# Philosophical consequences of Quantum Mechanics

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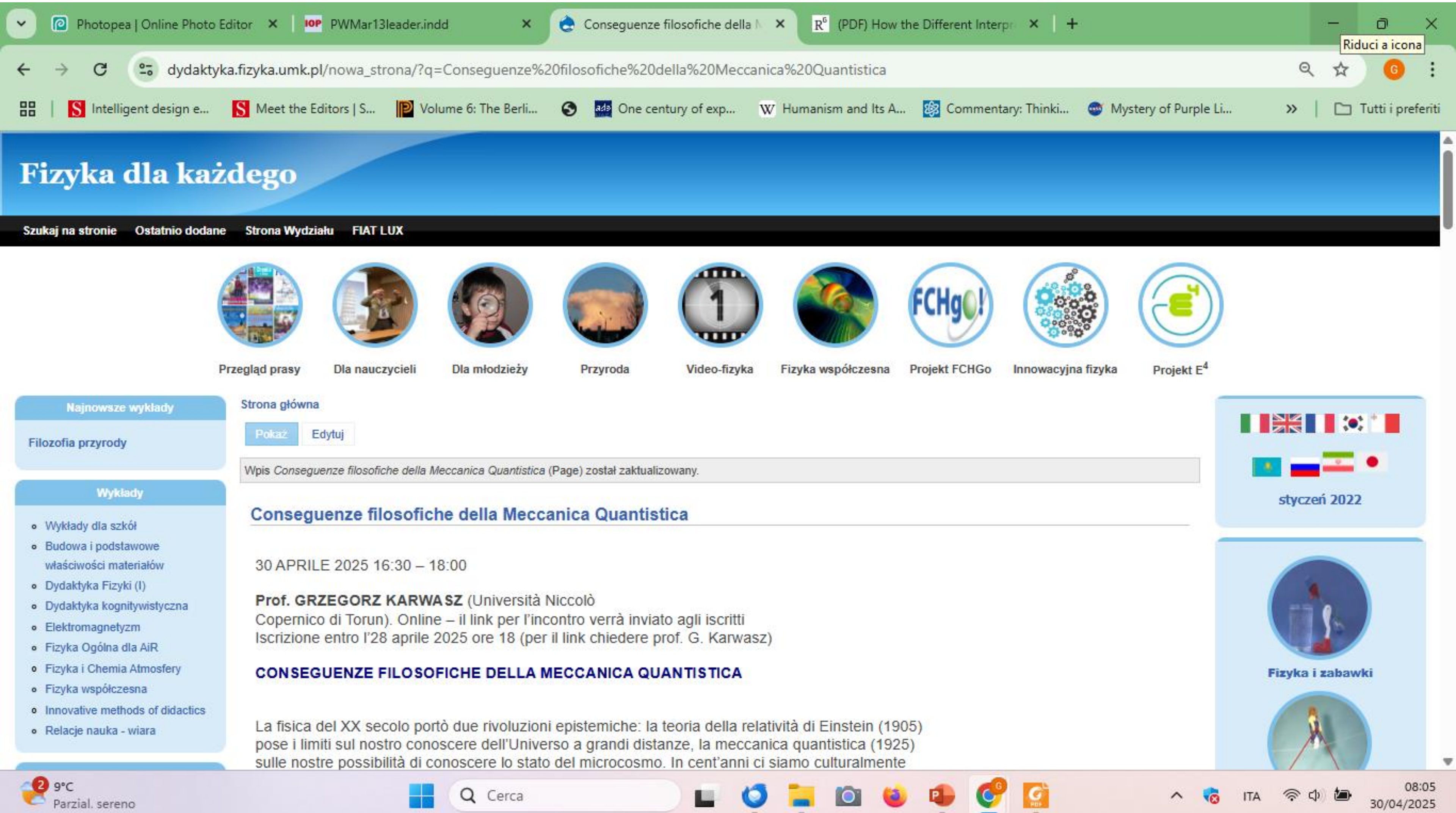


# Abstract

PHILOSOPHICAL CONSEQUENCES OF QUANTUM MECHANICS

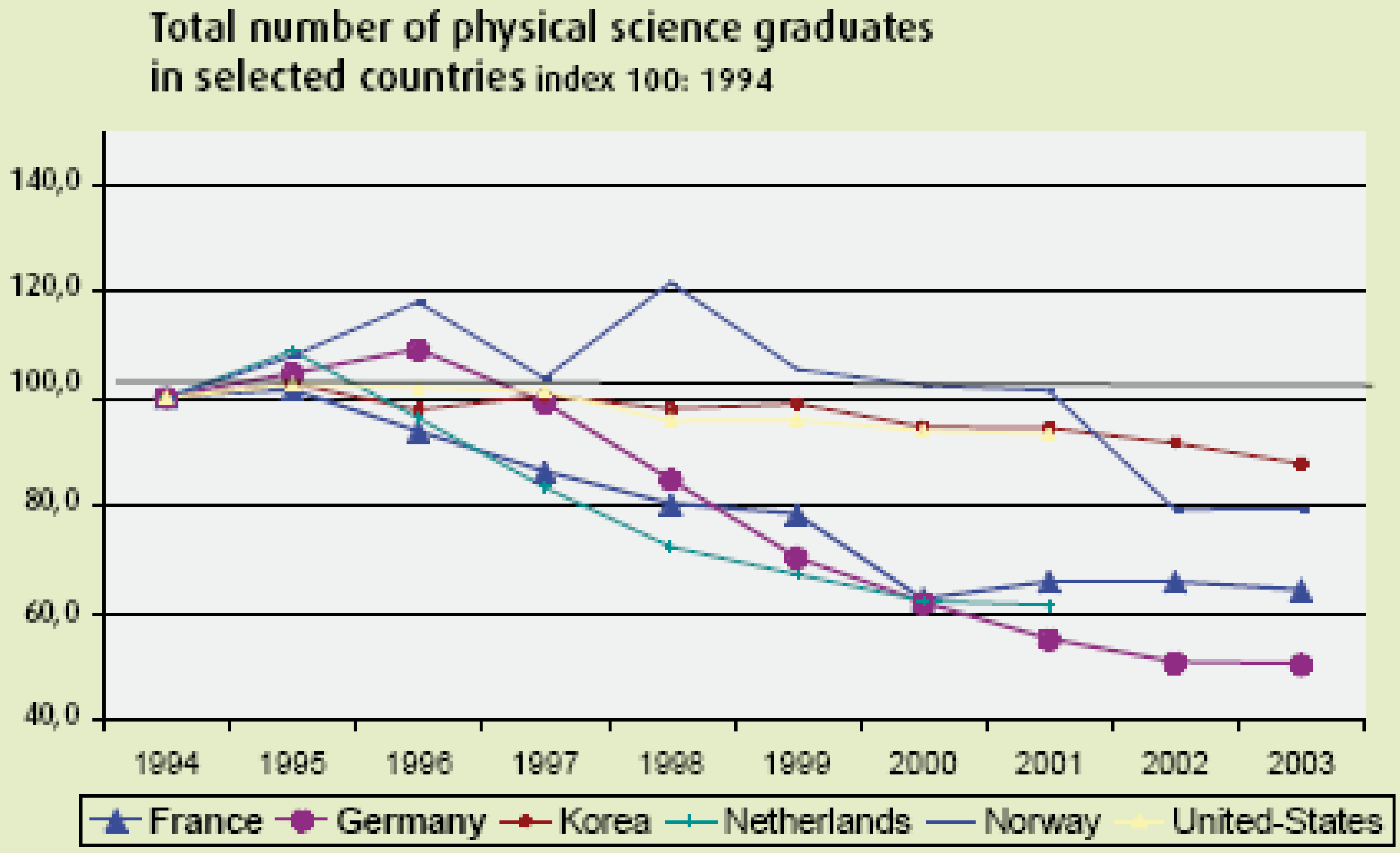
Twentieth-century physics brought two epistemic revolutions: Einstein's theory of relativity (1905) placed limits on our knowledge of the Universe at great distances, quantum mechanics (1925) on our possibilities of knowing the state of the microcosm. In a hundred years we have culturally become accustomed to this situation of uncertainty. Indeed, Heisenberg's principle of indeterminacy is recalled in various articles not only on physics, but also on philosophy and even theology. Not always in a sensible way.

It seems, however, that we will soon face other challenges. The so-called Einstein-Podolsky-Rosen paradox (1935), confirmed with the Nobel Prize for the experimental works of Aspect, Clauser and Zeilinger (2022), binds the microstates of two objects (e.g. photons) at any distance. From the theoretical works comes a disturbing result: between free will, the principle of causality and the location of events we have to abandon one of three. The difficult choice is yours!

# Outline

1. Teaching physics in Poland
2. „What Heisenberg’s principle is?”
3. Lev Pitaevskij: “Do we really need to know everything?”
4. Galileo: “God speaks to us in two way”
5. Einstein: “Subtle is the Lord”
6. GK: “Explain as simple as possible, and even simpler”
7. A. Raczynski: “Quantum physics still awaits its Copernicus”

# EU (2007) „Rocards' Report"




EU: 50% fall in 10 years

ISBN – 978-92-79-05659-8
ISSN 1018-5593



*Printed in Belgium*

# Maturity exam in physics, 2022

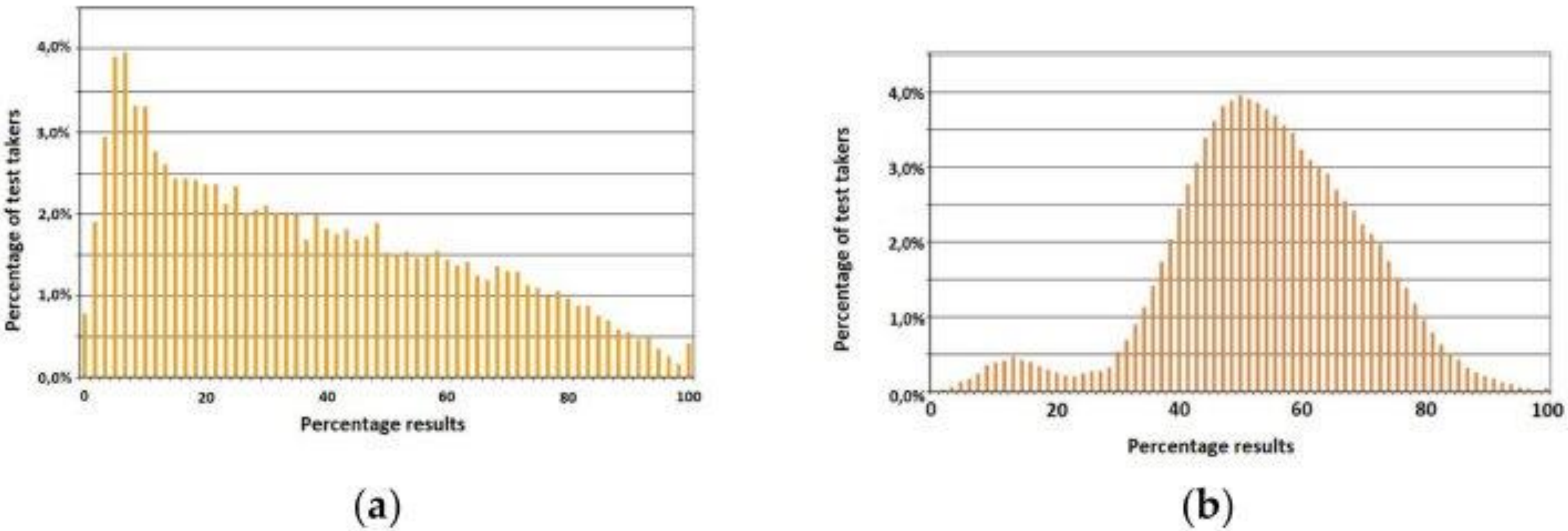



**Figure 1.** Why teaching physics requires new approaches. Results of the maturity exam in Poland in 2022. (**a**) Physics. (**b**) Polish language and literature. The "sufficiency" threshold in Poland is 30%. Source: Report of Polish Ministry of Education [27]. Reproduced with permission.

(a) Physics (b) Polish language and literature
Zh. Akimkhanova, K. Turekhanova, G. Karwasz, *Education sciences,* 2023

«Houston, we have a problem»

# Heisenberg's principle and God of gaps

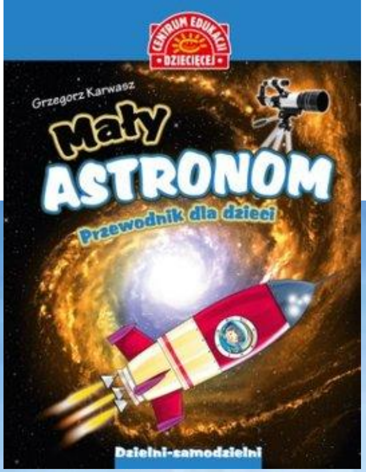
## THEOLOGY AND THE HEISENBERG UNCERTAINTY PRINCIPLE

Christopher Mooney (Fairfield University) presented a paper entitled "Theology and the Heisenberg Uncertainty Principle." The paper was divided into three sections that dealt with (a) the substance of the principle, (b) its meaning for science, and (c) its meaning for theology. Following the presentation participants engaged the speaker with probing questions and additional insights.

A problem arose, however, when scientists tried to measure with precision the location and velocity (direction and speed) of subatomic particles. Unlike what happens in the macroworld, the measuring process itself creates a disturbance so that a total fix on the whereabouts and dynamism of quanta is not possible. In 1927 Werner Heisenberg summed up the state of affairs in his famous uncertainty principle which states: the more accurately one knows by repeated experiment the position of any subatomic particle, the less accurately one knows its velocity, and vice versa. The quantum state of a subatomic particle (its position and velocity) can thus never be known or predicted with certainty.

Lizabeth Johnson, Fordham University, CTSA Proceedings, 47-1992
https://ejournals.bc.edu/index.php/ctsa/article/download/3763/3337/6771

# Why do we need a calendar?




## Do czego służy kalendarz?

Każdy dziś wie, co to jest kalendarz. Ale przed wiekami ludzie go nie znali. Pradawny człowiek, który żył w jaskiniach, musiał przewidzieć porę budzenia się niedźwiedzi z zimowego snu i wpływania do rzek wielkich łososi. Nie było to łatwe, ale jednak wiedział, którego dnia wyruszyć na łowy na jelenie, a kiedy lepiej schronić się przed zamiecią śnieżną.

### Od Stonehenge do Mezopotamii i Egiptu

Wszyscy potrafimy zaobserwować, że zimą dzień jest krótszy, tylko jak stwierdzić bez kalendarza, kiedy nadchodzi ta pora roku? Wiosną dzień się wydłuża, ale znów nie dałoby się ustalić, od którego momentu, gdyby nie było kalendarza.
Aby pamiętać, kiedy zaczyna się lato, 5 tysięcy lat temu ustawiono w kole ogromne głazy. Stoją one do dziś w Anglii i nazywają się Stonehenge – czyli kamienny krąg. Jest tam 5 wielkich, podwójnych głazów, które wyznaczały dni tygodnia oraz 16 mniejszych oznaczających miesiące.
Kiedy w Anglii zbudowano ten kamienny krąg, w innej części świata, pustynnej Mezopotamii (dziś jest to Irak), wzniesiono już całe miasta i potężne, wysokie wieże nazywane zigguratami. Nie wiemy, do czego służyły. Być może do patrzenia w niebo. Obserwując gwiazdy, można było znacznie dokładniej przygotować się na początek wiosny i jesieni.
Już 3000 lat temu kapłani w Egipcie potrafili przewidzieć zaćmienie Słońca – zjawisko polegające na tym, że nagle w dzień robi się zupełnie ciemno, ptaki chowają się do gniazd i zaczyna wiać zimny wicher. Z przepowiedniami kapłanów musieli się liczyć nawet potężni władcy – faraonowie. Ich grobowce w piramidach budowano w taki sposób, aby po śmierci mogli „patrzeć" na gwiazdy.

**WARTO WIEDZIEĆ**

*Chińczycy, którzy podobnie jak Egipcjanie od tysiącleci obserwowali niebo, świętują nowy rok w lutym, ale co roku w nieco innym dniu. Również Arabowie mają inny kalendarz niż my. Może to i lepiej, bo kto podróżuje, może częściej świętować nadejście nowego roku.*

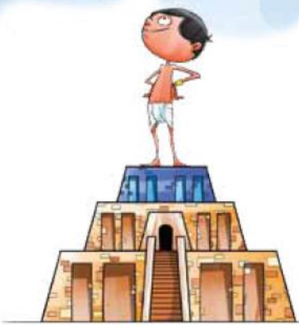
Wielkie kamienne głazy niedaleko miasta Salisbury w Anglii, ustawione tam 5000 lat temu, służyły, zapewne, jako prehistoryczny kalendarz – mały „celownik" wskazywał wschód Słońca w najdłuższym dniu roku.

### Kalendarz juliański

Przez tysiące lat kalendarz był znany tylko nielicznym osobom. Nie używali go nawet starożytni Grecy. Dopiero władca starożytnego Rzymu, Juliusz Cezar, w 46 roku przed naszą erą ogłosił kalendarz składający się z 12 miesięcy. Kolejne miesiące miały w nim na przemian 31 lub 30 dni. Tylko lipiec i sierpień, choć następują po sobie, liczą ich 31, kosztem nieszczęśliwego chyba, bo zimnego lutego, który ma ich 28.
Kalendarz Juliusza Cezara był jednak bardziej skomplikowany. Aby wiosna wypadała zawsze tego samego dnia, co cztery lata luty miał 29 dni. Taki rok nazywamy **rokiem przestępnym**. Był nim 2012, jest 2016, będzie 2020.

### Kalendarz gregoriański

Kalendarz juliański był używany przez półtora tysiąca lat. Okazało się jednak, że nie jest dokładny. W ciągu tego czasu wiosna „przesunęła się" o 11 dni. Był to duży problem dla Kościoła, bo Wielkanoc powinna wypadać na wiosnę, a nie zimą. Papieże poprosili więc uczonych, aby obliczyli dokładniej, ile dni musi mieć rok. Pomagał w tych pracach



również polski astronom Mikołaj Kopernik (przeczytasz o nim w rozdziale „Od Ptolemeusza do Kopernika"). Okazało się, że wystarczy, aby co setny rok nie był przestępny.
Zmianę zarządził papież Grzegorz XIII, dlatego ten nowy kalendarz nazywamy gregoriańskim. Zdarzyło się to w 1582 roku, który był bardzo dziwny – aby wyrównać opóźnienie, „pominięto" w nim 10 dni, od 5 do 14 października. Kalendarz gregoriański jest używany do dziś. My również z niego korzystamy.

G. Karwasz, Astronomy for Kids, Publicat, 2022

# In summer, lay down on a blanket…

## Gdzie zobaczysz gwiazdy?

Aby oglądać gwiazdy, nie trzeba udawać się w specjalne miejsce. Najjaśniejsze z nich widać nawet w zadymionym mieście. Jednak by naprawdę podziwiać rozgwieżdżone niebo, warto wyjechać za miasto: w góry, nad jezioro, może nawet na pustynię.

Niebo najlepiej oglądać w zupełnym mroku. Namów rodziców, abyście latem wyjechali nad jezioro, gdzie nie ma lamp ani świateł domów. W ciepłą noc połóż się na kocu i spójrz na niebo. Zaczynamy naszą astronomiczną przygodę!

### Namów rodziców...

Gwiazdy są bardzo daleko – ich światło, które oglądamy, podróżowało do nas dziesiątki, setki, a czasem miliony lat. Aż dziw, że ludzkie oko je widzi. Jednak nie ta odległość jest główną przeszkodą, ale zakłócenia, jakie człowiek sam wytwarza. W wielkich miastach, a nawet mniejszych miejscowościach, jest tak wiele latarni ulicznych, że trudno zobaczyć gwiazdy.
Aby je dostrzec, nasze oko musi najpierw przyzwyczaić się do ciemności. Zajmuje to 20 minut.

### Wielki Wóz

Najpierw popatrz na północ, to jest tam, gdzie nigdy nie świeci Słońce. Siedem gwiazd jest ułożonych jak wóz z czterema kołami i dyszlem po lewej stronie. To Wielki Wóz. Mały Wóz, też złożony z siedmiu gwiazd, znajduje się nad nim. Wyciągnij przed siebie rękę, rozstaw palce i zmierz odległość między tylnymi kołami Wielkiego Wozu. A teraz popatrz w górę, ponad jego tylne koła – pięć odległości nad nimi znajdziesz inną jasną gwiazdę: to Gwiazda Polarna, która wskazuje drogę żeglarzom. Niebo, a wraz z nim wszystkie gwiazdy, cały czas kręci się nad głową. Tylko Gwiazda Polarna nie zmienia miejsca – jest to tak zwana gwiazda biegunowa.

### Łabędź, Lutnia

Po drugiej stronie Gwiazdy Polarnej, naprzeciw Wielkiego Wozu, zobaczysz sześć gwiazd tworzących jakby krzyż – jedna z nich, na czubku, świeci bardzo jasno. Jeśli przyjrzysz się bliżej, to na ramionach tego krzyża zauważysz jeszcze kilka gwiazd – teraz to już nie jest krzyż, ale raczej ptak z rozpiętymi skrzydłami, przypominający łabędzia! Tak też nazwali te gwiazdy Grecy: Łabędź.

# Copernicus: “and what could be more beautiful than the sky?”

„Nebulosa” di Barnard (costellazione di Orione)

# *De Revolutionibus* (1543)


1473 (Toruń)
-1543 (Frombork)

Among the many and varied studies of letters and arts, with which the minds of men are nourished, I think we should especially embrace—and cultivate with the greatest love—those which deal with the most beautiful and most worthy of knowledge. That is, those which treat of the divine revolutions of the world and of the course, of the magnitudes, of the distances, of the rising and setting of the stars and of the causes of the other celestial phenomena, and which, finally, explain the whole order.

For what is more beautiful than heaven, which contains all beautiful things? Which, moreover, the names Caelum and Mundus themselves indicate, the former referring to purity and ornamentation, the latter to chiselling. Most philosophers, precisely because of his exceptional beauty, have called him visible God.

https://www.saveriocantone.net/profcantone/fisica/pdf/copernico_DE_RIVOLUTIONIBUS_sottolineato.pdf
Nicolao Copernico, *Opere*, UTET, 1979

# Nicolao Copernico – un bravo (?) studente

Cracovia (1492-1496)
Cattedrale SS. Maria
Canonic law

Bologna (1496-1500)
Torre degli Asinelli
Civic law

Padova (1501-1503)
Basilica di S. Antonio
Medicine

Doctor in canonic law, Ferrara 30/05/1503

# Look into sky: Moon and planets are moving!

Jupiter, Venus and Moon
Bamberg, Germany, 25.03.2012

Trento, Italy, 26.03.

# Ptolemeus (151-212): Sun and stars are moving

Katedra Wniebowzięcia NMP w Toruniu

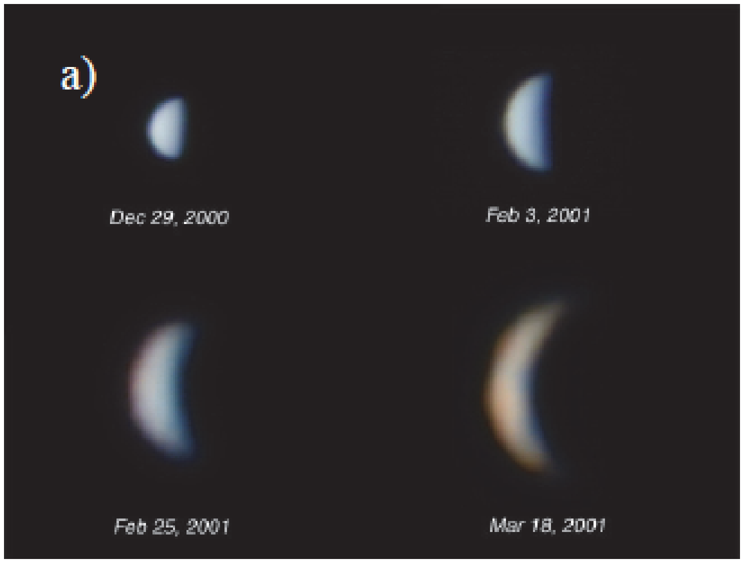
# Ptolemeus (151-212): Sun and stars are moving

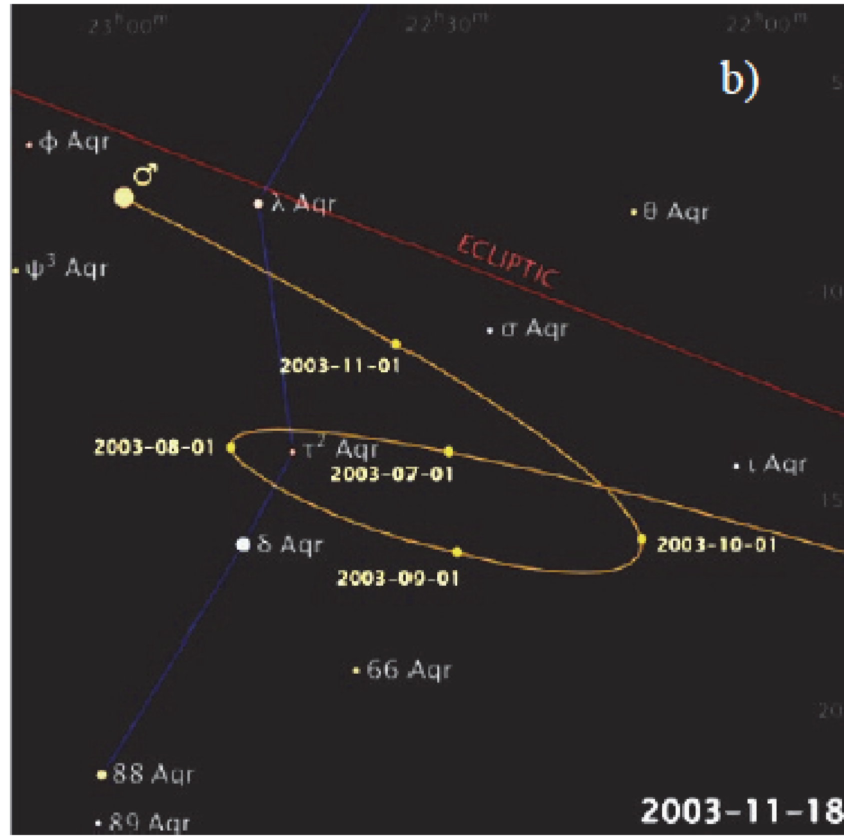
Katedra Wniebowzięcia NMP w Toruniu

# Ptolemeus (151-212): Sun and stars are moving

Katedra Wniebowzięcia NMP w Toruniu

# Planets, or wandering stars

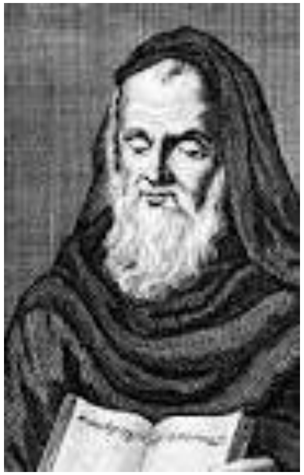



**Fot. 4.14.** Dwa dowody na prawdziwość teorii Kopernika: **(a)** fazy Wenus[14], zaobserwowane po raz pierwszy przez Galileusza;
**(b)** zapętlona (jeśli widziana z Ziemi) trajektoria Marsa na niebie[15].

**4.7. Nasze najbliższe kosmiczne sąsiedztwo – Układ Słoneczny**

G. Karwasz, Toruń's ex-book, 2020



# Roger Bacon (1197): „Devil induced this error!”

I will now discuss a problem which should become the duty of the Church to solve, which introduces danger and chaos and should no longer be tolerated. What I am aiming for is to improve the calendar that the Church uses.

And since the true equinox is constantly shifting, so that about the year 1481 will be the V Idi Martii (March 5), and so moving further in the direction to the beginning of March and beyond March ... it is necessary that Easter should be about the beginning of March or in February. And this is absolutely impossible, because [...] the real beginning of Lent of the Forty Days will move forward, and in this way, in the real season of Lent, Christians will eat meat, which is the most absurd.

These things are terrible in themselves, and all the more so they are extremely stupid and worthy of ridicule, for it was probably the devil himself who caused this to happen to the Church as a result of his *ignorance and carelessness.*

(Roger Bacon, Major Treaty, 1197, s. 451)

# Principle of relativity

"So we leave to the natural philosophers the question of whether the world is finite or infinite. It is enough for us to know that the Earth is closed by poles and a spherical surface. Why, then, do we hesitate to admit to him a movement which corresponds to his own nature, rather than accept the movement of the whole world, the limits of which we do not and cannot know?

Why not say clearly that this phenomenon of daily rotation is something evident in the sky and in the reality on earth, and that the question is just as Aeneas expressed it when he said in Virgil: "We move away from the port, lands and cities recede"?

Because when a ship sails on a calm sea, everything outside, they see people sailing on it, as if it were moving like the movements of a ship, and on the contrary, it seems to them that they themselves are standing still with everything that is with them.

The same can undoubtedly be true of the Earth's movement, and give the impression that the whole world is spinning."

[1] Ci allontaniamo dal porto, e terre e città retrocedono

https://ilcrepuscolo.altervista.org/php5/index.php?title=Biblioteca:Virgilio,_Eneide,_Libro_III

# Justification of the Earth's **threefold** motion

“In general, it must be assumed that it is threefold. The first, which the Greeks, as we have said, call nychtomerinos, that is, the night-day movement, is a rotation peculiar to day and night, taking place around the earth's axis from west to east, so that one has the impression that the world is turning in the opposite direction.

The second is the annual movement of the center of the earth, which circles the zodiac around the sun, also from west to east, that is, following the order of the signs of the game, running – as we have said – between Venus and Mars with everything that belongs to the earth [flowers, houses, people].

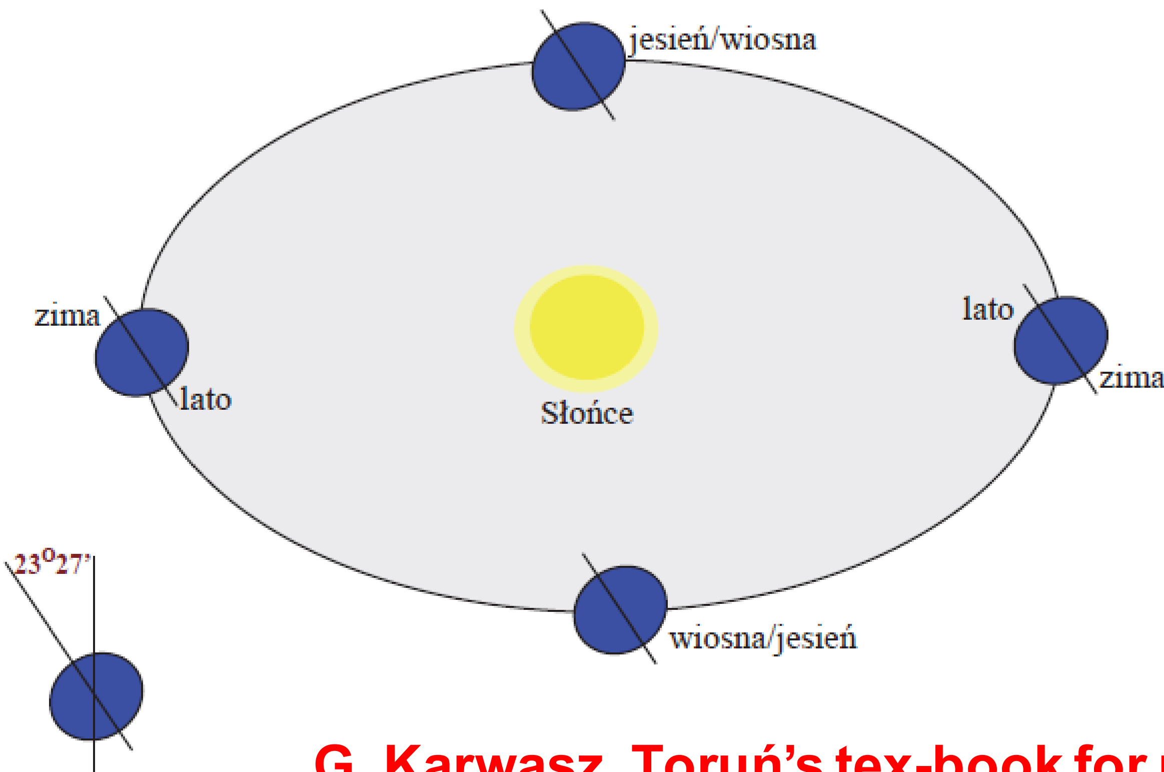
In turn, therefore, the inclination movement goes as the third movement of the Earth, also with a one-year period, but contrary to the order of the zodiac, that is, going in the opposite direction from the movement of the center of the Earth. Thus, because the two motions <u>are *almost equal* and at the same time opposite</u>, the axis of the earth and the greatest parallel on it, the equator, are turned almost constantly to one and the same side of the world, as if they were motionless. (p.24)”

He calculated the period of the <u>precession</u> as 28512 years: i.e. the correction of the Julis calendar is 3 days every 400 years,

# The Four Seasons

## 4.5. Cztery pory roku

Skąd się biorą pory roku i do czego „służą”? Fascynowały one nie tylko geografów i astronomów ale też kompozytorów i poetów. Powodem występowania pór roku jest dość znaczne (23°27’) nachylenie osi obrotu Ziemi do płaszczyzny obiegu dookoła Słońca (czyli ekliptyki), zob. ryc. 4.13.




G. Karwasz, Toruń’s tex-book for physics, 2020

**Ryc. 4.13.** Występowanie pór roku (lata w lipcu na półkuli północnej a w styczniu na półkuli południowej) jest uwarunkowane nachyleniem osi obrotu Ziemi do płaszczyzny ekliptyki.

# Padre della scienza moderna

## Galileo Galilei

From Wikipedia, the free encyclopedia

*"Galileo" redirects here. For other uses, see Galileo (disambiguation) and Galileo Galilei (disambiguation).*

**Galileo di Vincenzo Bonaiuti de' Galilei** (15 February 1564 – 8 January 1642) was an Italian astronomer, physicist and engineer, sometimes described as a polymath. Commonly referred to as **Galileo**, his name was pronounced /ˌɡælɪˈleɪ.oʊ ˌɡælɪˈleɪ.iː/ (*GAL-ih-LAY-oh GAL-ih-LAY-ee*, Italian: [ɡaliˈlɛːo ɡaliˈlɛi]). He was born in the city of Pisa, then part of the Duchy of Florence.[4] Galileo has been called the "father" of observational astronomy,[5] modern physics,[6][7] the scientific method,[8] and modern science.[9]

Galileo studied speed and velocity, gravity and free fall, the principle of relativity, inertia, projectile motion and also worked in applied science and technology, describing the properties of pendulums and "hydrostatic balances". He invented the thermoscope and various military compasses, and used the telescope for scientific observations of celestial objects. His contributions to observational astronomy include telescopic confirmation of the phases of Venus, observation of the four largest satellites of Jupiter, observation of Saturn's rings, and analysis of lunar craters and sunspots.

Galileo's championing of Copernican heliocentrism (Earth rotating daily and revolving

**Galileo Galilei**

1636 portrait by Justus Sustermans

| | |
|---|---|
| **Born** | Galileo di Vincenzo Bonaiuti |

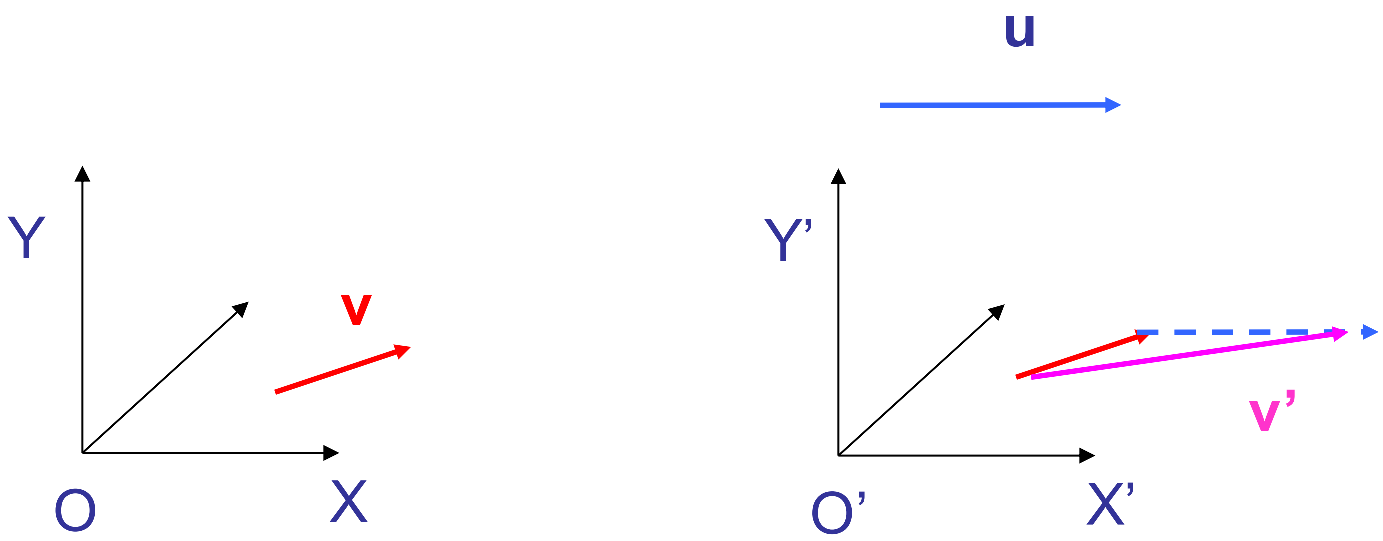
# Principio di relatività

- "Shut yourself up with some friends in the largest room that is under the cover of some large ship, and there make sure that you have flies, butterflies and similar flying animals: let there also be a large pot of water, and in it some little fish; a few buckets should also be suspended at the top, which drop by drop pour water into another vase with a narrow mouth that is placed at the bottom; and while the ship is stationary, watch diligently how those little flying animals with equal speed go towards all parts of the room. [..]
- Observe that you will have all these things diligently, although there is no doubt while the vessel is stationary they must not happen in this way: make the ship move as fast as you want; for (even if the motion is uniform and not fluctuating hither and thither) you will not recognize the slightest change in all the effects named; nor will you be able to tell from any of them whether the ship is moving or standing still.“

- *Dialoghi sopra due massimi sistemi del mondo*

# Le trasformazioni di Galileo

**v’** = **v** + **u**




All observers moving at a constant speed are equivalent

# Maxwell's equations (~1865)


God said:

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon_0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

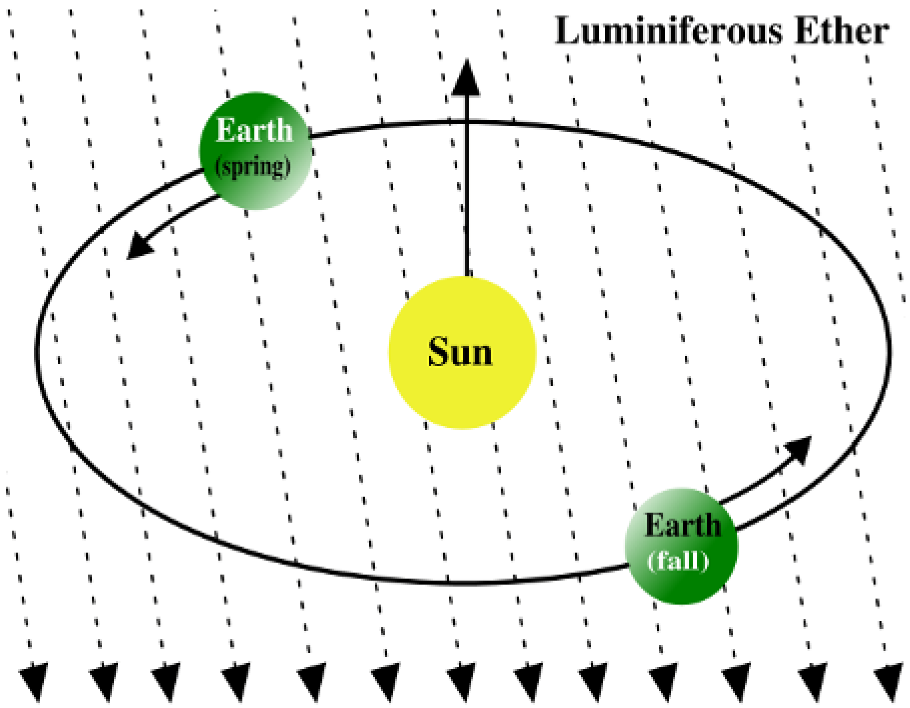
$$\nabla \times \mathbf{B} = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

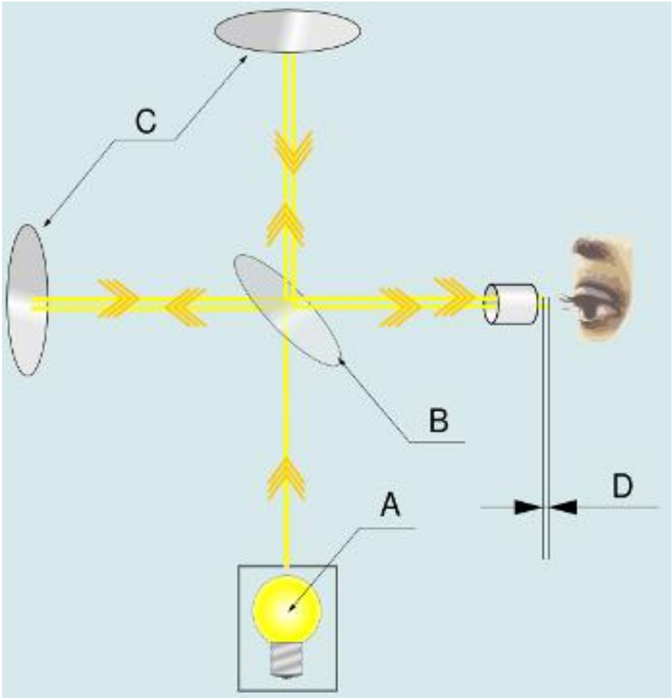
and there was light!

# Abraham Michelson – Experiment on the motion of the Earth (Potsdam, 1881)

Born in Strzelno (50 km from Toruń) in 1852.
The family moved with his parents to the United States when he was 3 years old.
First American Nobel Prize (1907)

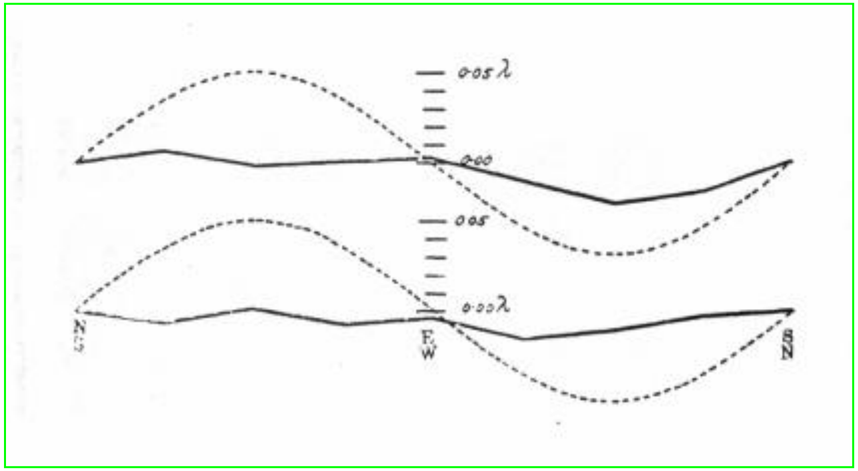
# Abraham Michelson – how does the speed of the Earth change in a year?




The speed of the Earth in orbit is 30 km/s.
The speed of light is 300 000 km/s.
We can measure it – with a methodùà based on the interference of ligh

# Abraham Michelson & Morley (1887 Cleveland):
# The Earth does not move!




Result:

No orbit velocity, within 0.1 of the expected values

? The Earth does not move

? There is no ether

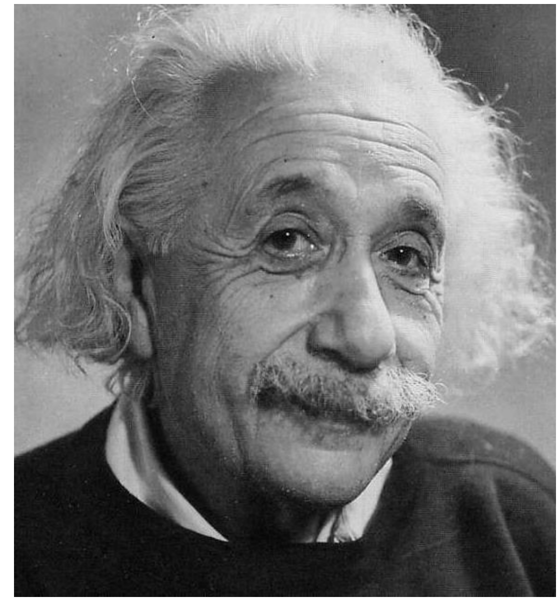
? There's something wrong with the speed of light

# On electrodynamics of moving bodies (Albert Einstein, June 1905)

3. ***Zur Elektrodynamik bewegter Körper;***
***von A. Einstein.***

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Magneten und einem Leiter. Das beobachtbare Phänomen hängt hier nur ab von der Relativbewegung von Leiter und Magnet, während nach der üblichen Auffassung die beiden Fälle, daß der eine oder der andere dieser Körper der bewegte sei, streng voneinander zu trennen sind. Bewegt sich nämlich der Magnet und ruht der Leiter, so entsteht in der Umgebung des Magneten ein elektrisches Feld von gewissem Energiewerte, welches an den Orten, wo sich Teile des Leiters befinden, einen Strom erzeugt. Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber — Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt — zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte.

Beispiele ähnlicher Art, sowie die mißlungenen Versuche, eine Bewegung der Erde relativ zum „Lichtmedium“



Come si trasformano le leggi di Maxwell in un sistema di riferimento in moto (uniforme)?

# Einstein, September 1905: "Does the mass of a body depend on its energy?

- The speed of light is constant, regardless of stillness or movement
- The speed of light is the limit with which we can transport information
- We can at will transform energy into mass

13. ***Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?***

***von A. Einstein.***

---

Die Resultate einer jüngst in diesen Annalen von mir publizierten elektrodynamischen Untersuchung[1]) führen zu einer sehr interessanten Folgerung, die hier abgeleitet werden soll.

Unter Vernachlässigung von Größen vierter und höherer Ordnung können wir setzen:

$$K_0 - K_1 = \frac{L}{V^2}\frac{v^2}{2}.$$

$E=mc^2$

Aus dieser Gleichung folgt unmittelbar:

Gibt ein Körper die Energie $L$ in Form von Strahlung ab, so verkleinert sich seine Masse um $L/V^2$. Hierbei ist es

(Eingegangen 27. September 1905.)

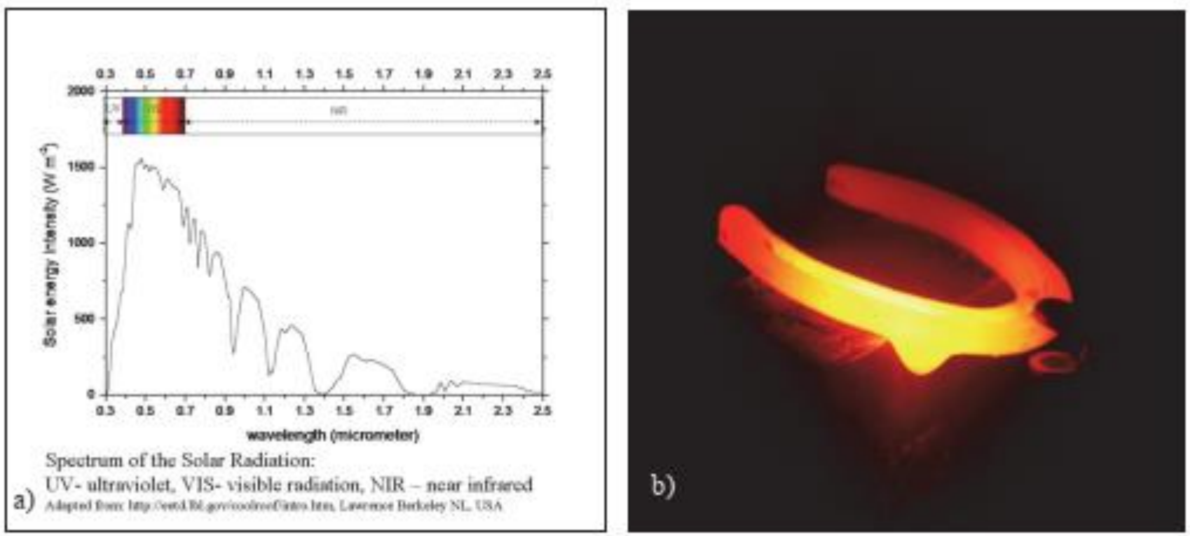
# The birth of Quantum Physics (?)

Thursday, 14.12.1900, 4:30 p.m., Berlin, Prussian Academy of Sciences

Where do the colors of the rainbow come from?

To explain this, Planck proposed a model of a black body (a box, with a slit through which the light comes out), at temperature T

But the model didn't work: it had to be assumed, that the EM vibrations inside the box are quantized E = hv (where v is the frequency). For geometric reasons, certain frequencies are not possible.



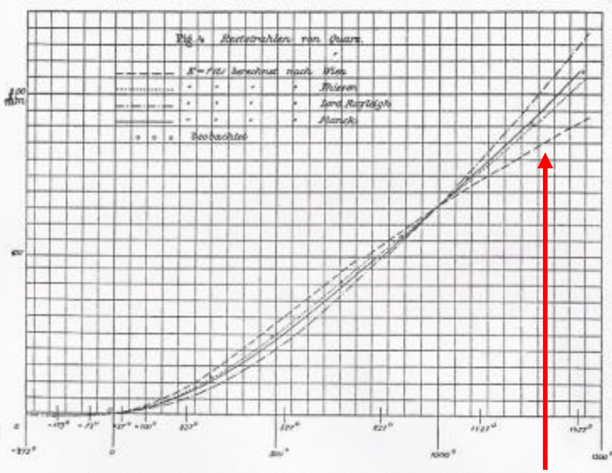

$$u_\nu(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$$

**Fot. 2.5.** Obserwacje leżące u podstaw rewolucji Plancka: **a)** widmo Słońca po przejściu przez atmosferę Ziemi; 40% energii przypada na podczerwień; **b)** kolory rozgrzanej podkowy

# «La fisica è completa»

The framework of Physics is now complete. A few decimal places remain to be filed(? Lord Kelvin ? Abraham Michelson)

a)



Rys. 3. Isochromaty, zmierzone przez Rubensa i Kurlbauma [15] dla kwarcu, porównane z wynikami teoretycznymi. Oś rzędnych przedstawia wychylenia galwanometru. Krzywe wyskalowano w ten sposób, by dawały jak najmniejsze różnice pomiędzy wartościami zmierzonymi i obliczonymi w temperaturze 1000°C.

b)

6. ***Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt; von A. Einstein.***

Zwischen den theoretischen Vorstellungen, welche sich die Physiker über die Gase und andere ponderable Körper gebildet haben, und der Maxwellschen Theorie der elektromagnetischen Prozesse im sogenannten leeren Raume besteht ein tiefgreifender formaler Unterschied. Während wir uns nämlich den Zustand eines Körpers durch die Lagen und Geschwindigkeiten einer zwar sehr großen, jedoch endlichen Anzahl von Atomen und Elektronen für vollkommen bestimmt ansehen, bedienen wir uns zur Bestimmung des elektromagnetischen Zustandes eines Raumes kontinuierlicher räumlicher Funktionen, so daß also eine endliche Anzahl von Größen nicht als genügend anzusehen ist zur vollständigen Festlegung des elektromagnetischen Zustandes eines Raumes. Nach der Maxwellschen Theorie ist bei allen rein elektromagnetischen Erscheinungen, also auch beim Licht, die Energie als kontinuierliche Raumfunktion aufzufassen, während die Energie eines ponderabeln Körpers nach der gegenwärtigen Auffassung der Physiker als eine über die Atome und Elektronen erstreckte Summe darzustellen ist. Die Energie eines ponderabeln Körpers kann nicht in beliebig viele, beliebig kleine Teile zerfallen, während sich die Energie eines von einer punktförmigen Lichtquelle ausgesandten Lichtstrahles nach der Maxwellschen Theorie (oder allgemeiner nach jeder Undulationstheorie) des Lichtes auf ein stets wachsendes Volumen sich kontinuierlich verteilt.

**Ryc. 2.7**. Dwie prace, które leżą u podstaw fizyki kwantowej: **a)** praca Plancka nt. widma ciała doskonale czarnego (Annalen der Physik, vol. 4, p. 553, 1901r.) – wykres przedstawia różne teorie porównane z danymi doświadczalnymi[14]; **b)** fragment pracy A. Einsteina nt. efektu fotoelektrycznego – niemożliwe było wyjaśnienie tego zjawiska bez założenia, że atomy pochłaniają energię światła w postaci ściśle określonych porcji, zależnych jedynie od koloru światła; porcje te nazywany fotonami.

Opisujemy to prostym wzorem,

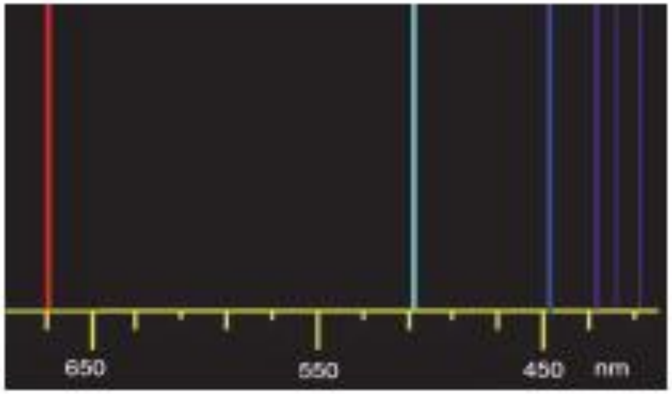
$$E = h \cdot v \tag{2.8}$$

Infrared blackbody emission: experimental data and various theories

The whole revolution happened because of this small difference

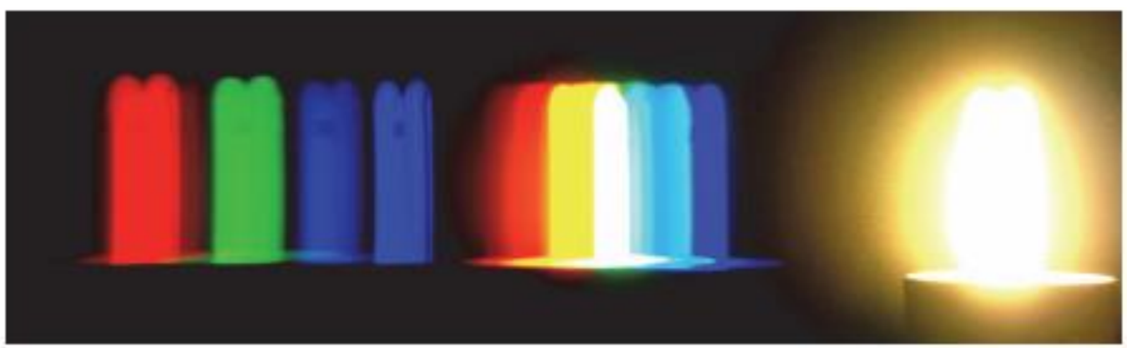
GK, *Torunski porecznik do fizyki. IV Fizyka wspolczesna i astrofizyka,* UMK, 2022

# Light emission is quantified



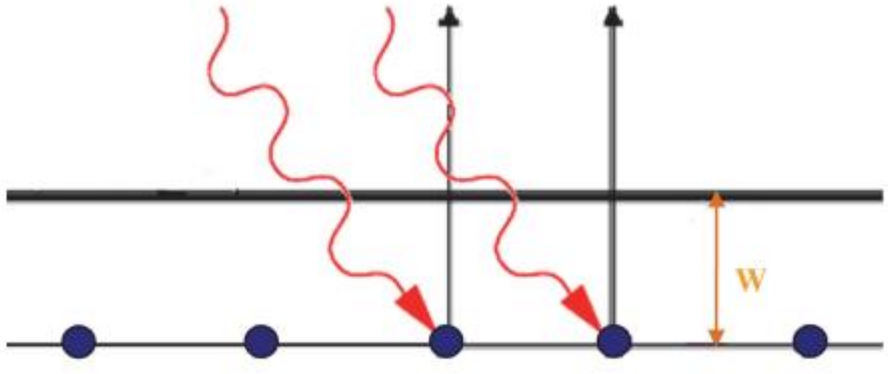

a)

b)

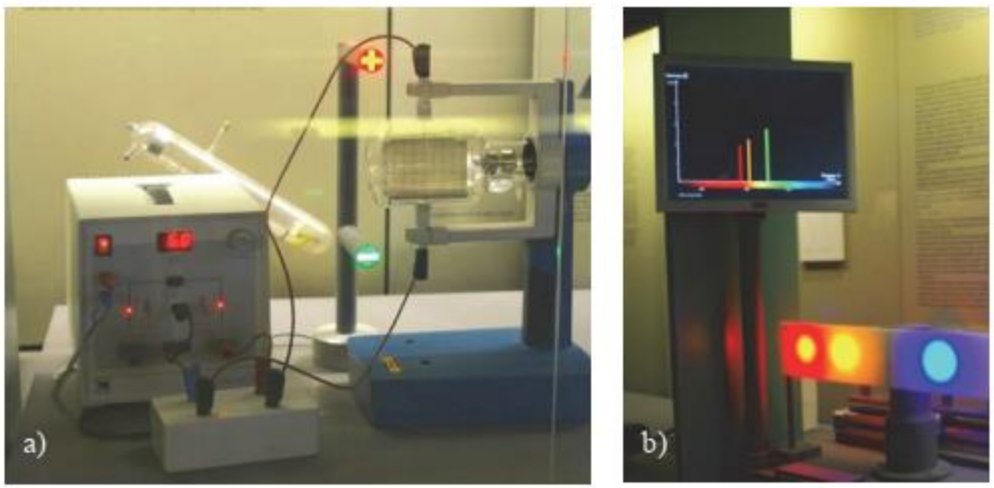


**Fot. 2.18.** Widmo żarówki energooszczędnej, uzyskane za pomocą siatki dyfrakcyjnej; ma ono charakter dyskretny – oddzielnych linii a brakuje np. koloru żółtego, pomarańczowego i fioletowego. Na tym zdjęciu obraz żarówki rozdziela się wyraźnie na poszczególne kolory składowe dopiero w drugim rzędzie dyfrakcji (foto KS).

# Photoelectric effect: light is a particle




**Ryc. 2.10.** Schemat zjawiska fotoelektrycznego.




**Fot. 2.11.** Współczesna wersja doświadczenia fotoelektrycznego Lenarda (Muzeum Nauki w Monachium): **a)** światło o różnych długościach fali (czyli różnych kolorach) wyrzuca elektrony z płytki metalowej, zamkniętej w opróżnionej z powietrza szklanej bańki zaś woltomierz mierzy energię wyrzucanych elektronów; **b)** komputer wykreśla energię elektronów w zależności od częstotliwości fali światła (czyli od odwrotności długości fali) – wykres jest liniowy, zgodnie ze wzorem Einsteina, równanie (2.11). Foto GK.

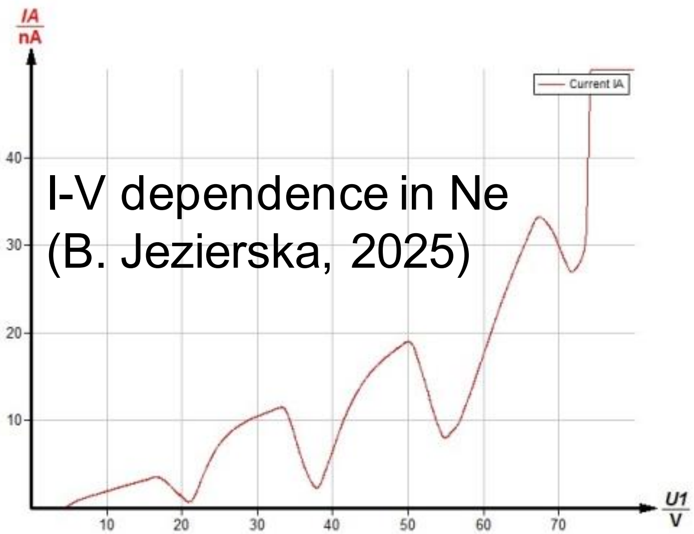
PV potentials
- green diode 1.5 V
- red diode 1.04 V

0.8 V is lost at the junction *n-p*

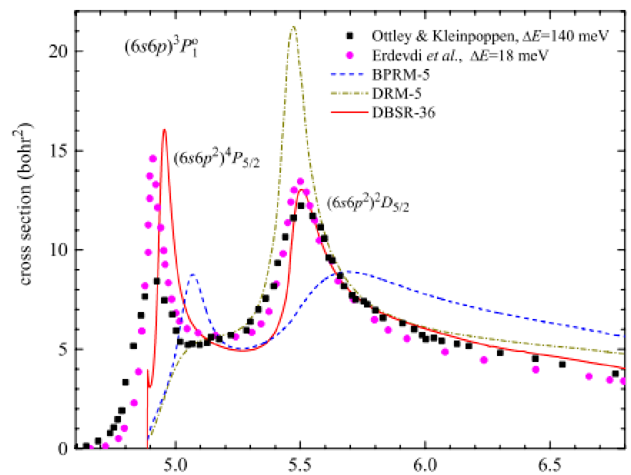
Museo di Scienze, Monaco di Baviera, Foto GK

https://cdn.prod.website-files.com/61544fc115d00da1bdba6bbb/627d1f665629d0caa4c0e606_ormeggiare%20una-barca-a-vela.jpg

# Franck-Hertz's experiment


I-V dependence in Ne
(B. Jezierska, 2025)




Cross sections for electron scatteirng in Hg
O Zatsarinny, K. Bartschat, PRA (2009)

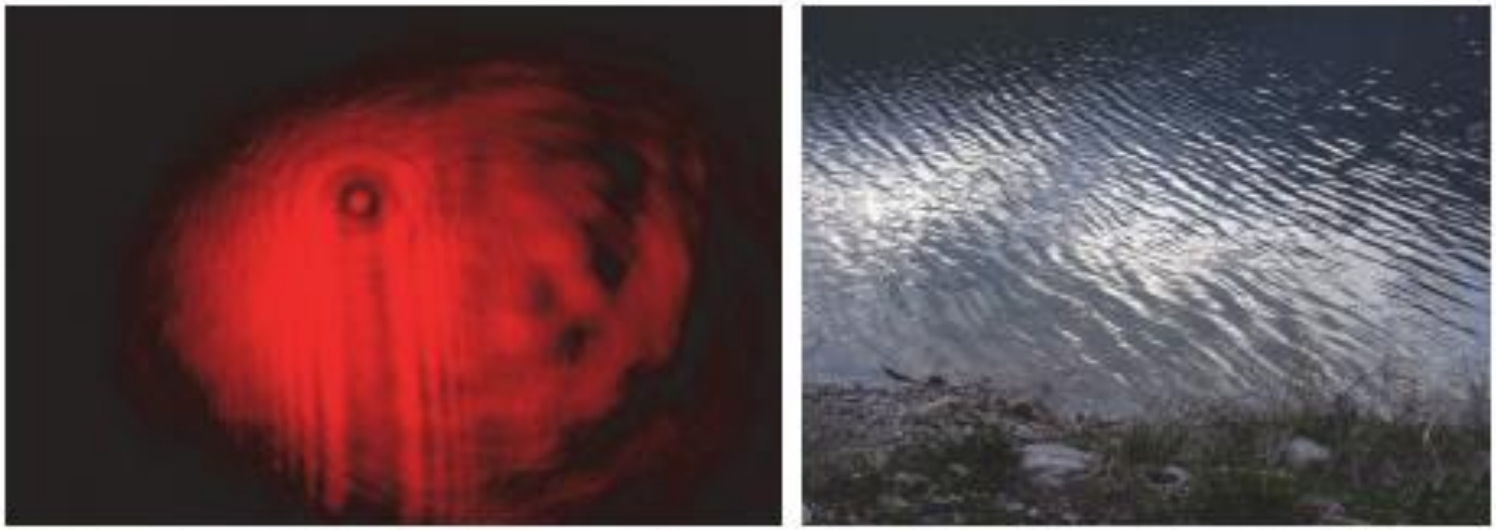
**The loss of energy is quantified**

**Special thanks to dr Finn Kraft, from Phywe**

ı1bdba6bbb/627d1f665629d0caa4c0e606_ormeggiare%20una-barca-a-vela.jpg

# Duality: Light is a wave

Na przeszkodach, jak kołek w jeziorze, fala ugina się i zmienia kierunek rozchodzenia się. Mówimy o zjawisku dyfrakcji[35]. Zjawisko ugięcia światła na mini-łepku szpilki pokazujemy na fot. 2.25.



**Fot. 2.25.** Ugięcie wiązki światła lasera na łepku szpilki (foto KS) i fal na wodzie (foto MK)

Light diffraction on the pin
Lago di Terlago (TN): foto Maria Karwasz

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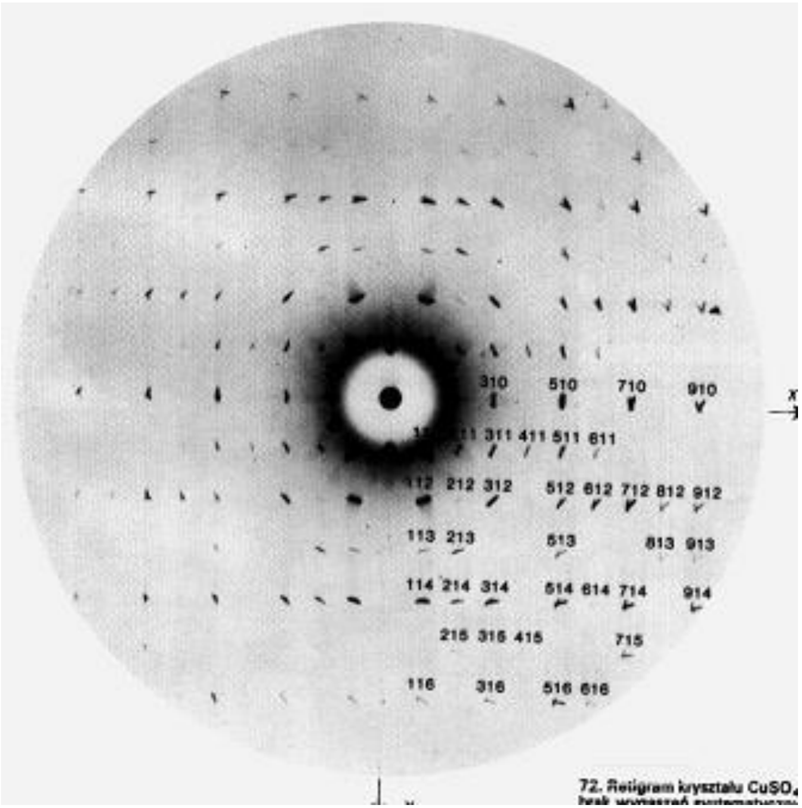
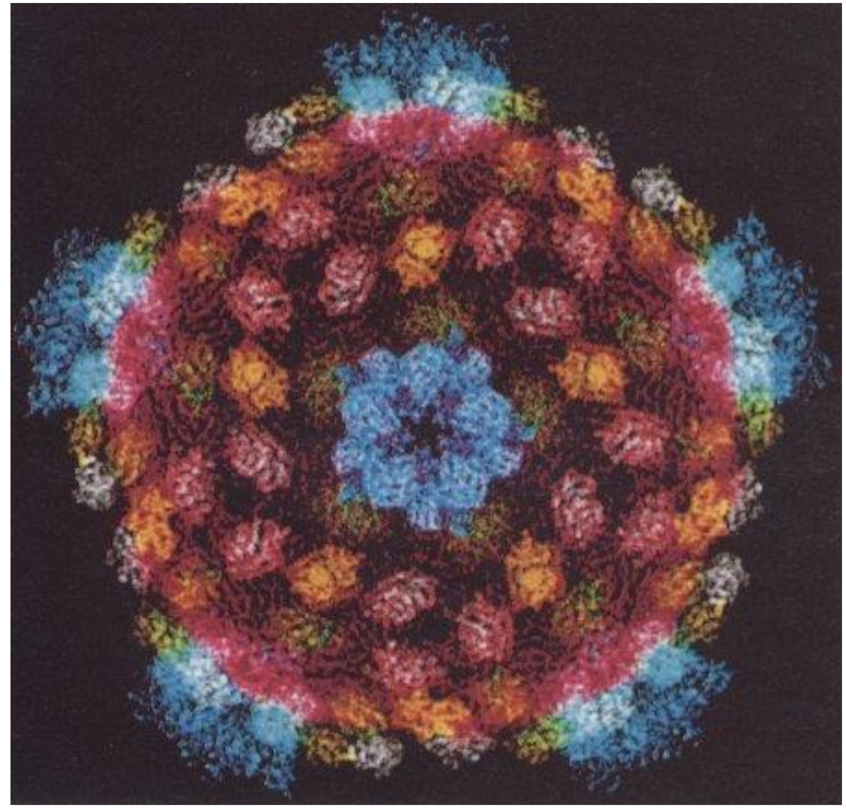
# Duality: X-rays are waves



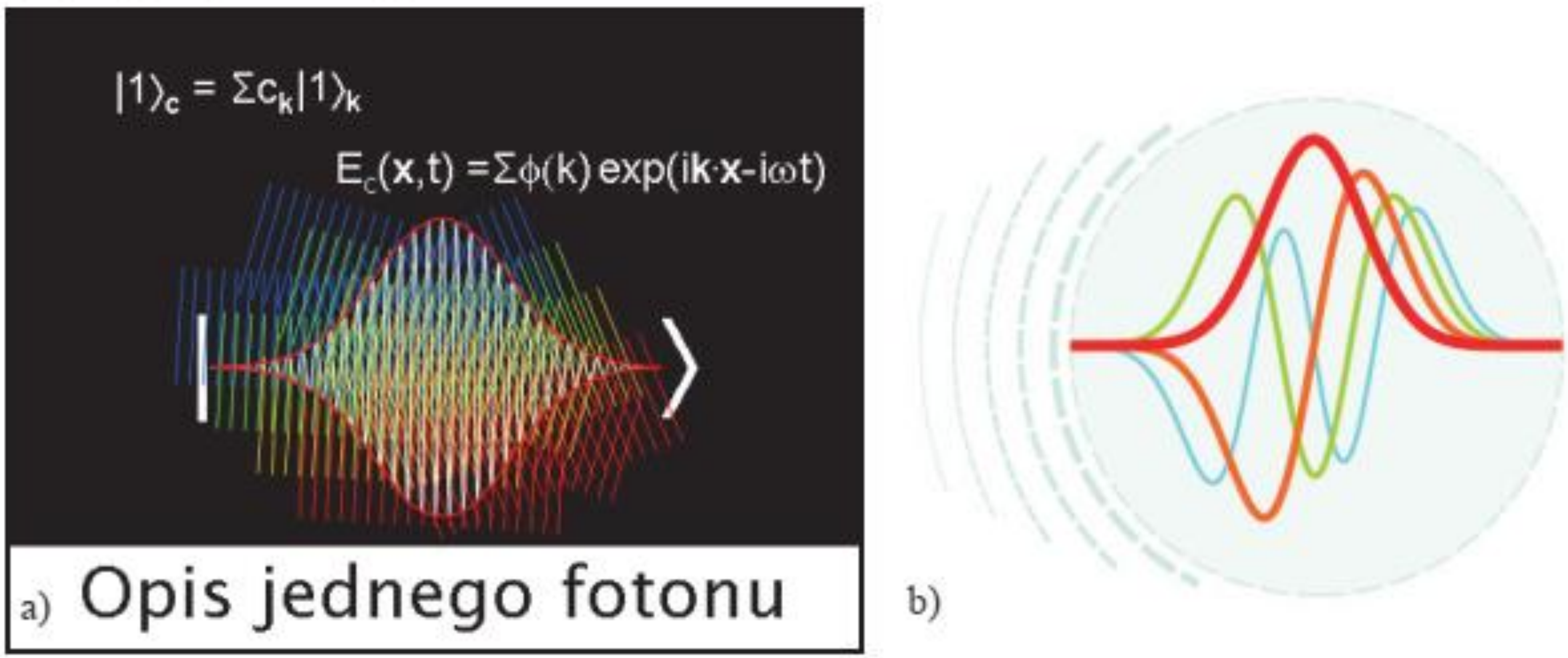
X-ray diffraction
Structure of a virus

https://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/dna.html
https://www.nature.com/articles/43403

# A single quantum of light

<u>Dla ciekawych</u>

Ale jak pogodzić dwoistą naturę światła w sposób fizyczny? Pokazali to młodzi doktoranci w Instytucie Fizyki UMK w 2007 roku. Fala (Maxwella) opisująca jeden kwant światła, to taki pojedynczy impuls, zob. ryc. 2.15.




**Ryc. 2.15. a)** „Pomiar kształtu pojedynczego fotonu metodą „rzutu na kota", wykład ZDF UMK, 2008 **b)** obwiednia pojedynczego fotonu („Źródła fotonów w łączności kwantowej", W. Wasilewski[22]).

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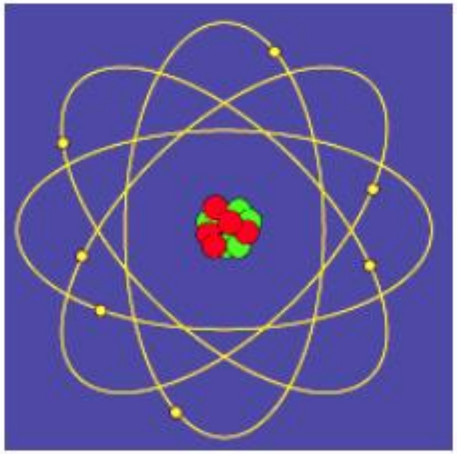
# Maybe an electron is also a wave?



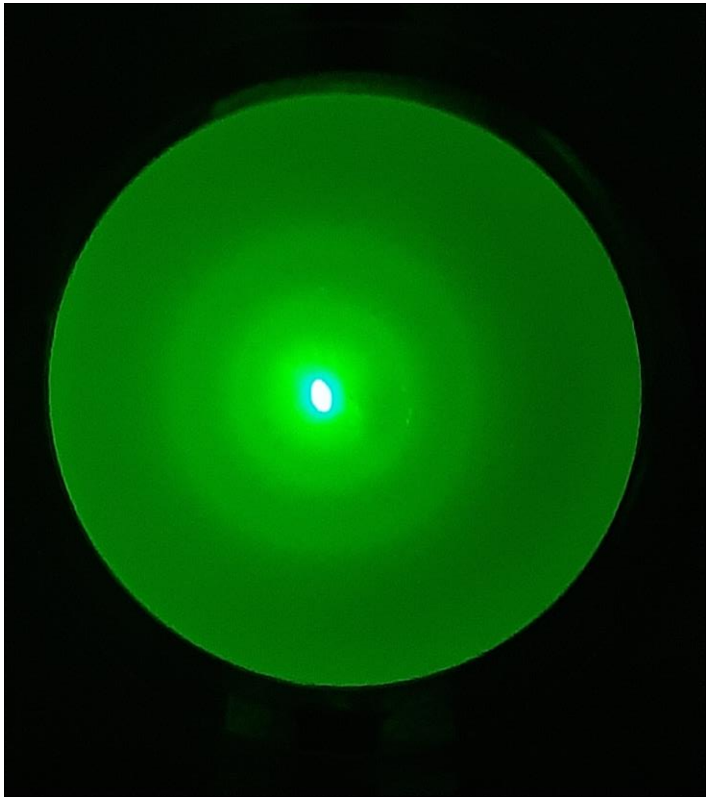
Caffeteria Gay Lussac a Parigi

Luise, 7th Comte de Broglie (graduated in history), doctorate in physics (1924):
If light is lichquanten, maybe an electron is also a wave?

$$\lambda = h/p$$

The idea did not appeal to physicists, but to Albert Einstein – yes.
Four years later it was verified with the electron diffraction experiment.
At this point: is Bohr's model simple a circular and standing wave?

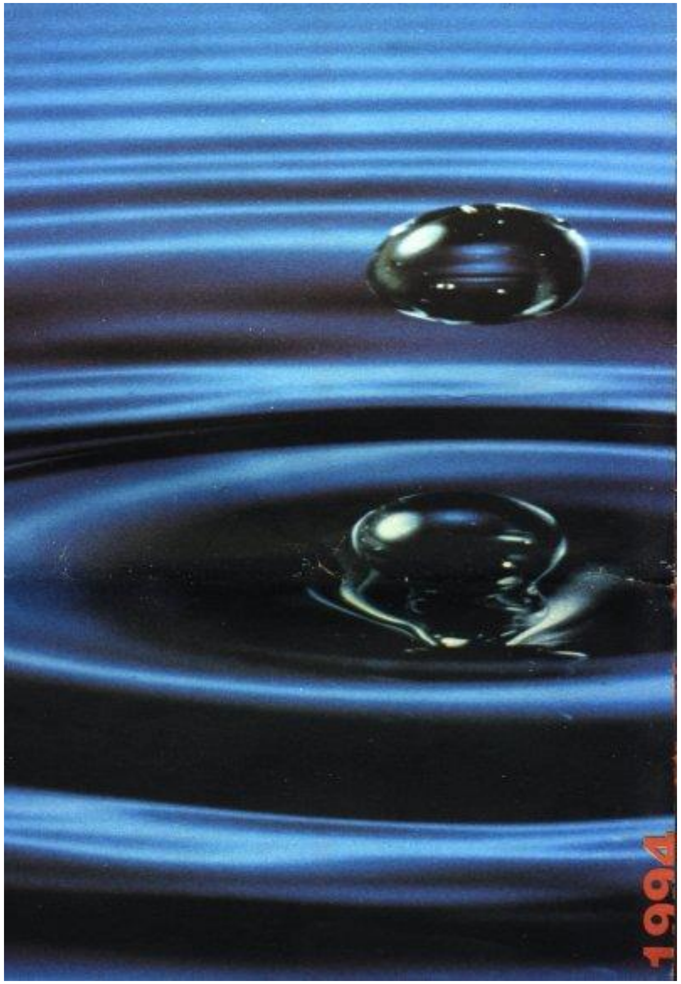
# Duality: electron is a wave

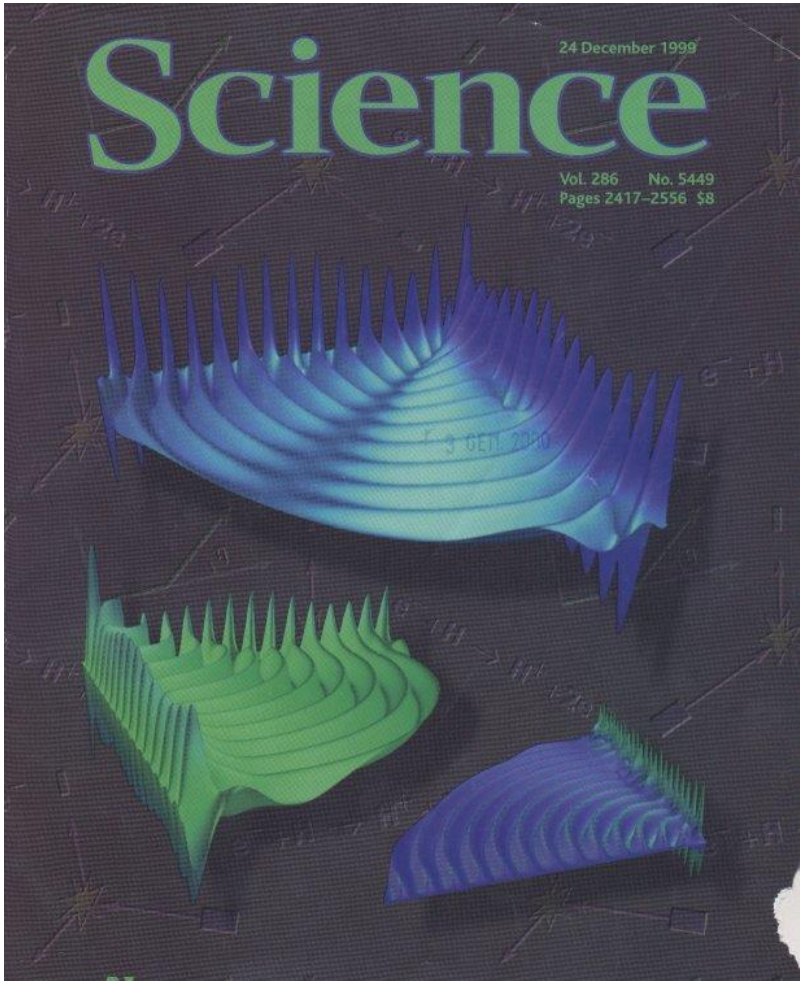


Electron diffraction (2 keV) on the Nickel crystal(UMK student lab)

https://www.tmj4.com/news/local-news/eye-to-the-sky-did-you-see-the-sun-halo

# Duality: An electron is a wave

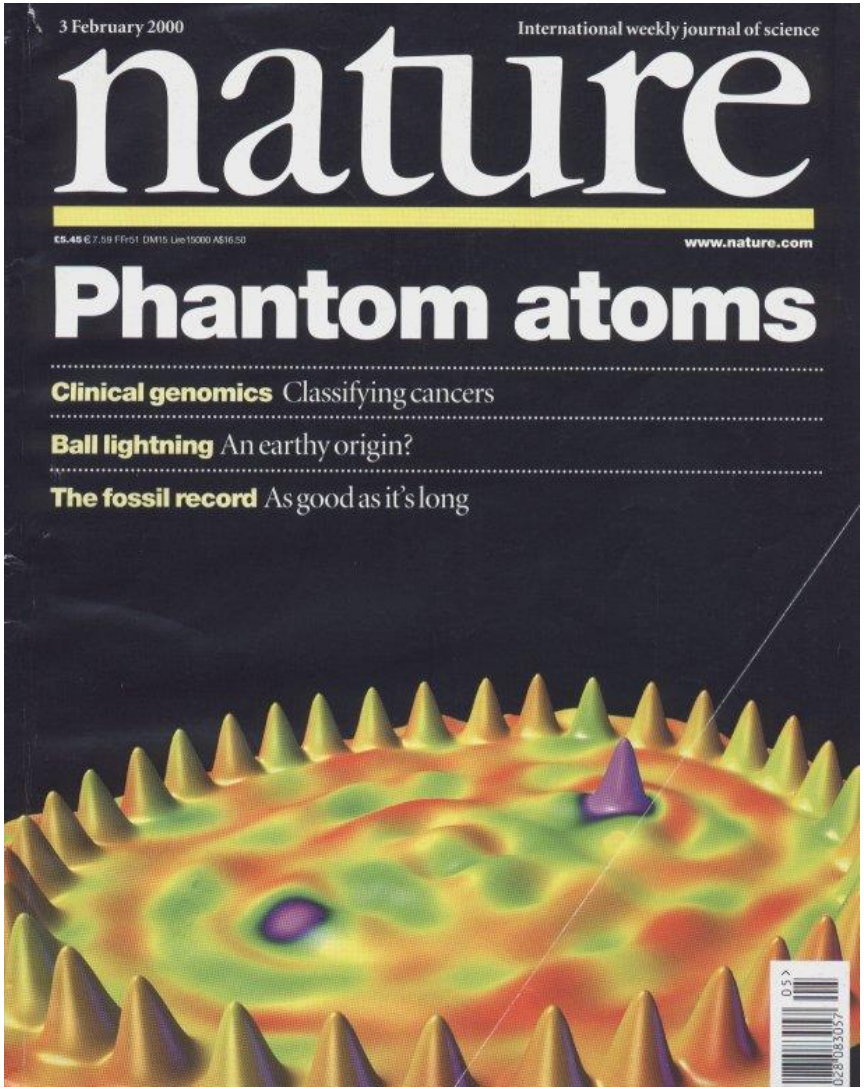



Propagation of an electron after ionization of the hydrogen atom

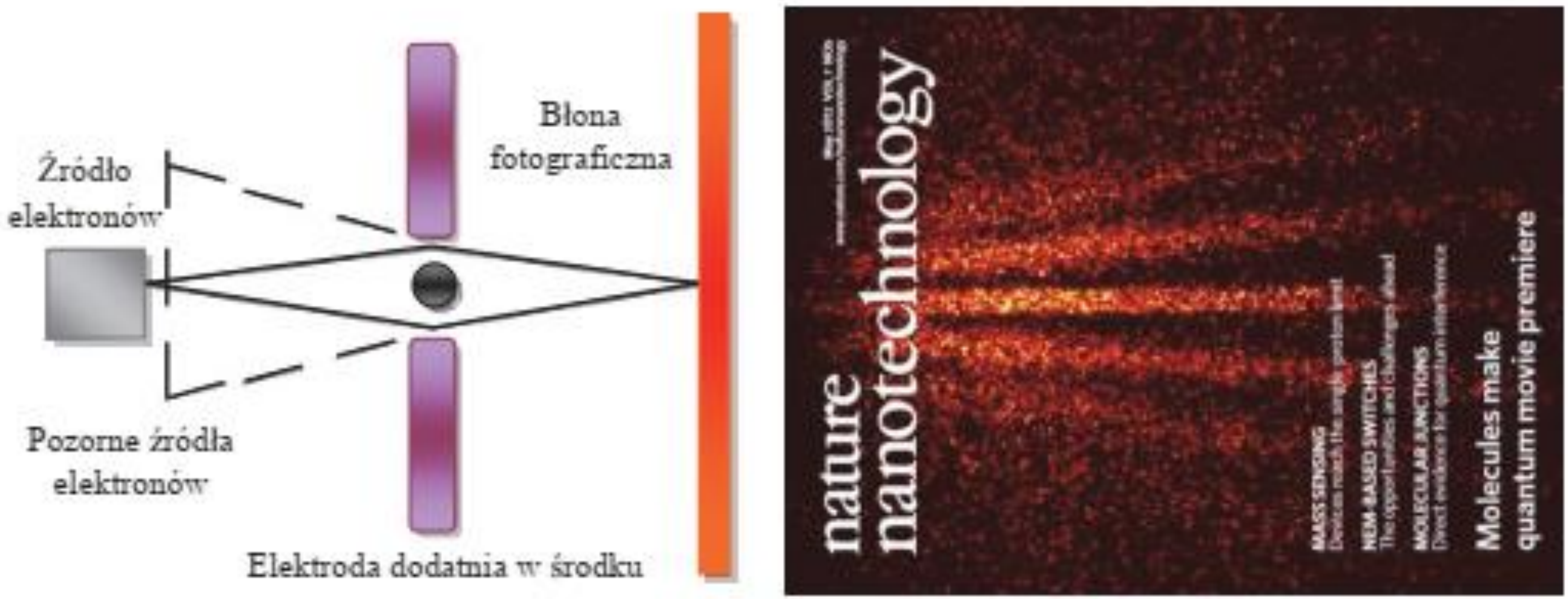
https://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/dna.html

# Duality: Light is a wave




https://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/dna.html

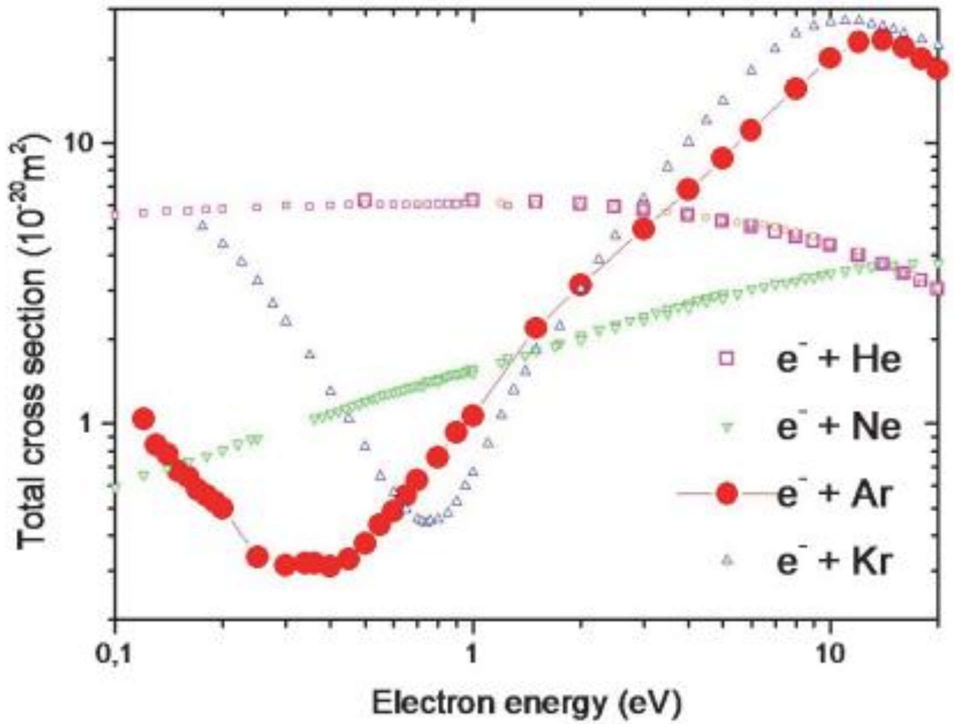
# Duality: atoms are also waves




**Rys. 2.29. a)** Schemat układu do obserwacji interferencja elektronów (lub atomów) pochodzących z dwóch pozornych źródeł elektronów; **b)** prążki obserwowane w interferencji drobin ftalocyjaniny (Uniwersytet w Wiedniu, 2012, na zdjęciu okładka czasopisma „Nature")

Phthalocyanine Beam Diffraction and Interference (University of Vienna)GK, *op. cit.*

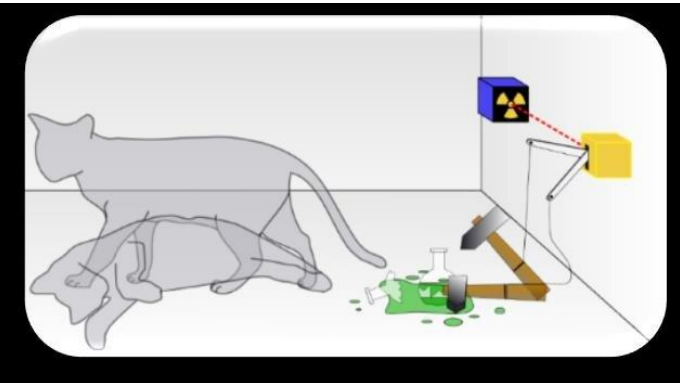
# Electron scattering




**Rys. 2.26.** Całkowite przekroje czynne na rozpraszanie elektronów w gazach szlachetnych: prawdopodobieństwo przejścia elektronów przez zbiornik z gazem (analiza[36] i pomiary autora na Politechnice Gdańskiej). W helu przekrój czynny maleje ze wzrostem energii elektronów, tak jak się tego można spodziewać z fizyki klasycznej; w argonie około energii 0,3-0,5 eV (i kryptonie około 0.7-0.8 eV) przekrój czynny ma głębokie minimum - gaz staje się dla elektronów przezroczysty; efekt ten, odkryty na Politechnice w Gdańsku przez C. Ramsauera ma zasadnicze znaczenie dla kwantowego obrazu świata (rys. GK).

Diffusion of electrons in noble gases: argon, krypton and xenon become transparent for electrons at energy about 0.3 eV. The effect discovered by Ramsauer (published 1919 in Danzig, not explainable by Planck's quantum mechanics. Misure GK*t.*

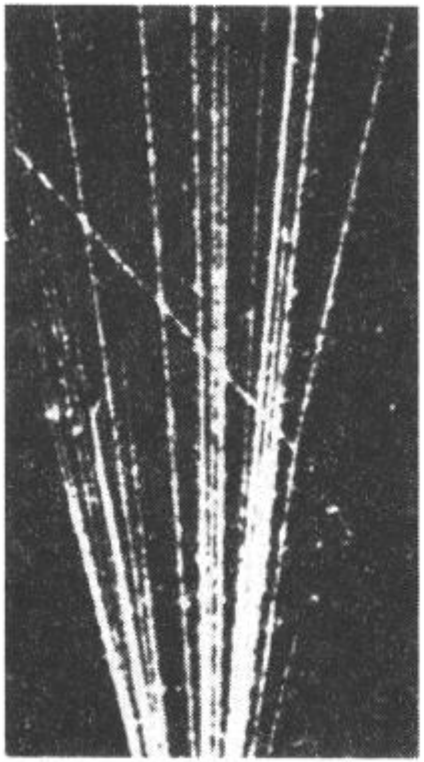
# Schrödinger's cat

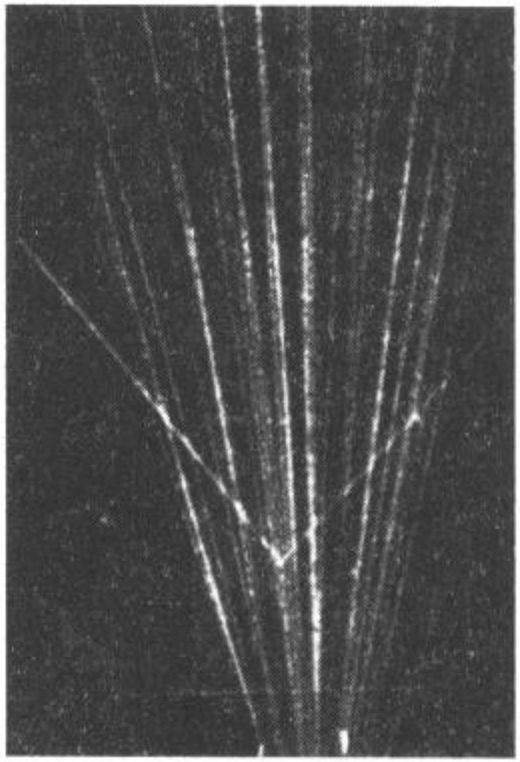


Overlapping principle:
Ψ= √½ ( Ψ+ + Ψ- )
alive and dead at the same time
But when opening the box: it's just alive or just dead
Theoretical physicists speak of the *collapse of the wave* function.
GK speaks of the projection of the "state in itself" on the level of our observation, that is, of the experiment set up by the scientist. The world is not an isolated entity
More: the wave function is a mathematical (ideal, Platonic) construction, and the cat is a physical reality.

https://dydaktyka.fizyka.umk.pl/Physics_is_fun/posters/koziol6.ppt

# Heisenberg: path of an electron?



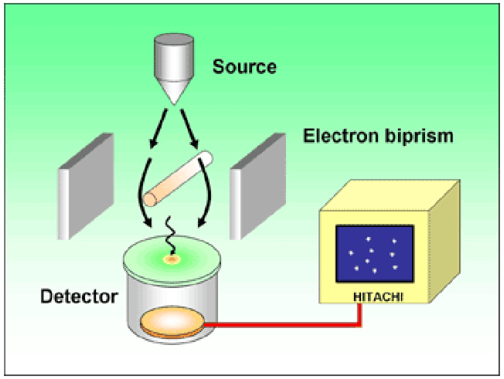



$\Delta x \Delta p \geq \hbar$ (?)
$\Delta x \Delta p \geq \hbar/2$ (?)
$\Delta x \Delta p \geq \hbar/4$ (?)

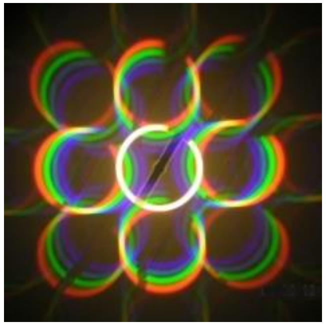
Two quantities that do not *comutate*, e.g. energy and time
We have to choose what we want to know.

https://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/kulki.html

# Where is the electron?

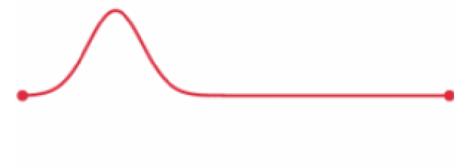



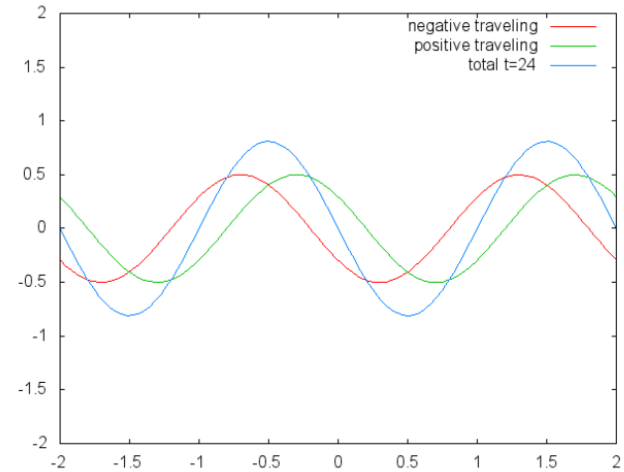

Interference image, such as the fringes of light observed in a diffraction grating
Do electrons, i.e. particles, behave like light, i.e. like waves?
Or is an electron a wave? What does "is" mean?



https://www.youtube.com/watch?v=PanqoHa_B6c
https://www.hitachi.com/rd/research/materials/quantum/doubleslit/index.html
https://dydaktyka.fizyka.umk.pl/zabawki/files/optyka/okulary.html

# Wave function



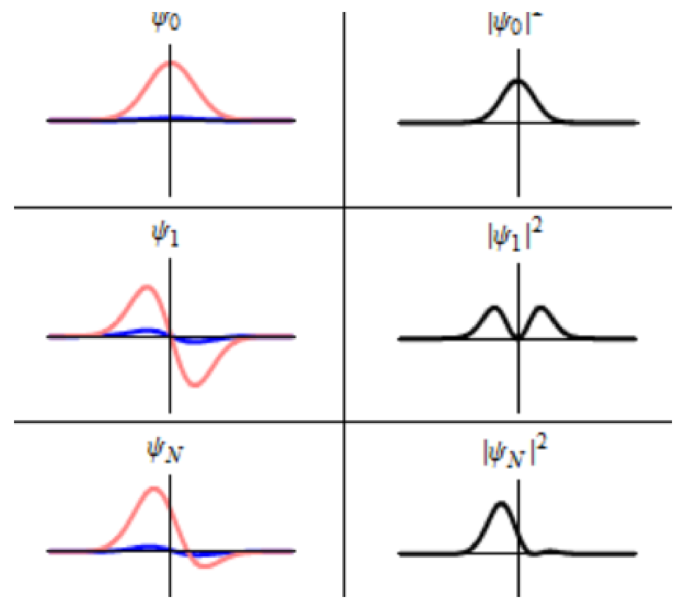



$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}.$$

Soluzione:
$u(x, t) = A \sin(\omega t - kx)$, wher $A$ l'ampiezza d'onda, $\omega$ – frequenza, $\omega = 2\pi/T$, dove $T$ – il periodo, $k$ – vettore d'onda, $k = 2\pi/\lambda$, con $\lambda$ – lunghezza d'onda

**Equazione di Schrödinger**

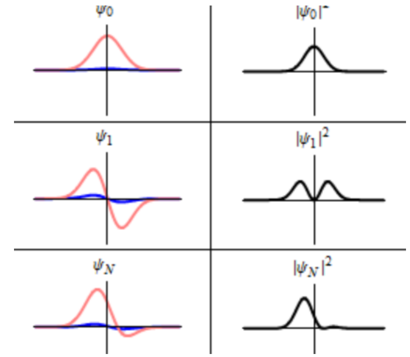
$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \left[-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\right]\Psi(x,t)$$




$\Psi(x, t)$ – funzione d'onda: il quadrato del suo modulo è la probabilità di trovare l'elettrone nel posto $x$ nel momento $t$, $i$ – unità immaginaria, $h$ – costante di Planck

https://en.wikipedia.org/wiki/Wave_equation
https://en.wikipedia.org/wiki/Schrodinger_equation

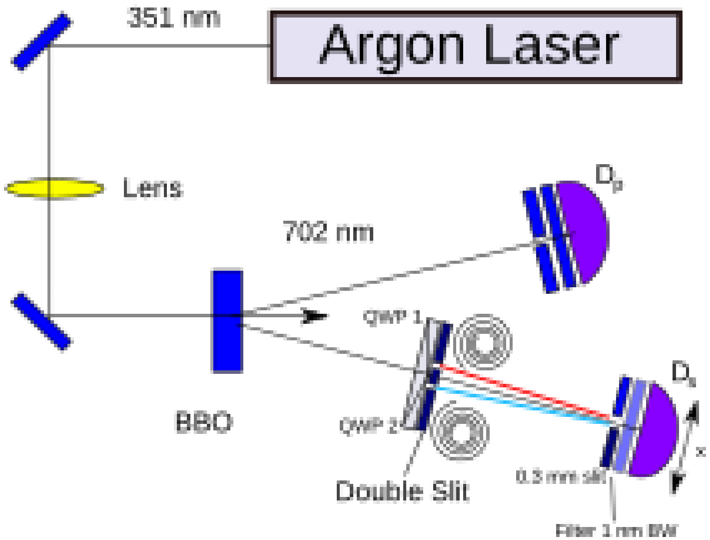
# Wrong question

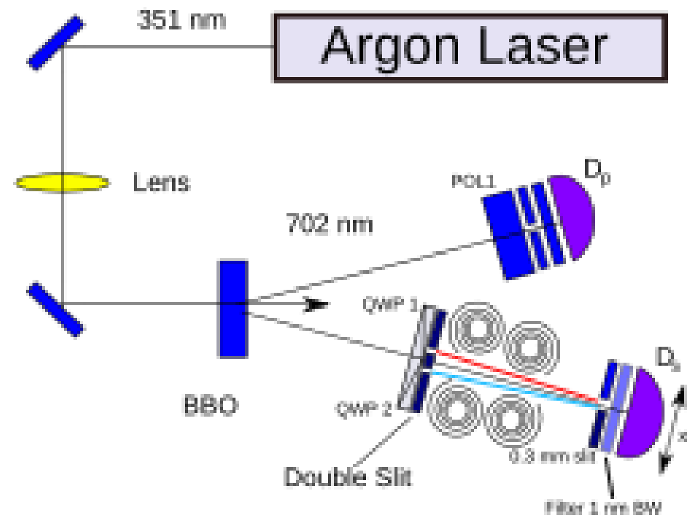

Position of the electron?
Experimental physicist: let's measure it! Let's send a photon and see where it comes back.
Theoretical physicist: insert a position operator x: $\langle x \rangle = \int \Psi^* \, x \, \Psi \, dx$
In other words, according to Schrödinger's equation, we do not know where an electron is currently located; we only know the probability *that if we measure its position*, the (possible) result will be described by the Schrödinger equation. But probability is a distribution of outcomes, with a large number of measures.
Schödinger's equation does not describe the electron, but only provides a possible result of the measurement (made) of its position (credits: Prof. Lev Pitaevski)
And what is the reason why the electron "chooses" a certain path? The question is asked incorrectly. Schrödinger's equation gives us only one probability.
In other words, nature "defends" itself, so as not to provide us with complete information.
Aristotle: the difference between *potentiality* and *actuality*

# Quantum eraser

We can know through which slit the electron has passed, if we illuminate it with photons. But at this point the image of interference disappears.
If we give up this information, the image reappears. The effect is called the«quantum eraser».




Walborn, Cunha, Padua, and Monken. Double slit quantum eraser experiment with polarizer (POL1) removed. In this configuration contrary polarizations prevent interference at Ds .




Walborn, Cunha, Padua, and Monken. Double slit quantum eraser experiment with polarizer (POL1) present. In this configuration, interference is detected at $D_s$.

https://en.wikipedia.org/wiki/Quantum_eraser_experiment

# Paradosso EPR (1935)

MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

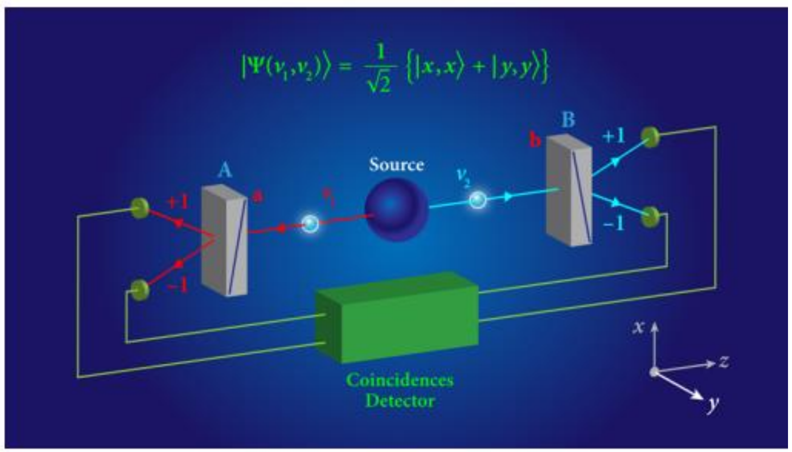
**Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?**

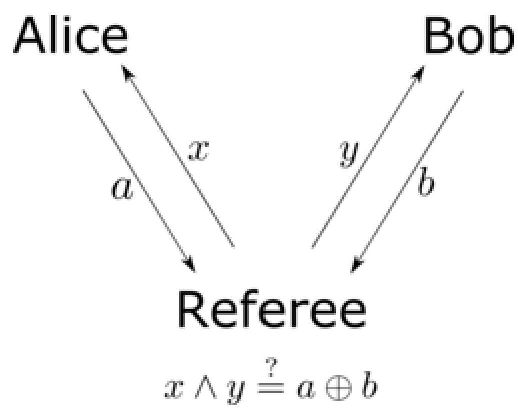
A. EINSTEIN, B. PODOLSKY AND N. ROSEN, *Institute for Advanced Study, Princeton, New Jersey*

(Received March 25, 1935)

If two quantum states remain entangled even at great distances, and the measurement on one state affects the distant state, then does a dirty (spooky) interaction occur that violates special relativity?

"spukhafte Fernwirkung"




Normal game <3/4

With corellated photons

$$\frac{2+\sqrt{2}}{4} \approx 0.85\,.$$

Einstein wanted to prove that the quantum description is not complete.
But as intrinsic assumptions he assumed: 1) realism (a measure corresponds to physical reality), 2) causality (things do not happen without cause), 3) locality (phenomena occur in a certain place in space-time), 4) the free will of the experimenter. Do they really hold all the assumptions?

Alain Aspect, *Closing the Door on Einstein and Bohr's Quantum Debate*, https://physics.aps.org/articles/v8/123
https://en.wikipedia.org/wiki/Bell%27s_theorem

# Realism, locality, completeness

"Entanglement is one of the properties of quantum mechanics that led Einstein and others to question its principles. In 1935 Einstein himself, Boris Podolsky and Nathan Rosen, formulated the famous "EPR paradox", a thought experiment that highlighted, precisely as paradoxical, the phenomenon of entanglement. It arose from the assumption of three hypotheses:

the principle of reality, the principle of locality and the completeness of quantum mechanics. For the paradox to be solved, it was necessary that one of the three hypotheses fall, but considering the first two certainly true, as they are evident, the authors came to the conclusion that quantum mechanics is incomplete (i.e. it contains hidden variables)."

"In philosophy, realism is the belief that a reality exists independently of our conceptual schemes, our linguistic practices, our beliefs."

"In physics, the principle of locality states that distant objects cannot have instantaneous influence on each other: an object is directly affected only by its immediate vicinity."

"In mathematical logic, the concept of completeness expresses the fact that a set of axioms is sufficient to prove all the truths of a theory and therefore to decide the truth or falsity of any statement that can be formulated in the language of the theory."

https://it.wikipedia.org/wiki/Entanglement_quantistico

# D’accordo di non essere d’accordo (2013)

## Agreeing to disagree

The quantum state exists before of the measure?
The answers were 50/50

A recent poll has highlighted physicists’ differing views over the interpretation of fundamental aspects of quantum theory, but **Maximilian Schlosshauer** argues that it might not be so bad

“If all this damned quantum jumping were really to stay,” Erwin Schrödinger complained to his colleague Niels Bohr in 1926, “I should be sorry I ever got involved with quantum theory.” Schrödinger, like Bohr, was a founding father of quantum theory, which had just turned our view of the world upside down. But he was not alone in his discomfort. Albert Einstein, too, spent years arguing with Bohr over whether atomic events are fundamentally random or if quantum theory really is all we can say about physical reality. Indeed, he once wrote that the theory reminded him of “the system of delusions of an exceedingly intelligent paranoiac”.

Today quantum theory underlies all modern technology: from transistors, light-emitting diodes and photovoltaics, to nuclear power, magnetic-resonance imag-


**God does not play dice** Einstein disagreed that at a quantum level the universe is random.

**Quantum physics has moved from philosophy to concrete action**

not tell us when it will actually decay – the individual event, when it happens, seems to come out of nowhere. Einstein could not accept the idea of a universe in which events truly randomly fall out one way or the other, famously declaring that “God doesn’t play dice.” But Einstein’s reservations didn’t seem to faze our respondents. A two-thirds majority declared Einstein’s view wrong and randomness a fundamental concept in nature, and half thought that the randomness we see in quantum phenomena is indeed fundamental and irreducible: that there is no “hidden hand”– no gambling God – governing these events.

### The challenge ahead

So what can we learn from our poll? One thing is clear: quantum physics has moved from philosophical debates to concrete action. Quantum-information science, hailed by an overwhelming majority as a breath of fresh air, is being put to use in looking at old problems from a new angle. It has helped us not only to get a better understanding of what we can do with quantum theory, but also to find new ways of understanding the theory itself. Various new interpretations based around quantum information have popped up in the last decade, and our poll shows them rivalling the

Maximilian Schlosshauer 2013 *Phys. World* **26** (03) 29**DOI** 10.1088/2058-7058/26/03/32
https://iopscience.iop.org/article/10.1088/2058-7058/26/03/32/meta

# Quantum certainties?


After a hundred years? Even worse!

But: Today quantum theory underlies all modern technology: from transistors, light-emitting diodes and photovoltaics, to nuclear power, magnetic-resonance imaging, lasers and atomic clocks. It is a seemingly inexhaustible source of new ideas and applications. Quantum-information science, for example, is a fresh take on information processing, and promises computers faster than anything we could currently imagine

Physics World March 2013

# GK: Causality is the most important law, not only in the material world

- All modern science criticizes Hume's ideas: belief in the principle of causality is the basis and motivation of all research. "I literally can't see the cause-and-effect relationship between the mosquito on my arm and the itching that follows its departure. But my cause-and-effect reasoning is based on a strong and fundamental belief," writes Patricia Churchland [2016] in How Biology Influence Philosophy.
- "Proving" causality is a difficult, or more accurately, impossible task. In other respects, it is enough to prove the existence of an example, say a unicorn, to prove that they exist. Normally, it is more difficult to show the non-existence of unicorns, because you would have to look at the entire globe. In the case of causation, you need to find an event that occurred without cause. The question is always the same: there was no cause, or we simply cannot identify the cause.

**Ontological causality or just epistemic?**

G. Karwasz, *Between physics and metaphysics – on determinism, arrow of time and causality*, Philosophy and Cosmology, vol. 24 (2020) 15-24.

# Violations of locality and free choice are equivalent resources in Bell experiments

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Edited by Anthony Leggett, University of Illinois at Urbana–Champaign, Urbana, IL, and approved March 11, 2021 (received for review October 1, 2020)

**Bell inequalities rest on three fundamental assumptions: realism, locality, and free choice, which lead to nontrivial constraints on correlations in very simple experiments. If we retain realism, then violation of the inequalities implies that at least one of the remaining two assumptions must fail, which can have profound consequences for the causal explanation of the experiment. We investigate the extent to which a given assumption needs to be relaxed for the other to hold at all costs, based on the observation that a violation need not occur on every experimental trial, even when describing correlations violating Bell inequalities. How often this needs to be the case determines the degree of, respectively, locality or free choice in the observed experimental behavior. Despite their disparate character, we show that both assumptions are equally costly. Namely, the resources required to explain the experimental statistics (measured by the frequency of causal interventions of either sort) are exactly the same. Furthermore, we compute such defined measures of locality and free choice for any nonsignaling statistics in a Bell experiment with binary settings, showing that it is directly related to the amount of violation of the so-called Clauser–Horne–Shimony–Holt inequalities. This result is theory independent as it refers directly to the experimental statistics. Additionally, we show how the local fraction results for quantum-mechanical frameworks with infinite number of settings translate into analogous statements for the measure of free choice we introduce. Thus, concerning statistics, causal explanations resorting to either locality or free choice violations are fully interchangeable.**

Surprisingly, nature violates Bell inequalities (8–15), which means that if the standard causal (or realist) picture is to be maintained at least one of the remaining two assumptions, that is locality or free choice, has to fail. It turns out that rejecting just one of those two assumptions is always enough to explain the observed correlations, while maintaining consistency with the causal structure imposed by the other. Either option poses a challenge to deep-rooted intuitions about reality, with a full range of viable positions open to serious philosophical dispute (16–18). Notably, quantum theory in its operational formulation does not provide any clue regarding the causal structure at work, leaving such questions to the domain of interpretation. It is therefore interesting to ask about the extent to which a given assumption needs to be relaxed, if we insist on upholding the other one (while always maintaining realism). In this paper, we seek to compare the cost of locality and free choice on an equal footing, without any preconceived conceptual biases. As a basis for comparison we choose to measure the weight of a given assumption in terms of the following question: *How often can a given assumption, i.e., locality or free choice, be retained, while safeguarding the other assumption, in order to fully reproduce some given experimental statistics within a standard causal (or realist) approach?*

This question presumes that a Bell experiment is performed trial-by-trial and the observed statistics can be explained in the standard causal model (or hidden variable) framework (1–7, 19–21), which subsumes realism. It means that the remaining two assumptions of locality and free choice translate into conditional independence between certain variables in the model,

# Between Physics and Metaphysics — on Determinism, Arrow of Time and Causality

The world may be totally deterministic, but we will never know.

**Grzegorz P. Karwasz**

The arrow of time could go backwards, but it would be very expensive.

Doctor of Science (Physics), Professor, Didactics of Physics Division,
Head of Faculty of Physics, Astronomy and Applied Informatics,
University Nicolaus Copernicus

The higher law of natures seems to be causality (!).

*Philosophy and Cosmology*, Volume 24, 2020: 15-28.
https://doi.org/10.29202/phil-cosm/24/2

*Contemporary physics, with two Einstein's theories (called "relativity" what can be interpreted erroneously) and with Heisenberg's principle of indeterminacy (better: "lack of epistemic determinism") are frequently interpreted as a removal of the causality from physics. We argue that this is wrong. There are no indications in physics, either classical or quantum, that physical laws are indeterministic, on the ontological level. On the other hand, both classical and quantum physics are, practically, indeterministic on the epistemic level: there are no means for us to predict the detailed future of the world. Additionally, essentially all physical principles, including the arrow of time and the conservation of energy could be, hypothetically, violated (with some exceptions in the world of heavier quarks, and probably, the cosmological arrow of time). However, in contrast to Hume's skepticism, we have no experimental evidence that the causality can be removed or even "hung on" in any case. The text contains some didactical-like issues, as well.*

*Keywords: Quantum mechanics, determinism, causality, classical physics*

# Conclusions (I): scientific revolutions

- History of Copernicus, Galileo, Copernicus shows that scientific revolutions are made on a social demand
- In the case of Copernicus, the reason was the need for the reform of the (ecclesiastical) calendar
- Beyond the social necessity, we need a young genius (26 years old Einstein, 27 years old Copernicus) who does not look at the traditional "authorities" (see the case of the young Galileo)
- You also need a good teacher (Domenico Novara) with whom the young person (Copernicus) can work

# Conclusions (II): matter and form

- With $E=mc^2$ it loses the sense "is made of". A proton turns into a neutron and vice versa: you just need to provide the energy.
-
- But the processes are regulated by mathematical formulas, so-called Cabbibo-Kobauashi-Maskawa matrices
-
- Are the matrices real or are they ideas?
-
- It also loses its meaning "is found at": it is not found, but it could be found if an appropriate experiment were carried out.
-
- Aristotle's distinction between the **actual and the potential** resonates here.

# Conclusions IV: epistemic*

The two revolutions in physics at the beginning of the twentieth century have ousted many physical/philosophical/common-sense terms:

- The absolute character of space and time, bringing them closer to Kant's conception, which are forms of our knowledge, that is, individual
- The certainty of classical physics in its optimistic epistemic determinism
- Certainties in the distinctions between the forms of matter (wave vs. particle)
- It overturned the objectivity (immutability) of the physical world, making it subject to variation due to the cognitive action of man
- Even **the locality of events** could be "sacrificed" in order to maintain human free will

The only certainty (intuition) that is saved seems to be **causality:** nothing happens by chance, and indeed – we never know – what our (good and bad) actions can cause

# Lev Pitaevski: «Do we really need to know everything?»

# A lesson



- Lev, the wavepacket *describing* an electron diverges in time. Does it result from a specia Gaussian form of the packet?
- No! Any packet diverges in time – this is a superposition of waves with different lengths Only a plane wave does not diverge in time.

- So, quantum mechanics does not describe electron as a stable object?
-**Wrong!** Electron is stable and point-like! Schrödinger's equation does NOT describe the electron itself but the probability of finding the electron in a given point!

- Lev, tell me what idea was behind Your famous equation?

- In 1956 H. Hall and W. Vined in UK discovered a very interesting phenomenon - quantum vortexes in superfluid Helium. They were predicted by L. Onsager and R. Feynman, but we had no good theory. I thought on the subject for several years and finally, in 1961, being on vacations, I understood that the theory can be developed for the Bose-condensed gases, which were in fact created in 1975 only. I remember that Landau agreed with my theory not immediately, but after several discussions.

Photos are from professor Pitaevskii's 70th birthday dinner. Thanks! Asking questions: GK

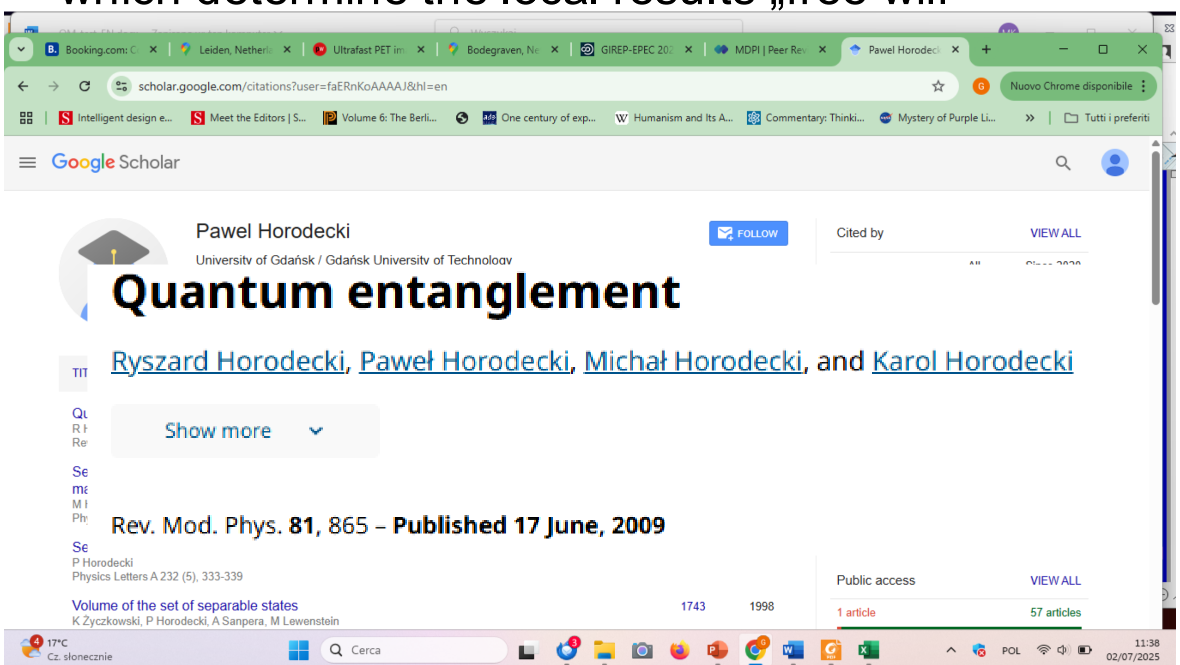
… pianto due alberi: uno per dare la vita e l'altro per infondere la conoscenza di tutto.

GK, On the track of Modern Physics, https://dydaktyka.fizyka.umk.pl/Physics_is_fun/posters/BEC6.ppt

# Paweł Horodecki: «The point is that we know how to operate it, but we do not understand how it works»

This holistic property of compound quantum systems, which involves nonclassical correlations between subsystems, has potential for many quantum processes, including canonical ones: quantum cryptography, quantum teleportation, and dense coding. Entanglement is considered to be the most nonclassical manifestation of quantum formalism.

(1) measurement results are determined by properties the particles carry prior to, and independent of, the measurement realism"; (2) results obtained at one location are independent of any actions performer at spacelike separation „locality"; and 3) the setting of local apparatus is independent of the hidden variables which determine the local results „free will"




# Conclusions (V): philosophical, i.e. existential

Man influences the world, including the arrow of time: for example, through the irreversibility of quantum measurement (Landau), not talking about the irreversibility of man as a biological (and mental) entity

Man would like to dominate the world, but he cannot:

- not for lack of his desire for omnipotence

- but for very **precise limits of its science (omniscience),** set by the two revolutions of the twentieth century: **quantum mechanics and the theory of relativity**

Twentieth-century physics teaches us scientific humility: Lev Pitaevski "Do we really have to know everything?"

"Quantum mechanics is still waiting for its Copernicus"

(Andrzej Raczynski, 2024)

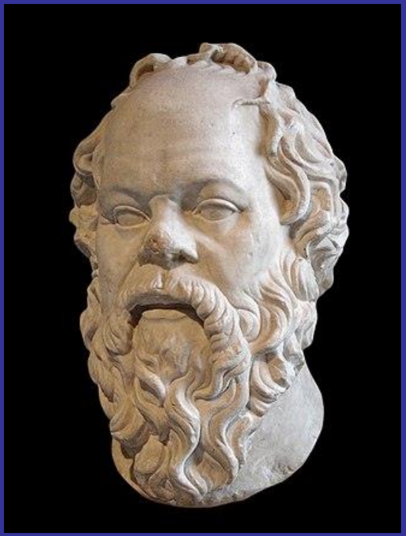
What the 21st century will bring? without a doubt, even more surprising revolutions

«Ai posteri l’ardua sentenza.» (Alessandro Manzoni, *Il Cinque Maggio* ,1821)

# The (epistemic) limits of our knowledge

The Earth, no matter how big the sphere is, is nothing compared t
to the greatness of the sky, of whose limits we do not know,
and probably we can't even know ...

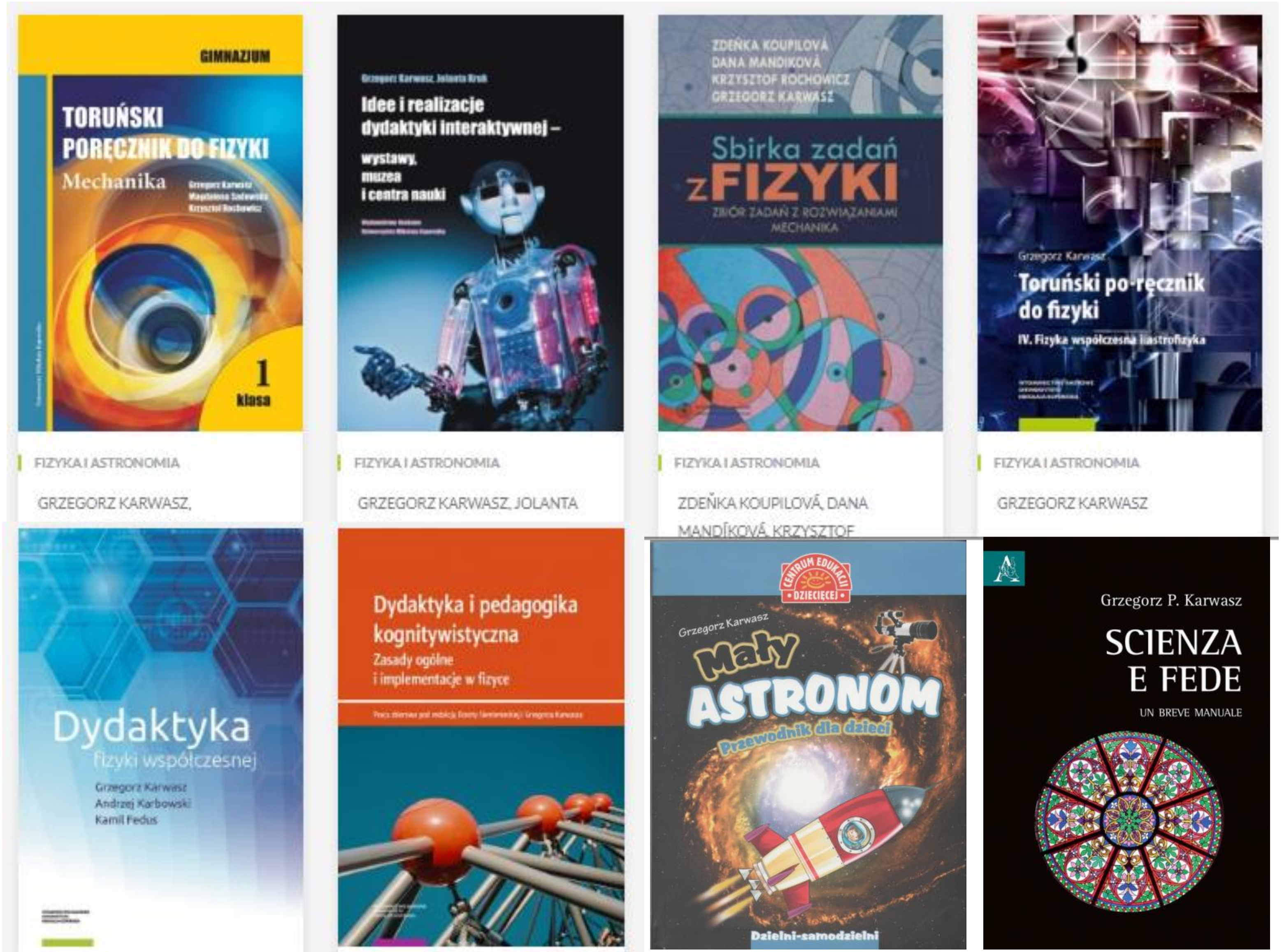
Nicolaus Copernicus, *De revolutionibus,* Norimberga, 1543



I know, that I don't know nothing
(Socrate 470-399 a.C)

**Thank you for your infinite patience!**

# Tek-books




Astronomy for kids (Poznan, 2018) Scienze e Fede (Roma, 2019)

# Test (secondary school & Theology Faculty)

1. Have you heard of Heisenberg's uncertainty principle?

a) No
b) Yes, it says that we cannot get to know the micro world
c) Yes, it says that we cannot measure with arbitrary precision, for example, the position and momentum of an electron
d) Yes, it is our cognitive limitation, more philosophical than physical

1. What does the term wave-corpuscular duality mean?

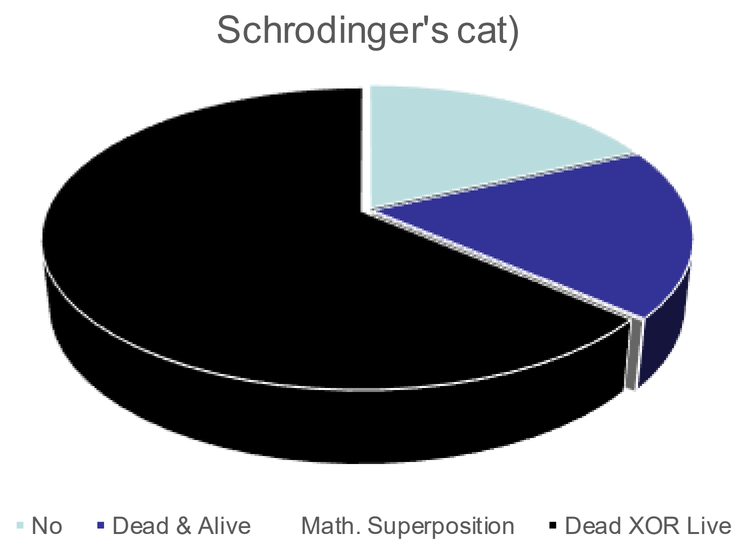
a) I do not know
b) It means that an electron is a wave and a particle
c) It means that an electron can be a particle and a wave at the same time
d) This means that, depending on the experiment carried out, wave or corpuscular aspects manifest themselves, e.g. of the electron

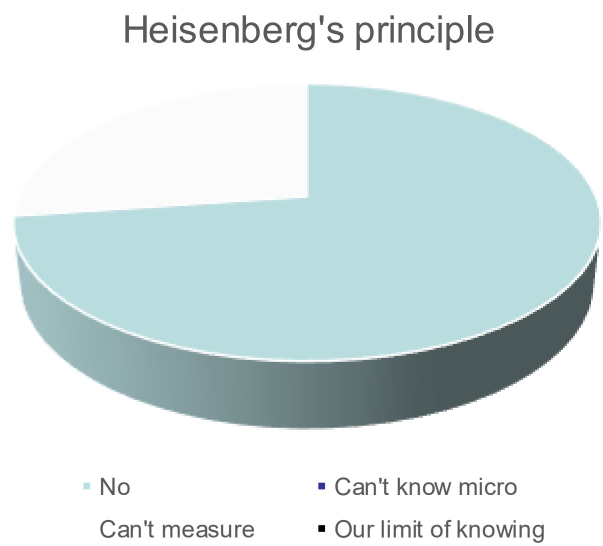
# Test (secondary school & Theology Faculty)

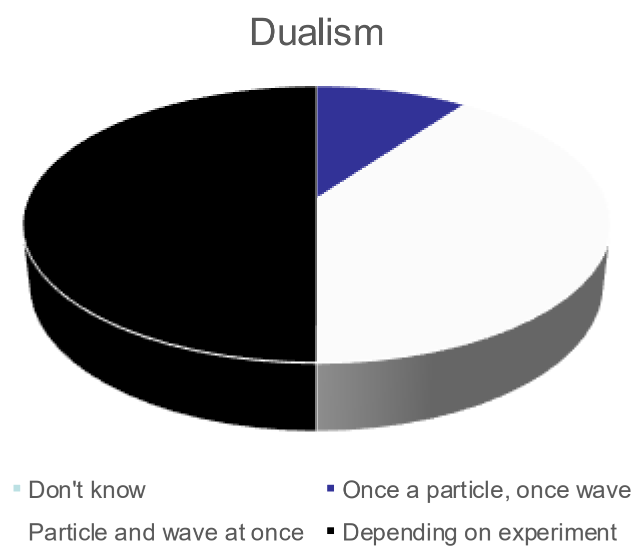
3. Have you heard of Schrodinger's cat?
a) No
b) Yes, it's a cat that's both alive and dead
c) Yes, it is a cat whose mathematical description is a combination of two wave functions
d) Yes, it's a cat that can be alive or dead when you open the box

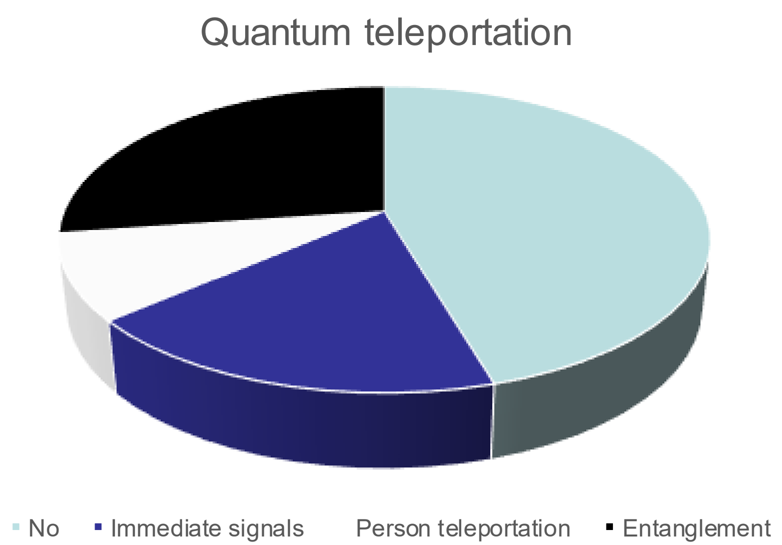
4. Have you heard of quantum teleportation?
a) No
b) Yes, you can transmit signals over a distance in instant time
c) Yes, it will be possible to transport humans to distant galaxies in the future
d) Yes, it's a poetic term for quantum entanglement

# Tests: results (Liceum, 4th yr)




All together: not bad results

Thanks to Maja Meyer and Marta Nowicka

# Lectures for schools

Not phenomenology, but a didactic path: interactive, constructivist

# Interactive exhibitions

«Gong downhill",Rogoźno, 2014

# From the real world to its mathematical representation (abstraction)

VIII LO Toruń, fot. J. Kosicki

# School competition


# Interactive theatre: «Robot’s fairytales» by S. Lem

# Einstein: “Explain everything as simple as possible, but not simpler”


**Fot. 4.17.** Poglądowość zastosowana do trudnych zagadnień fizyki współczesnej – tzw. cząstek elementarnych (protonów, neutronów, elektronów, kwarków): **a)** funkcję poglądową spełnia rysunek, plakat z opisem; **b)** funkcję tę spełnia także kawałek żelaza o masie proporcjonalnie większej niż masa jednego eurocenta greckiego – leptonu (wykład autora w gimnazjum, Rzęgnowo, 3.11.2011, fot. MK)

«Dear Albert: Leave the didactics to experts in didactics»

- hyper-constructivism
- neo-realism

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