann, und daß schließlich eine Ausdehnung der Quantenregeln auf die Behandlung der Atome mit mehreren Elektronen sich als unmöglich erwiesen hat. Es ist üblich geworden, dieses Versagen der quantentheoretischen Regeln, die ja wesentlich durch die Anwendung der klassischen Mechanik charakterisiert waren, als Abweichung von der klassischen Mechanik zu bezeichnen. Diese Bezeichnung kann aber wohl kaum als sinngemäß angesehen werden, wenn man bedenkt, daß schon die (ja ganz allgemein gültige) Einstein-Bohrsche Frequenzbedingung eine so völlige Absage an die klassische Mechanik oder besser, vom Standpunkt der Wellentheorie aus, an die dieser Mechanik zugrunde liegende Kinematik darstellt, daß auch bei den einfachsten quantentheoretischen Problemen an

W.Heisenberg, "On the Quantum-Theoretical Reinterpretation of Kinematic and Mechanical Relations," Zeitschrift für Physik 33 (1925): 879-893

In this work, an attempt is made to find the foundations for a theoretical quantum mechanics entirely based on relations **between quantities that are, at least in principle, observable**.

...the formal rules used by quantum theory can be **seriously criticized for containing, as a fundamental element, relations between unobservable quantities**, such as, for example**, the position of an electron in an atom or the period of its orbit**...

Chapter I – classical calculation

$$\xi_n(t) = \sum_{s=-\infty}^{\infty} \xi(n,s) = \sum_{s=-\infty}^{\infty} x(n,s)\ \exp[2\pi i \upsilon(n,s)t]$$ Standard Fourier expansion

$$\upsilon(n,s) = \upsilon_n\, s, \qquad \upsilon(n,s+s') = \upsilon_n\, s + \upsilon_n\, s'$$ Composition law for Fourier frequencies

$$\xi_n^2(t) = \sum_{s=-\infty}^{\infty} x(n,s)\ \exp[2\pi i \upsilon(n,s)t] \times \sum_{s'=-\infty}^{\infty} x(n,s')\ \exp[2\pi i \upsilon(n,s')t]$$

$$= \sum_{s'=-\infty}^{\infty} x(n,s-s')\ \exp[2\pi i \upsilon(n,s-s')t] \times \sum_{s=-\infty}^{\infty} x(n,s)\ \exp[2\pi i \upsilon(n,s')t]$$

$$= \sum_{s=-\infty}^{\infty} x^2(n,s)\ \exp[2\pi i \upsilon(n,s)t]$$

$$x^2(n,s) = \sum_{s=-\infty}^{\infty} x(n,s') \cdot x(n,s-s')$$ Multiplication law for amplitudes

Chapter 2 – „quantum theoretical" calculation (quantization)

$$v(n,s) \Rightarrow v(n,n-s)_{\mathrm{QM}}$$

the first Born's idea adopted from the paper „Zür Quantenmechanik" 2024, concerns QM frequencies

$$x(n,s) \Rightarrow x(n,n-s)_{\mathrm{QM}}$$

Heisenberg's idea, inspired by paper with Kramers on dispersion (2024), concerns QM amplitudes

$$\xi_n(t) \Rightarrow \xi_n(t)_{\mathrm{QM}} = \sum_{s=-\infty}^{\infty} x_{\mathrm{QM}}(n,n-s)\, \exp[2\pi i v_{\mathrm{QM}}(n,n-s)t]$$

$$\xi_n^2(t)_{\mathrm{QM}} = \left(\sum_{s=-\infty}^{\infty} x_{\mathrm{QM}}(n,n-s)\, \exp[2\pi i v_{\mathrm{QM}}(n,n-s)t]\right)^2$$

But what is $\xi_n(t)_{QM}$? Some quantity (Gesamtheit) which describes the quantum object

$$\boxed{v_{\mathrm{QM}}(n,n-s') + v_{QM}(n-s',n-s) = v_{\mathrm{QM}}(n,n-s)}$$

Rydberg-Ritz sum rule for frequencies is the first hint

$$= \sum_{s=-\infty}^{\infty} x^2_{\mathrm{QM}}(n,n-s)\, \exp[2\pi i v_{\mathrm{QM}}(n,n-s)t]$$

$$x^2(n,n-s)_{\mathrm{QM}} = \sum_{s'=-\infty}^{\infty} x(n,n-s')_{\mathrm{QM}} \cdot x(n-s',x-s)_{\mathrm{QM}}$$

Consistency requires new multiplication rule for „quantum amplitudes"

New multiplication rule is non-commuttative !!!

$$[xy](n, n-s)_{\mathrm{QM}} = \sum_{s'=-\infty}^{\infty} x(n, n-s')_{\mathrm{QM}} \cdot y(n-s', n-s)_{\mathrm{QM}}$$

$$\neq \sum_{s'=-\infty}^{\infty} y(n, n-s')_{\mathrm{QM}} \cdot x(n-s', n-s)_{\mathrm{QM}} = yx(n, n-s)_{\mathrm{QM}}$$

Chapter 2

$$J = \oint p\,\mathrm{d}q = \int m\dot{x}^2\,\mathrm{d}t = nh$$

In „old quantum theory" the Poincare invariant, may be used to determine initial conditions

$$J = \int_0^{1/v} m\dot{x}^2\,\mathrm{d}t = 4\pi^2 m \sum_s s v(n,s) \left| x(n,s) \right|^2 = nh$$

Calculation *à la* „old quantum theory" gives

$$4\pi^2 m \sum_s s \frac{\mathrm{d}}{\mathrm{d}n}\left(v(n,s) \left| x(n,s) \right|^2 \right) = h$$

Differentiated with respect to n, justified by analogy to action-angle variables

$$s\frac{\mathrm{d}}{\mathrm{d}n}\Phi(n,s) \Rightarrow \Phi(n+s,s)_{\mathrm{QM}} - \Phi(n,n-s)_{\mathrm{QM}}$$

The second Born's idea from „Zür Quantenmechanik" – quantization „means" replacement of differential relations by difference ones

$$8\pi^2 m \sum_{s=0}^{\infty} \left(v(n+s,n)_{\mathrm{QM}} \left| x(n+s,n)_{\mathrm{QM}} \right|^2 - v(n,n-s)_{\mathrm{QM}} \left| x(n,n-s)_{\mathrm{QM}} \right|^2 \right) = h$$

Reiche-Kuhn-Thomas rule

in contemporary notation, using eigenbasis of *H*

$$\langle k | \left[x, [H,x] \right] | k \rangle = 2 \sum_n \left| \langle k | x | n \rangle \right|^2 (E_n - E_m)$$

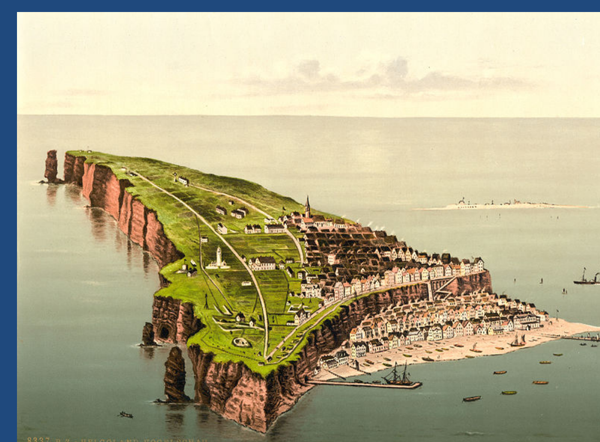
Chapter 3 – oscillator energy, does it is conserved?

This chapter constitutes about half of the work and, similarly to perturbation methods for classical Hamilton-Jacobi approach, contains quite a few rather complicated calculations. Heisenberg, starting from the classical equations of motion for an anharmonic oscillator and applying his own multiplication rule, calculates (in the second order of perturbation theory) the energy of the anharmonic oscillator, and as a "byproduct," the energy of the harmonic oscillator.

$$E = \frac{h\omega_0}{2\pi}\left(n + \frac{1}{2}\right)$$

An independent calculation of the frequency and energy allows for checking whether they satisfy Bohr's rule – this test comes out positive, which Heisenberg considers a serious argument in favor of his approach.

Probably, this very calculation for the anharmonic oscillator, carried out late in the evening on June 15th, marked Heisenberg's "moment of enlightenment" in which, through the fog of complex formulae, he perceived a completely new reality.



Heisenberg leaves Helgoland on June 18 or 19. On his return journey to Göttingen, he visits Pauli in Hamburg, with whom he discusses his idea. Pauli accepts Heisenberg's concept, which greatly pleases the latter, as we know from a letter Heisenberg sent to Pauli from Göttingen on June 21. Another letter, dated June 24, contains all the fundamental theses of the work "On the Quantum-Theoretical Reinterpretation...", as well as abbreviated calculations from chapters 1 and 2 and the energy calculations for the harmonic oscillator.

The manuscript of the work is ready by July 9 – Heisenberg sends it to Pauli in Hamburg, and on July 11 or 12, just before departing for Leiden and Cambridge, he hands the text to his boss, Max Born, requesting his evaluation and possible submission for publication (Born is the editor of Zeitschrift für Physik). Heisenberg also asks Born to consider whether and how the ideas from Helgoland can be further utilized, as his (Heisenberg's) inspiration has already been exhausted. Before leaving, Heisenberg also talks about his work at a private seminar with Hertha Spaner, where Pasqual Jordan is present.

Max Born does not read the work immediately but certainly does so before July 15 – he is fascinated! On July 15, he writes to Einstein: "...Heisenberg, my new collaborator, has written an important paper. Mystical, but certainly correct and profound..."

In the meantime — from Heisenberg ‘s letter to Pauli (9 VII 1925 r.)

I am convinced that explaining the Rydberg formula [e.g., for hydrogen] by referring to circular and elliptical orbits (according to classical geometry) makes no physical sense whatsoever. I devote all my desperate efforts to completely destroying the concept of an orbit —which cannot be observed anyway—and replacing it with a more appropriate concept.

Max Born, recalling Rosanes' lectures, immediately recognizes the matrix multiplication rule in Heisenberg's multiplication law, as well as the (matrix) relation $px - xp = -i\hbar$ for the diagonal elements, which is equivalent to the Reiche-Kuhn-Thomas rule.

On July 19, Born travels by train from Göttingen to Hanover to attend a meeting of the German Physical Society. On the way, he meets Pauli, to whom he proposes involving him in the work on Heisenberg's ideas using matrix language. Pauli's response is: "I know you are fond of difficult and complicated formalism. You only intend to spoil Heisenberg's beautiful physical ideas with your empty mathematics."

Faced with such a statement, the next day Born invites Jordan to collaborate. He himself departs for a vacation in Switzerland, while Jordan goes to his parents in Hanover, where, as he used to do, begins working intensely…

M.Born&P.Jordan, Zur Quantenmechanik, Zeit.Phys.34(1925)858-888 (27th September 1925)

1. Heisenberg multiplication is matrix multiplication.

2. Proof that $px - xp = -\mathrm{i}\hbar$ (for diagonal and off-diagonal terms!, proof goes through consistency with equations of motion), the statement that finite-dimensional matrices cannot satisfy this relation.

3. Evolution equations that we today call Heisenberg's evolution equations, written as Hamilton equations with Jordan’s "differentiation over matrices„.

4. An attempt to quantize the electromagnetic field using Heisenberg multiplication.

In mid-September, Born and Jordan return to Göttingen. After returning from England, Heisenberg departs for Copenhagen — he is kept updated on Born and Jordan's progress through letters. The three of them intensively engage in the "matrix program," which they carry out at the end of September and in October. On October 28th, Born leaves for the United States, leaving the final editing of the text to Heisenberg and Jordan. On November 16th, the *Dreimannerarbeit* (Three-Man Paper) is completed. Paper is 68 pages long and contains:

1. Generalization of the formalism to a greater number of degrees of freedom, also gives the full form of canonical commutation rules
2. Observation that the matrices been used (including the one corresponding to the Hamiltonian) are Hermitean, and conclusions drawn from this fact, first of all real eigenvalues
3. Utilization of Hermiticity in the construction of perturbation theory
4. Analysis of cases with a continuous spectrum
5. Analysis of the properties of angular momentum

With submitting „Dreimannerarbeit” for publication

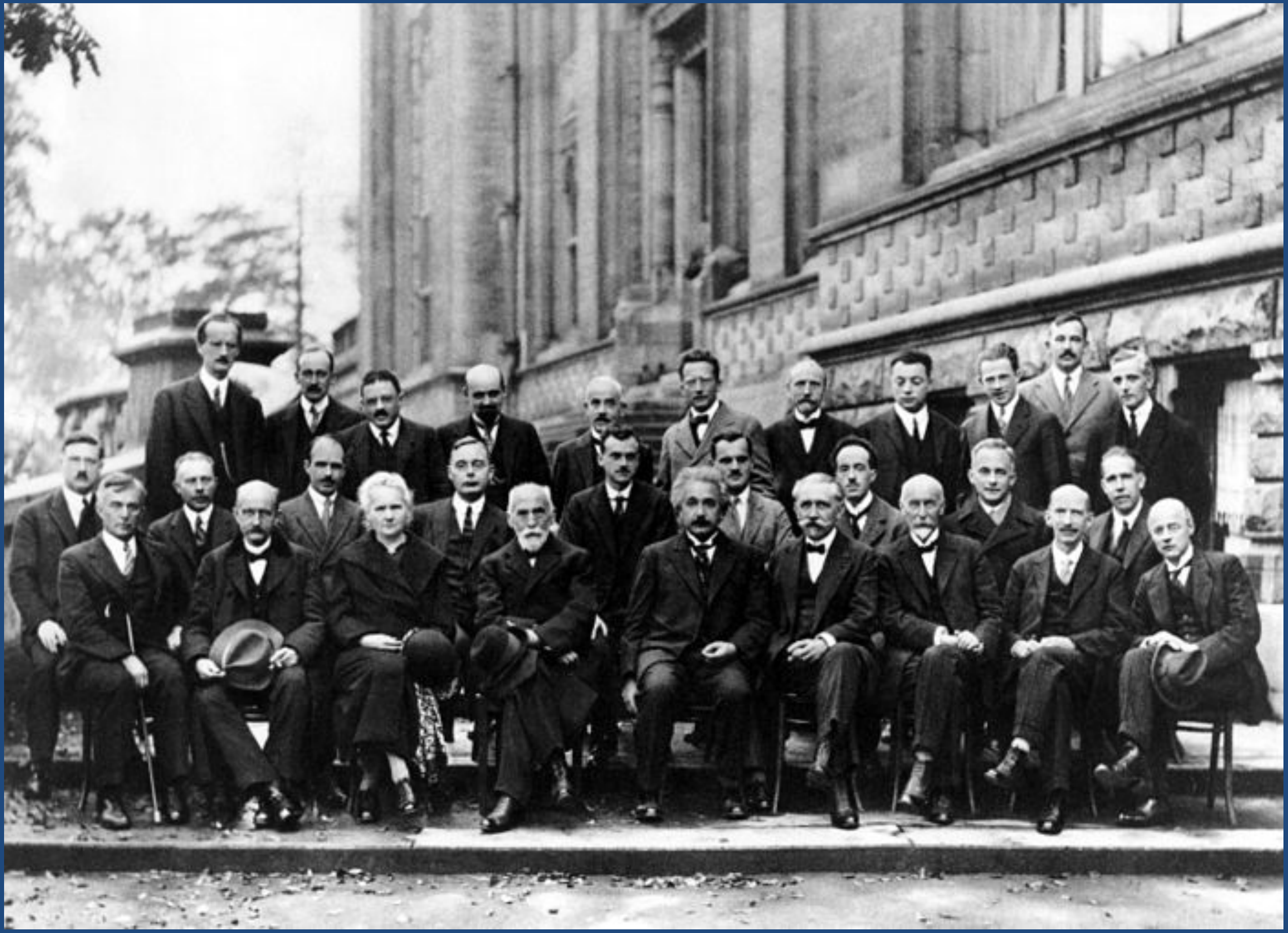
M.Born, W.Heisenberg & P.Jordan, Zur Quantenmechanik II, Zeit.Phys.35(1926)557-615

the matrix mechanics is complete. Its formulation and preparing papers for publication took the authors 6 months. Additionally, by the end of the year, Pauli demonstrated the Balmer formula using Heisenberg's method

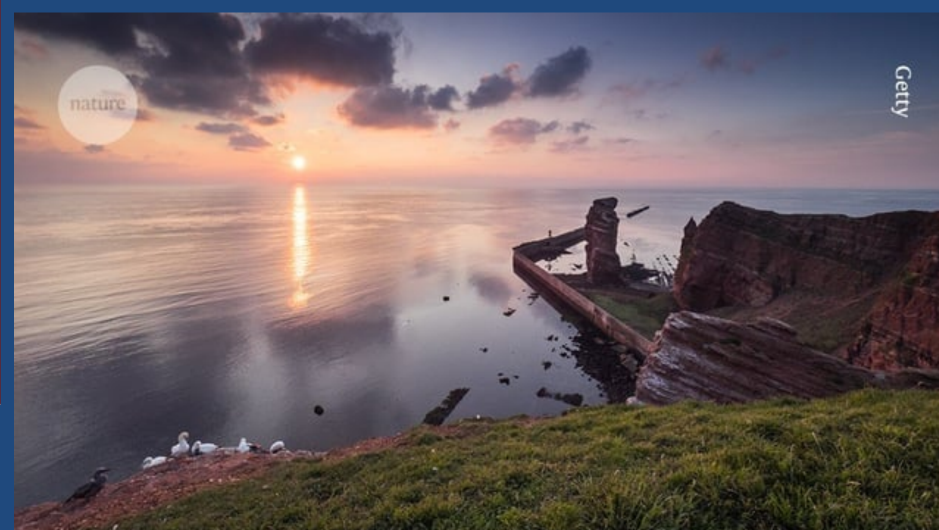
But the near future belonged to someone else…

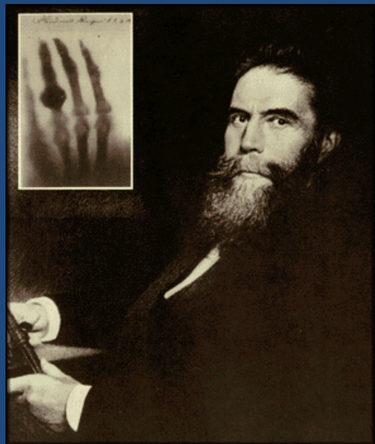
Stockholm, December 2033, Nobel prize winners for 2032 and 2033

V-th Solvay Congress, Brussels, 1927,
the most important group photo ever made

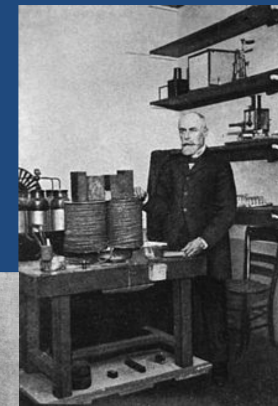


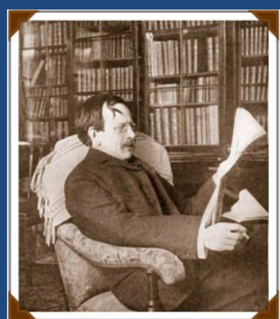
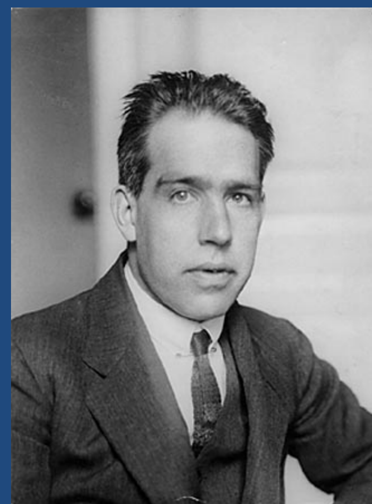
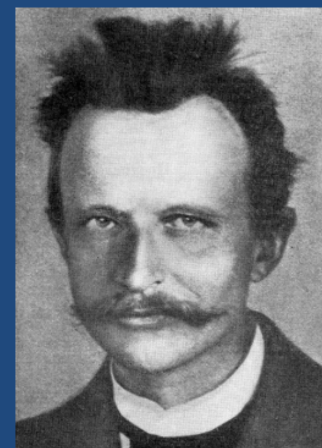
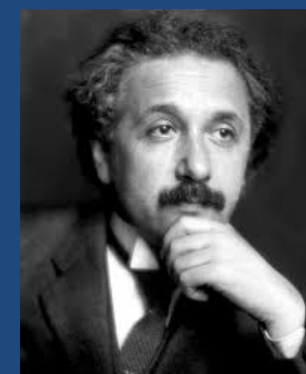
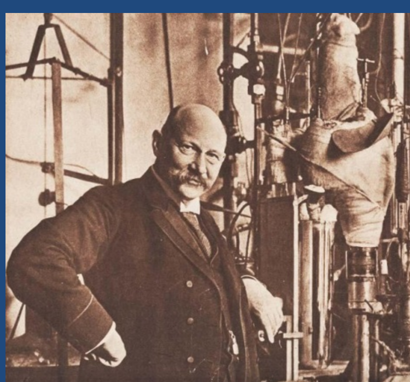
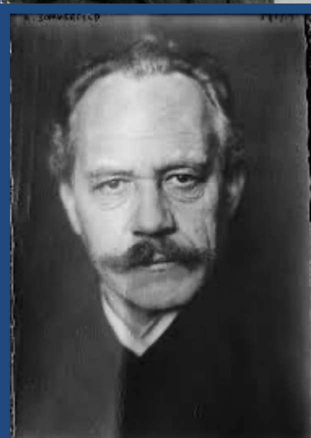
2025, the centenary year of quantum mechanics was proclaimed by United Nations „The International Year of Quantum Mechanics”





Thanks for your attention




Thanks for your attention

Thanks for your attention

Max Jammer: „*The conceptual development of quantum mechanics*" (Mc Graw-Hill Book Company, 1985)
B.L. van der Waerden: „*Sources of quantum mechanics*" (North Holland, 1967)
Jagdish Mehra & Helmut Rechenberg: „*Historical development of quantum theory 1-6*" (Springer, 2001)
David C.Cassidy: „*Beyond uncertainty; Heisenberg Quantum Physics and the bomb*" (Bellevue, 2009)
Sheilla Jones: „*The quantum ten*" (Thomas Allen, 2008)

Dlaczego Pascual Jordan nie dostał Nagrody Nobla?

Miał ogromny, w wielu miejscach kluczowy, udział w powstaniu prac „Zur Quantenmechanik I, II"; należy uważać go za prekursora kwantowej teorii pola, ale…

-- w 1933 wstąpił do NSDAP (i nawet do SA), pisał dla służb III-ciej Rzeszy raporty z konferencji międzynarodowych w których uczestniczył; w 1939 roku wstąpił o Luftwaffe, ale…

-- nigdy nie atakował swoich kolegów i współpracowników pochodzenia żydowskiego, próbował bronić stworzonej przez nich fizyki w przeciwieństwie do Lenarda, Starka i innych ; stanowisko profesora otrzymał w (dość prowincjonalnym) Rostocku, a w Peenemunde zajmował się przygotowywaniem prognoz pogody; nie wszedł też do niemieckiego programu atomowego (kierowanego przez Heisenberga)…

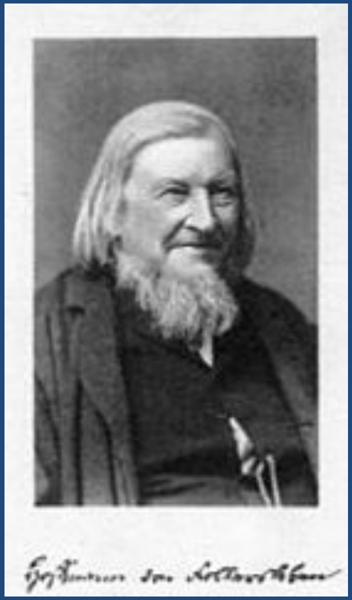
-- a może dlatego, że w połowie lat 30-tych odszedł od fizyki kwantowej i zajął się kosmologią, biologią teoretyczną, a nawet geologią…

Moment olśnienia na Helgoland
90 lat mechaniki kwantowej

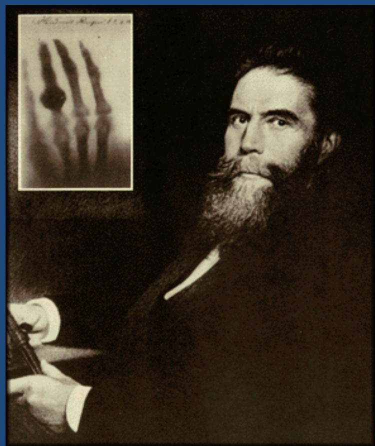
Andrzej Horzela

Zakład Fizyki Matematycznej

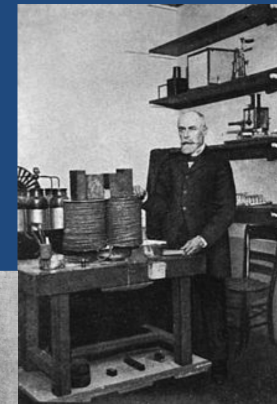
i Astrofizyki Teoretycznej IFJ PAN

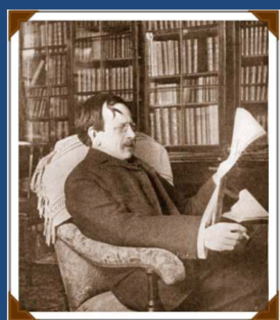


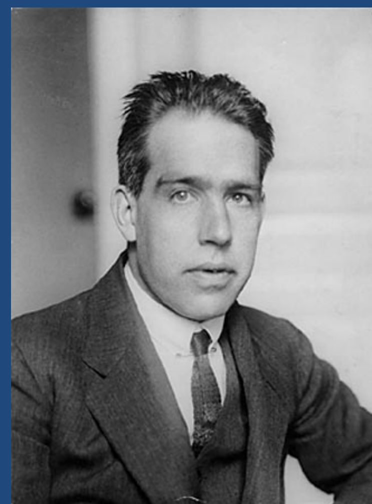
August Heinrich Hoffman
von Fallersleben

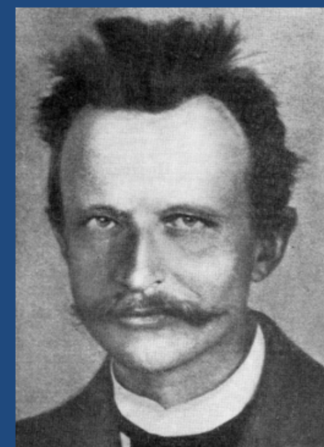


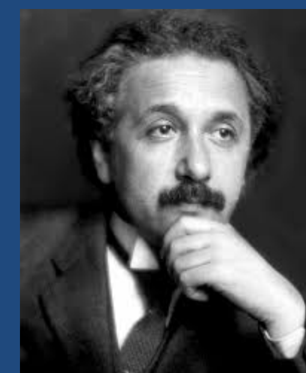
Belle Époque
Golden Age

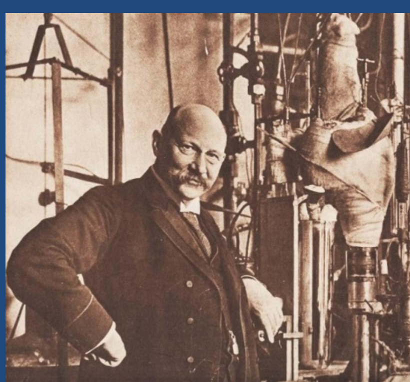












28 czerwca 1914, kilka minut przed godziną 11-tą, Sarajevo, Bośnia

I-sza wojna światowa, zwana Wielką Wojną, trwa 4 lata 3 miesiące i 14 dni. W wyniku działań wojennych ginie ok. 16 milionów ludzi, nie licząc trudnej do oszacowania liczby ofiar na „głębokich tyłach" oraz ofiar pandemii hiszpanki.

Ofiarą wojny pada też rozkwit fizyki Belle Époque, szczęśliwie „***nowa fizyka***" nie ma (jeszcze!!!) znaczenia militarnego i udaje jej się przetrwać stosunkowo nieźle.
Nie odnosi się to wszakże do wszystkich nauk…

Synteza amoniaku z wodoru i azotu atmosferycznego

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3 \quad (\Delta H = -92.4\ \mathrm{kJ/mol})$$

Fritz Haber

„Gdy panuje pokój uczony należy do całego świata, lecz gdy jest wojna należy do swojej Ojczyzny”

Około połowy białek obecnych w organiźmie ludzkim zawiera azot, który „przeszedł” przez reakcję Habera

II-ga bitwa pod Ypres, 22 kwietnia 1915, ok. 17-tej

Na froncie

„Für Kaiser und Vaterland”

Heisenberg senior, z synami Erwinem i Wernerem, 1915

Erwin Schrödinger, front włoski, 1915

Max Born, ok.1915

Wojna zmieniła obraz Europy – upadły trzy cesarstwa, wiele narodów i państw odzyskało suwerenność. Po Kongresie Wersalskim sytuacja polityczna, społeczna i ekonomiczna, szczególnie państw pokonanych oraz „nowych” krajów Europy Środkowej i Wschodniej była bardzo trudna. Stabilizacja i powolna poprawa, z wieloma zawirowaniami, następuje od ok. roku 1923.

Sir Arthur S. Eddington

Także fizyka zaczyna powracać na tory „przedwojennego” rozwoju - ekspedycja Eddingtona (1919) potwierdza przewidywania OTW (*Solar ecclipse of 29th May 1919*); model Bohra i wyrosła z niego stara teoria kwantów Bohra-Sommerfelda ma coraz więcej problemów w konfrontacji z nowymi danymi doświadczalnymi – nie potrafi satysfakcjonująco opisać atomów wieloelektronowych, molekuł, a nawet efektu Zeemana dla wodoru…

Pojawiają się nowe pytania i nowi ludzie

A. Sommerfeld i N. Bohr


nature
Getty

Czerwiec 1925