

**A physicist
meets**

filmmakers

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NATIONAL
GEOGRAPHIC

171 countries
45 languages

Genius.

10 EPISODES
ON TUESDAYS

Based on book by **Walther Isaacson**
Script by: **Kenneth Biller, Noah Pink** *et al.*
Produced by: **Brian Grazer, Ron Howard** *et al.*
Starring: **Geoffrey Rush** ("old Einstein"),
Johnny Flynn ("young Einstein") *et al.*

<http://channel.nationalgeographic.com/genius/>

Photos © National Geographic

Series shot in Czechia!



Staff: 250 – 400 people
95 % Czech crew



Physics plays the “central role”!



Czech “physics crew”: Jiří Podolský (Fac.Math.Phys.,Charles Uni.)
Stanislav Daniš (Fac.Math.Phys.,Charles Uni.)
Pavel Cejnar (Fac.Math.Phys.,Charles Uni.)
Jiří Svoboda (Astr.Inst.,Acad.Sci.Czech Rep.)

Blackboards, blackboards, blackboards...

All together approx. 100 blackboards

Czech “physics crew”: Jiří Podolský (Fac.Math.Phys.,Charles Uni.)
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Blackboards, blackboards, blackboards...

“Playing blackboards” vs. “Background blackboards”

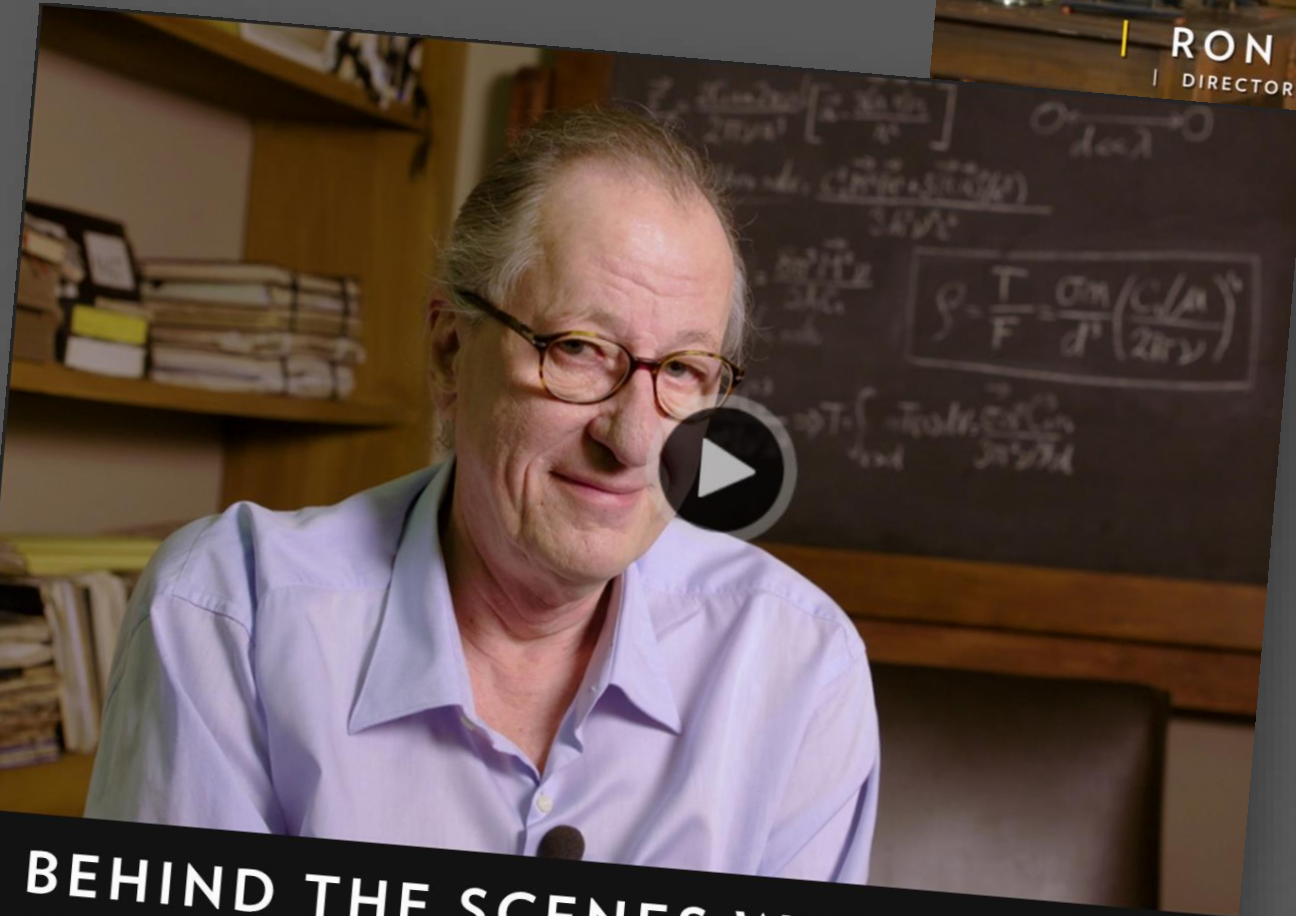


Blackboards, blackboards, blackboards...

Background blackboard: Example 1



RON HOWARD
| DIRECTOR / EXECUTIVE PRODUCER |



BEHIND THE SCENES WITH
GEOFFREY RUSH

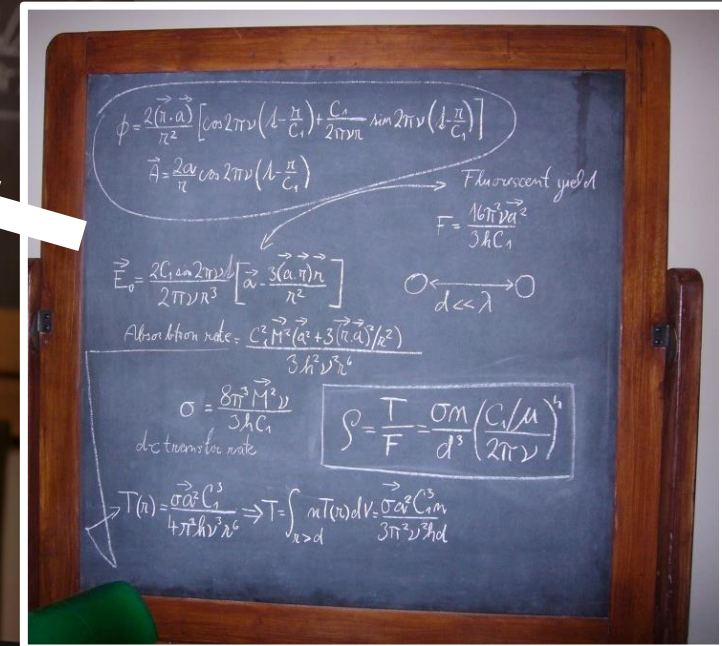
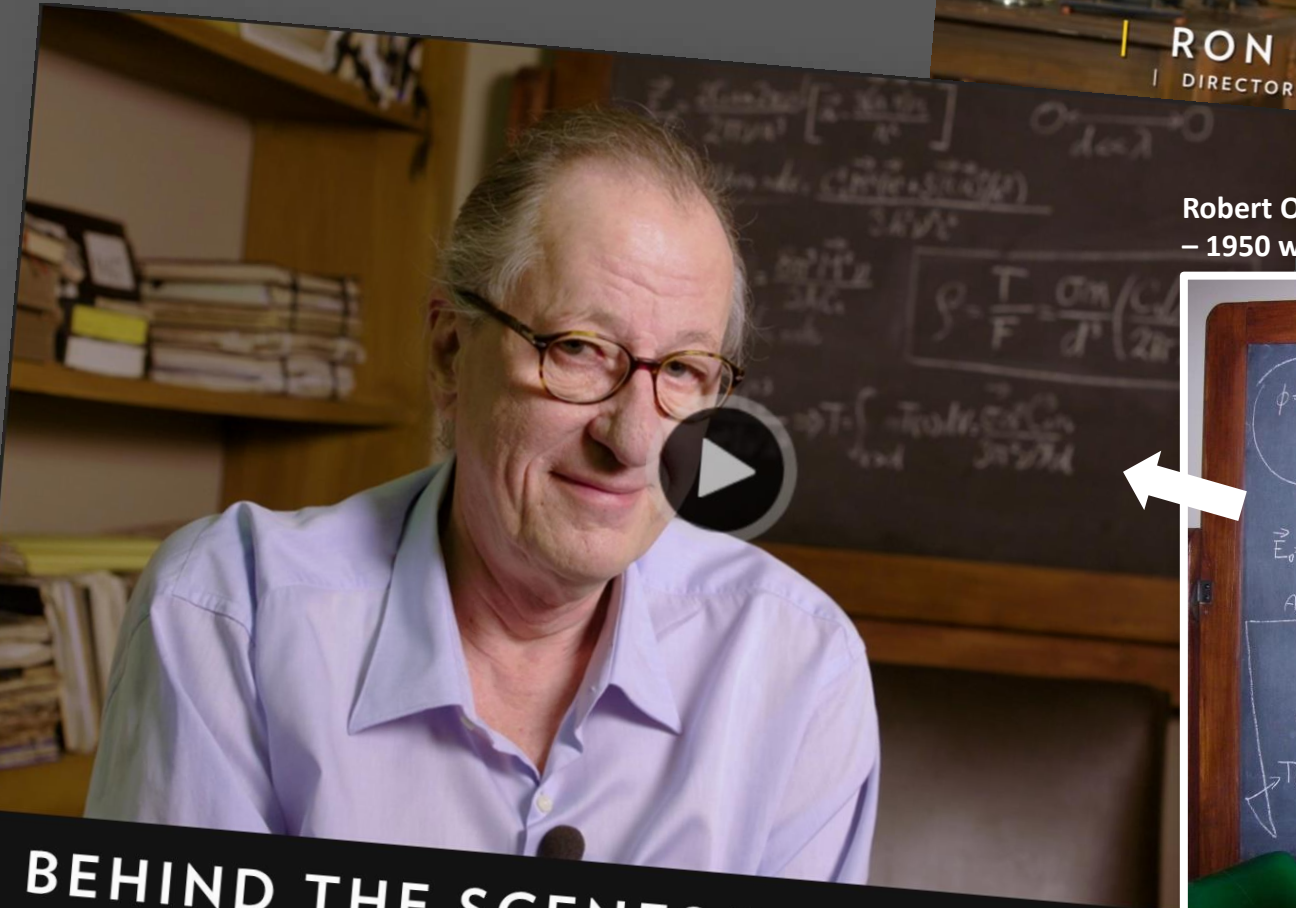
Blackboards, blackboards, blackboards...

Background blackboard: Example 1



RON HOWARD
DIRECTOR / EXECUTIVE PRODUCER

Robert Oppenheimer's blackboard
– 1950 work on photosynthesis

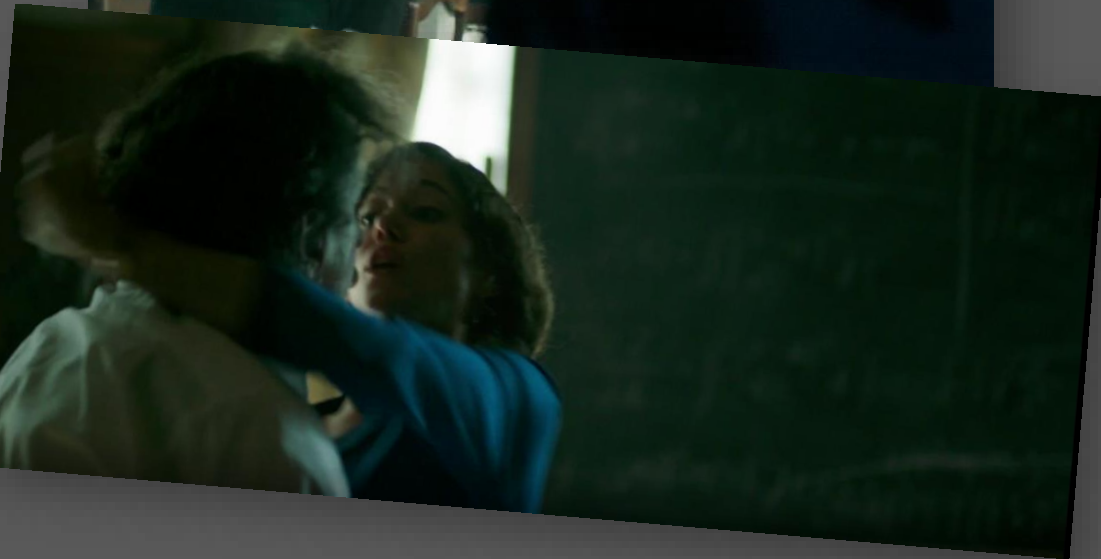


BEHIND THE SCENES WITH
GEOFFREY RUSH

Blackboards, blackboards, blackboards...

Background blackboard: Example 2

Episode 1, erotic scene, Berlin 1922



Blackboards, blackboards, blackboards...

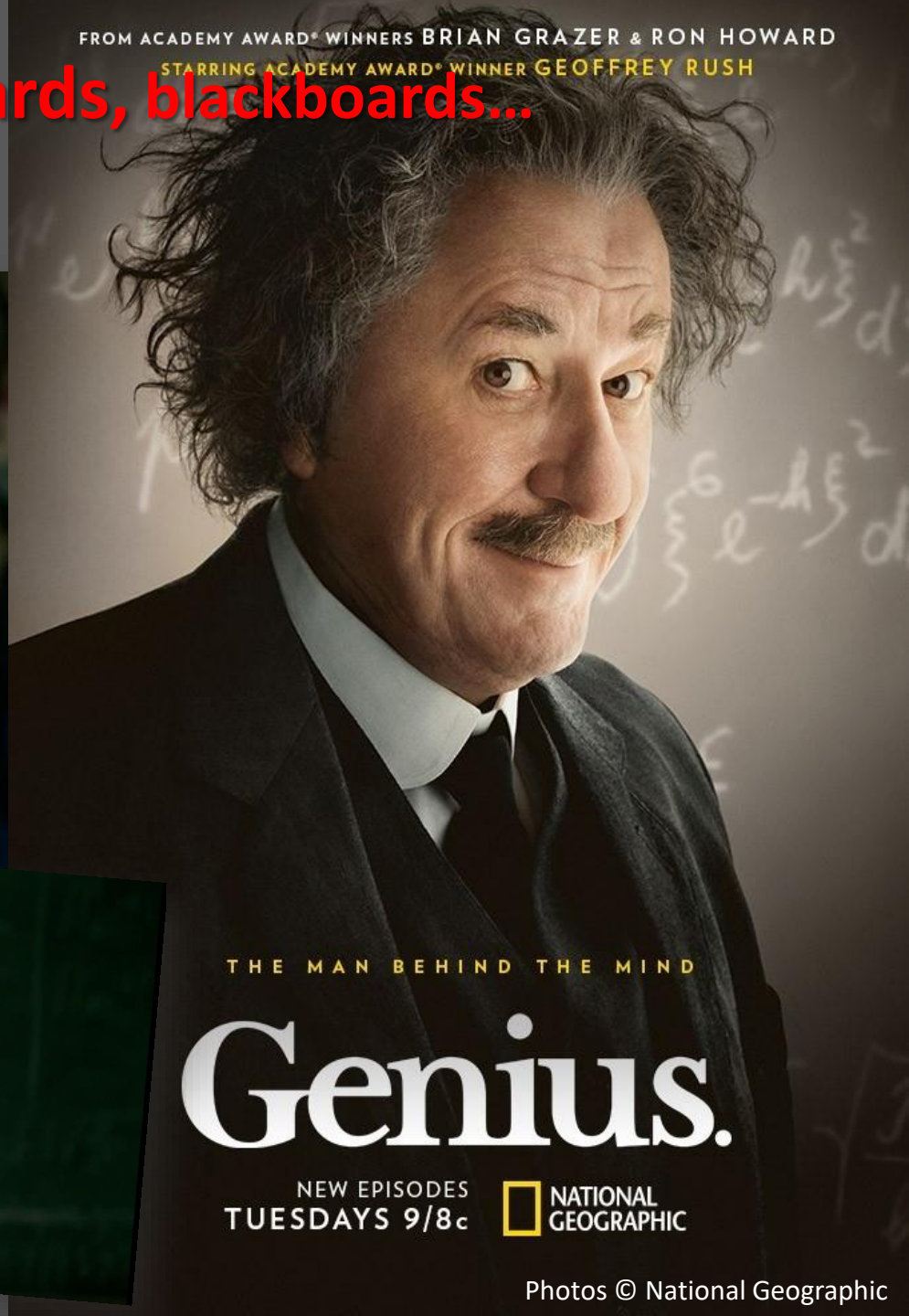
Background blackboard: Example 2

Episode 1, erotic scene, Berlin 1922



FROM ACADEMY AWARD® WINNERS BRIAN GRAZER & RON HOWARD

STARRING ACADEMY AWARD® WINNER GEOFFREY RUSH



THE MAN BEHIND THE MIND

Genius.

NEW EPISODES
TUESDAYS 9/8c



Photos © National Geographic

Blackboards, blackboards, blackboards...

Background blackboard: Example 2

Episode 1, erotic scene, Berlin 1922

FROM ACADEMY AWARD® WINNERS BRIAN GRAZER & RON HOWARD

STARRING ACADEMY AWARD® WINNER GEOFFREY RUSH

$$\int e^{-h\xi^2} d\xi = \sqrt{\frac{\pi}{h}}$$

$$\int \xi^n e^{-h\xi^2} d\xi = 0 \quad n \text{ unger.}$$

$$\int \xi^2 e^{-h\xi^2} d\xi = \frac{1}{2} \sqrt{\frac{\pi}{h^3}}$$

$$\int \xi^4 e^{-h\xi^2} d\xi = \frac{3}{4} \sqrt{\frac{\pi}{h^5}}$$

$$\int \xi^6 e^{-h\xi^2} d\xi = \frac{15}{8} \sqrt{\frac{\pi}{h^7}}$$

$$\mathcal{Y}(h) = \int \xi^4 e^{-h\xi^2} d\xi$$

$$\frac{\partial \mathcal{Y}}{\partial h} = \int -\xi^6 e^{-h\xi^2} d\xi = -\frac{5}{2} \cdot \frac{3}{4} \sqrt{\frac{\pi}{h^7}} = -\frac{15}{8} \sqrt{\frac{\pi}{h^7}}$$

THE MAN BEHIND THE MIND

Genius.

NEW EPISODES
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Courtesy: Jiří Podolský

Photos © National Geographic

Blackboards, blackboards, blackboards...

Playing blackboard: Example 1

Episode 1, secondary school, Munich 1894

Standard method of solution

$$\frac{dy}{dx} = \frac{x^2 + 3y^2}{2xy}$$
$$\frac{dy}{dx} = \frac{1 + 3\frac{y^2}{x^2}}{2\frac{y}{x}}$$

subst. $v = \frac{y}{x}$

$$y = xv$$
$$\frac{dy}{dx} = x \frac{dv}{dx} + v$$
$$x \frac{dv}{dx} + v = \frac{1 + 3v^2}{2v}$$
$$x \frac{dv}{dx} = \frac{1 + 3v^2}{2v} - v = \frac{1 + 3v^2 - 2v^2}{2v} = \frac{1 + v^2}{2v}$$
$$\frac{2v}{1 + v^2} \frac{dv}{dx} = \frac{1}{x}$$

integration by separation of variables:

$$\int \frac{2v dv}{1 + v^2} = \int \frac{dx}{x}$$

$\ln(1 + v^2) = \ln(c \cdot x)$ (*)

$$1 + v^2 = cx$$
$$v^2 = cx - 1$$
$$\frac{v^2}{x^2} = cx - 1$$
$$y^2 = cx^3 - x^2$$

that is

$$x^2 + y^2 = cx^3 = 0$$

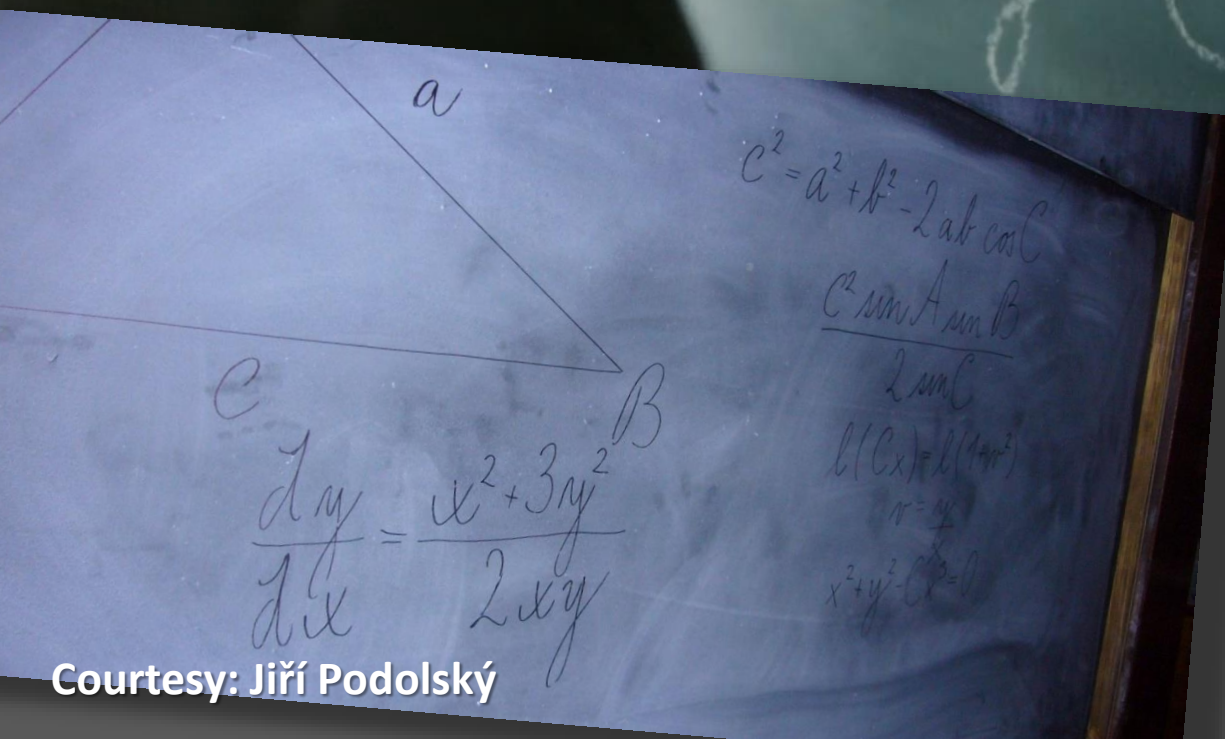
the general result

$l = \ln$

Blackboards, blackboards, blackboards...

Playing blackboard: Example 1

Episode 1, secondary school, Munich 1894



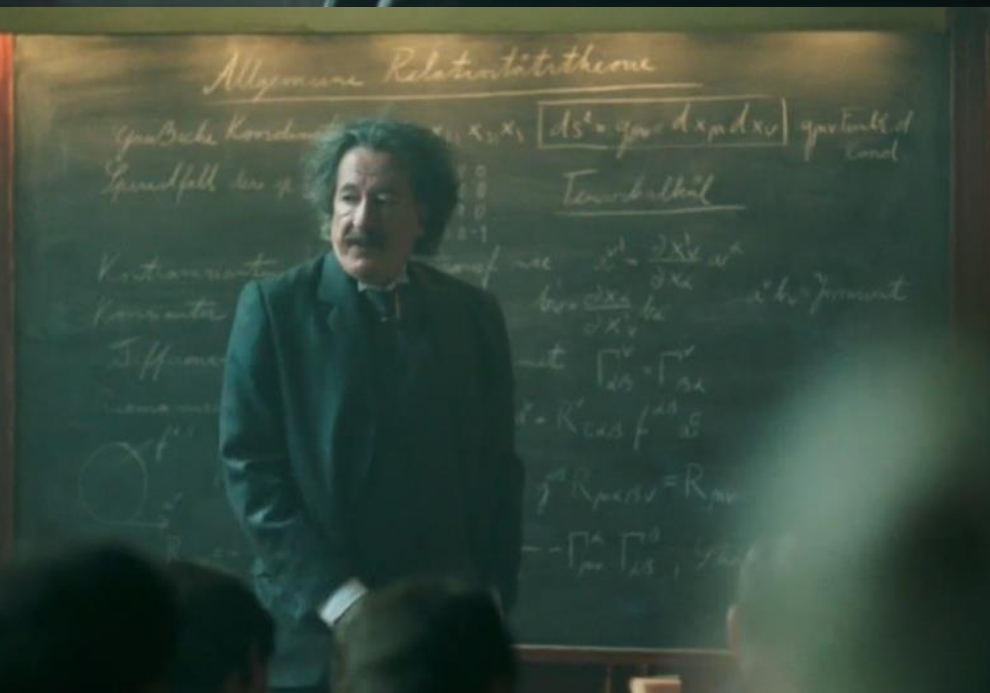
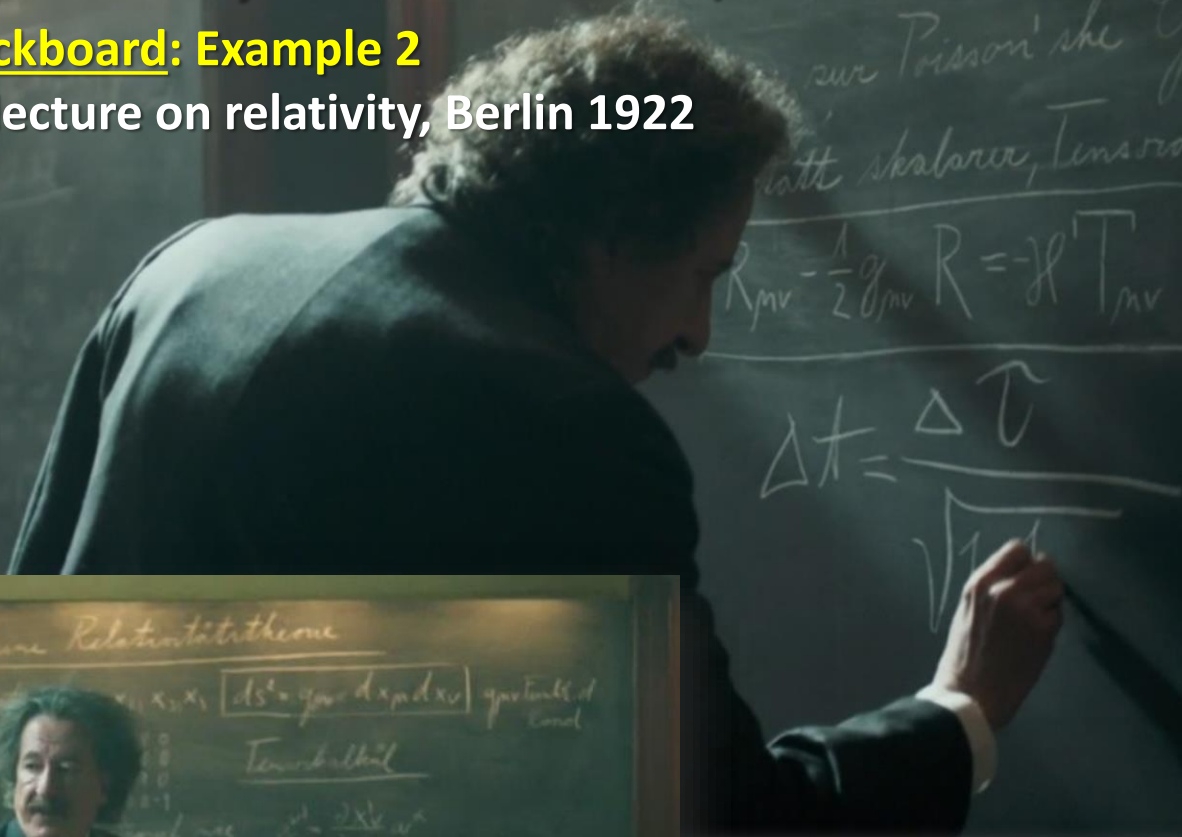
$$l = \ln$$

Courtesy: Jiří Podolský

Blackboards, blackboards, blackboards...

Playing blackboard: Example 2

Episode 1, lecture on relativity, Berlin 1922



Blackboards, blackboards, blackboards...

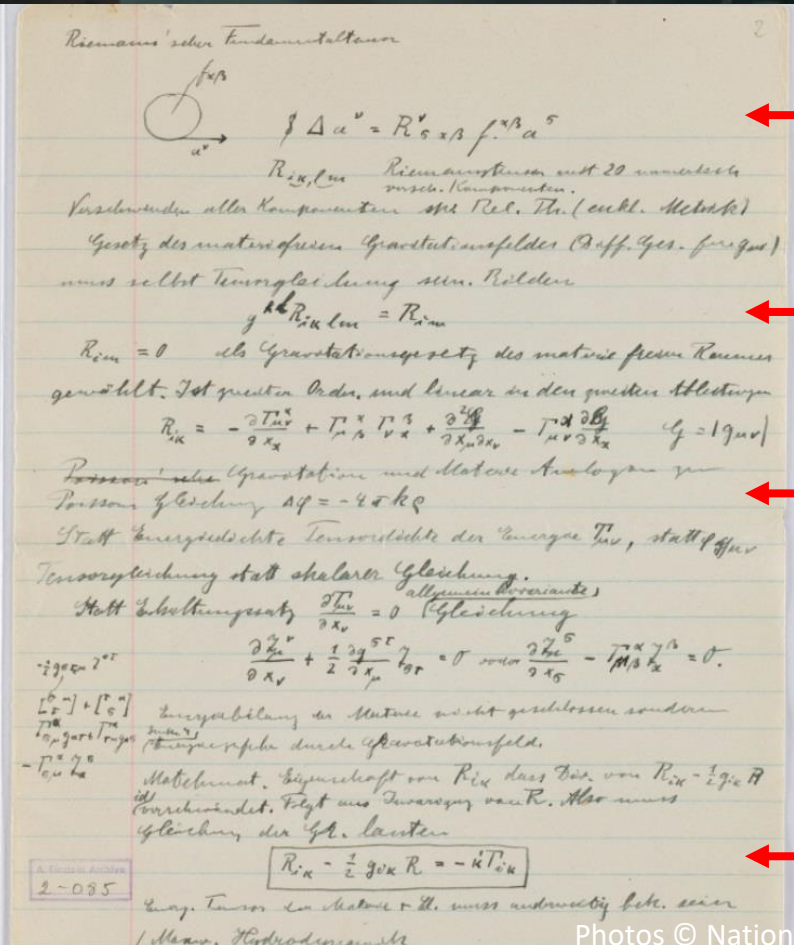
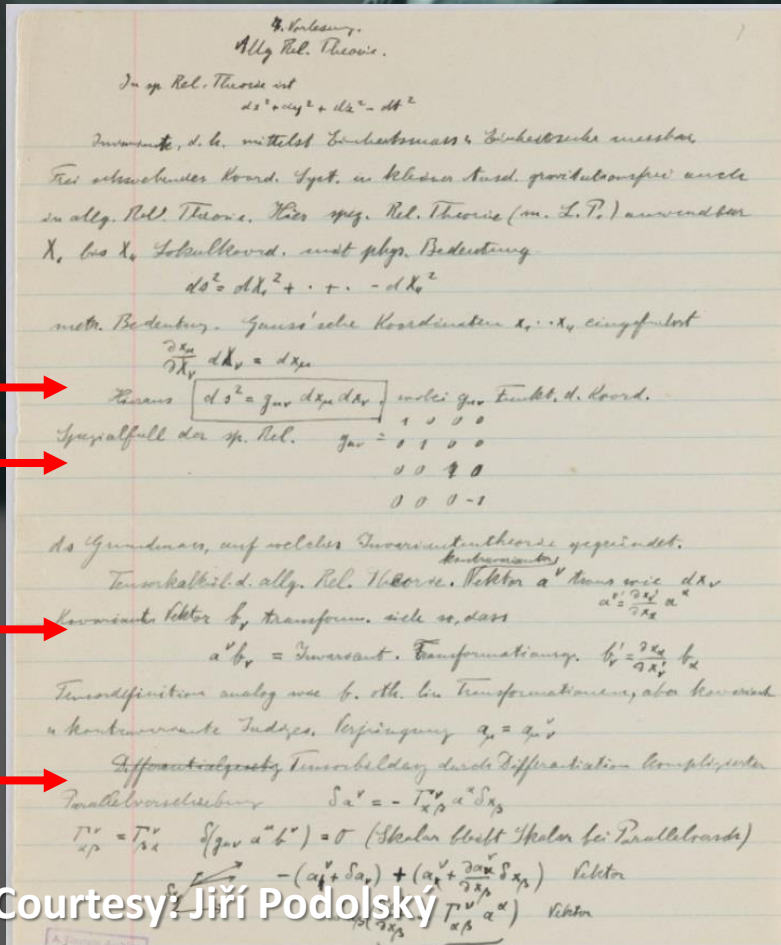
Playing blackboard: Example 2

Episode 1, lecture on relativity, Berlin 1922

Manuscript *Über die spezielle und allgemeine Relativitätstheorie 1. Vorlesung, 1921*

Albert Einstein Archives, The Hebrew University of Jerusalem

<http://www.albert-einstein.org/>



Courtesy: Jiří Podolský

Photos © National Geographic

Blackboards, blackboards, blackboards...

Playing blackboard: Example 2

Episode 1, lecture on relativity, Berlin 1922



Dr. Jiří Svoboda

Experiments, instruments, labs...

Röntgen 1895

Lenard 1901

Skłodowska, Curie 1898, 1902

Haber 1908

....



Courtesy: Stanislav Daniš

Experiments, instruments, labs...

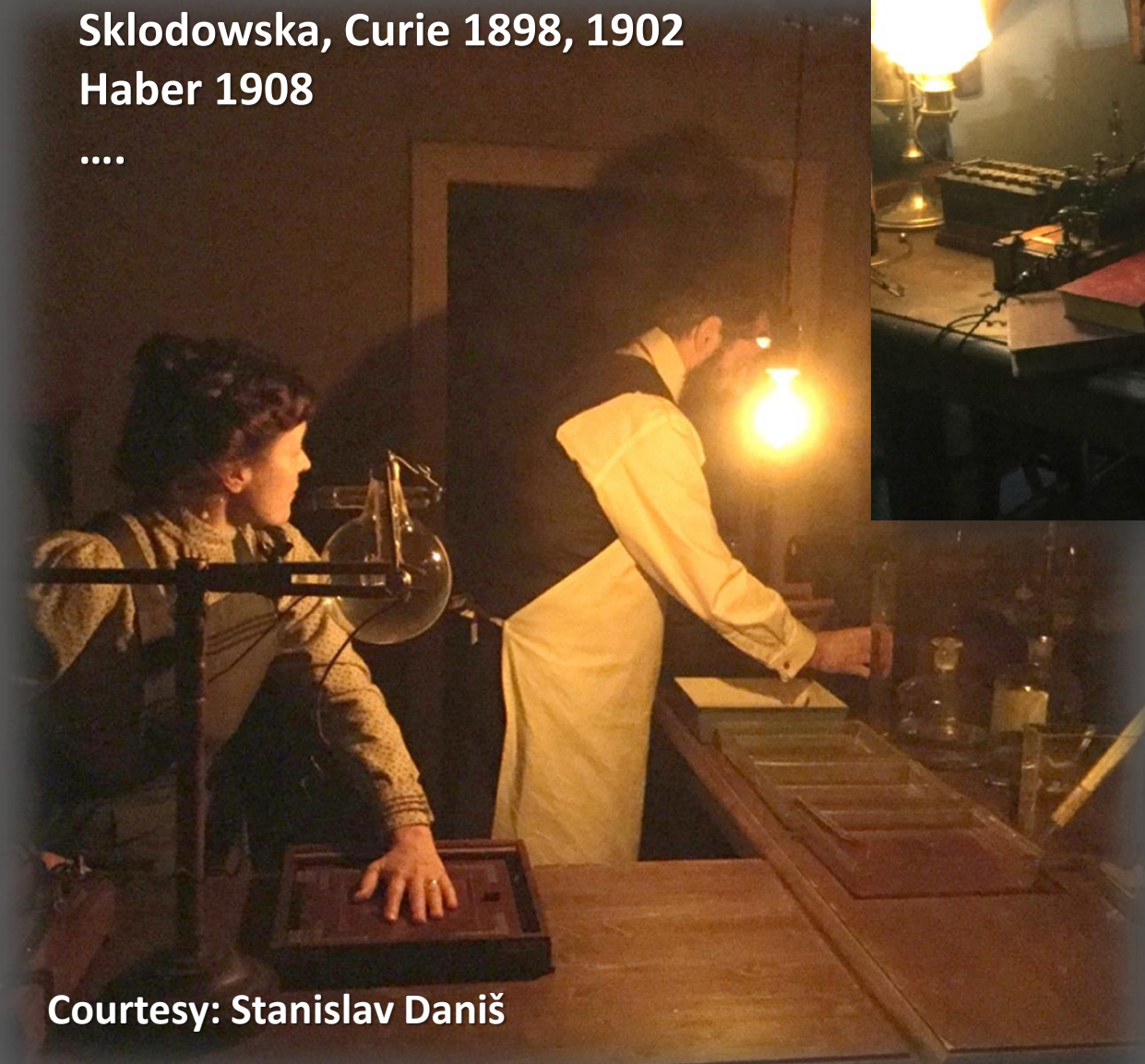
Röntgen 1895

Lenard 1901

Skłodowska, Curie 1898, 1902

Haber 1908

....



Courtesy: Stanislav Daniš

Experiments, instruments, labs...

Röntgen 1895

Lenard 1901

Skłodowska, Curie 1898, 1902

Haber 1908

....



Courtesy: Stanislav Daniš

Experiments, instruments, labs...

Uranprojekt, Berlin 1939

$$E(Z, N) = E_v + E_0 + E_c$$

Volumenenergie

$$E_v = -\sqrt{\alpha^2 + \beta^2} (Z+N) + \sqrt{\alpha^2 (Z+N)^2 + \beta^2 (Z-N)^2}$$

Oberflächenenergie

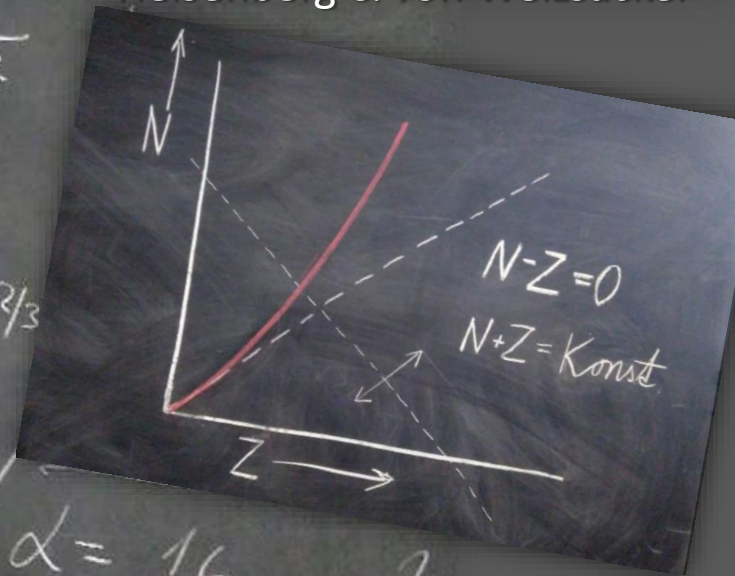
$$E_0 = \left(\sqrt{\alpha^2 + \beta^2} - \sqrt{\alpha + \beta \frac{(Z-N)^2}{(Z+N)^2}} \right) \gamma (Z+N)^{2/3}$$

Coulombschen Energie

$$E_c = \frac{3e^2}{5} \frac{Z^2}{r_0 (Z+N)^{1/3}} \left(1 - \delta \frac{|Z-N|}{Z+N} \right)$$



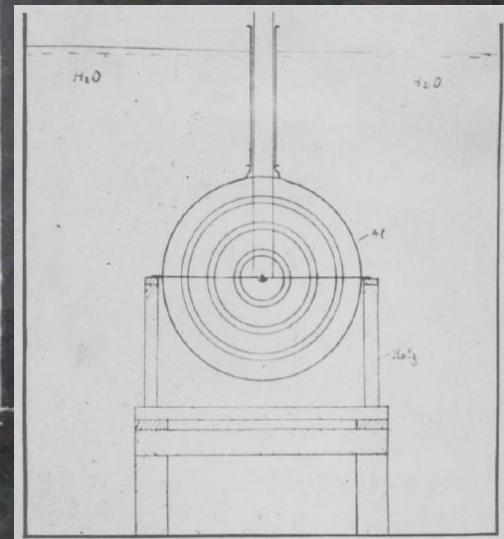
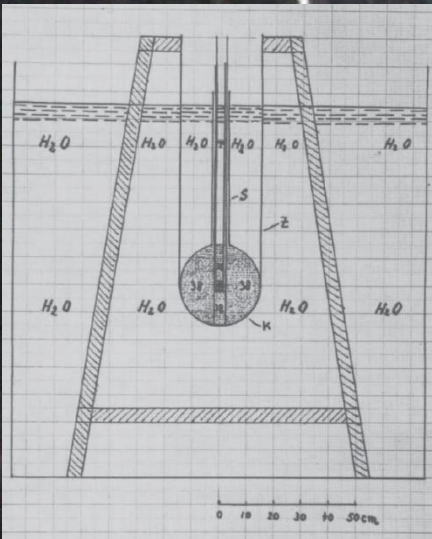
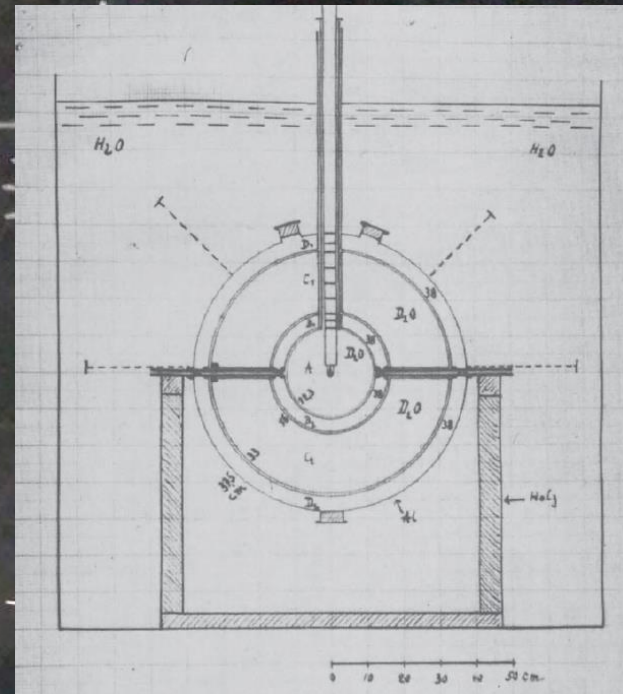
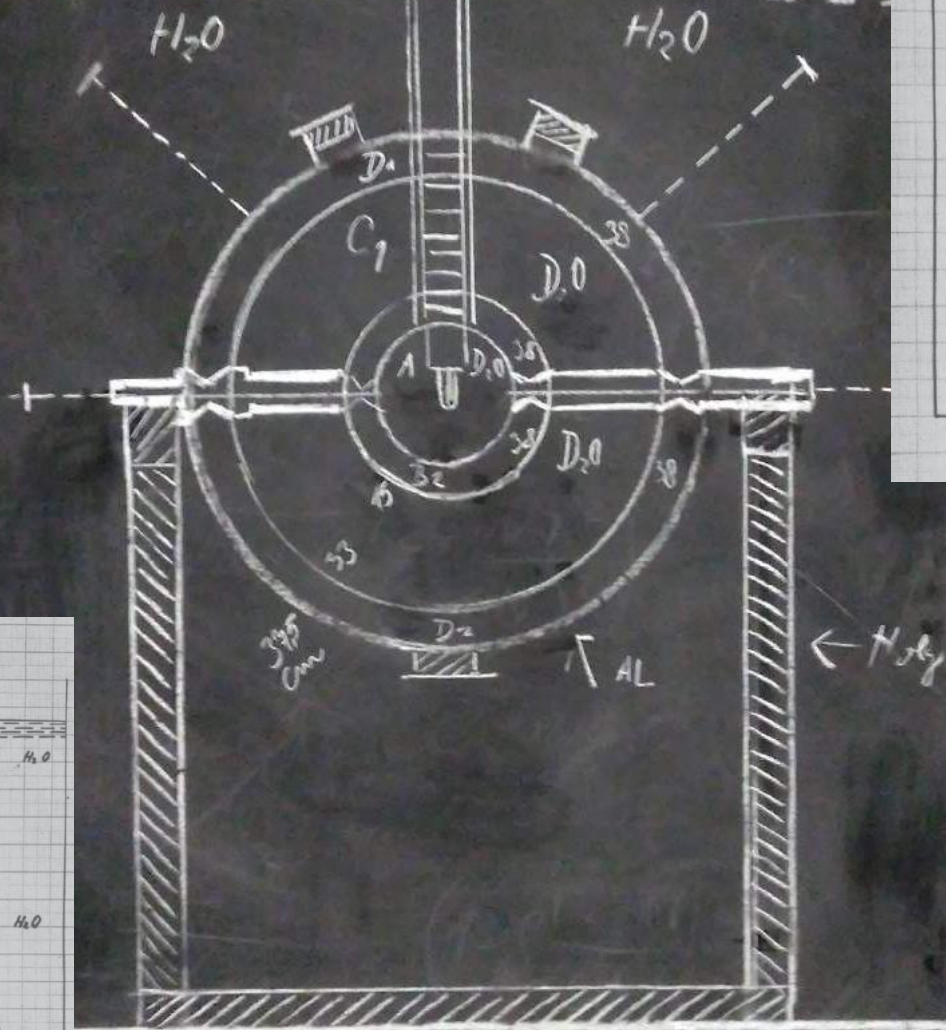
Heisenberg & von Weizsäcker



$\alpha = 1,6$	$2,6$
$\beta = 13,9$	$18,7$
$\gamma = 0,6$	$1,07$
$(\delta = 0)$	$1,1$
$r_0 = 0,45$	$0,42$

Experiments, instruments, labs...

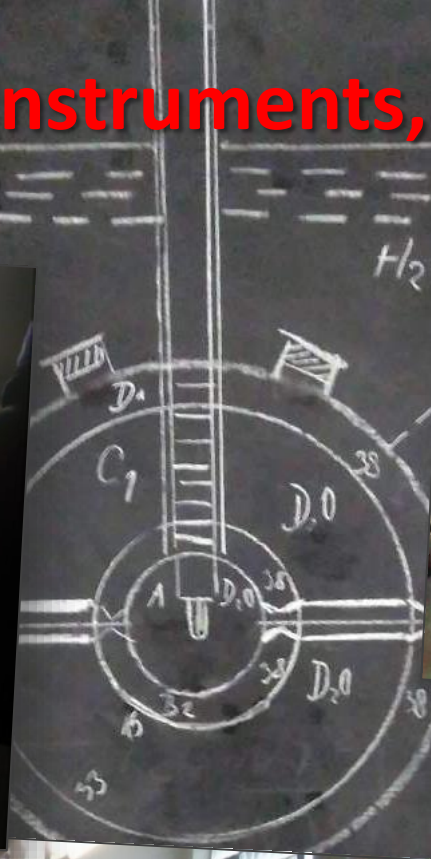
Uranprojekt, Leipzig 1942



0 10 20 30 40 50 cm

Experiments, instruments, labs...

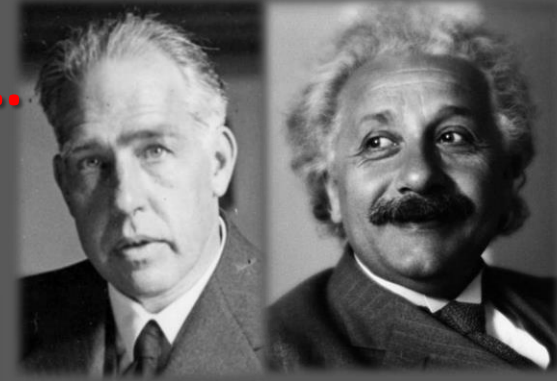
Uranprojekt, Leipzig 1942



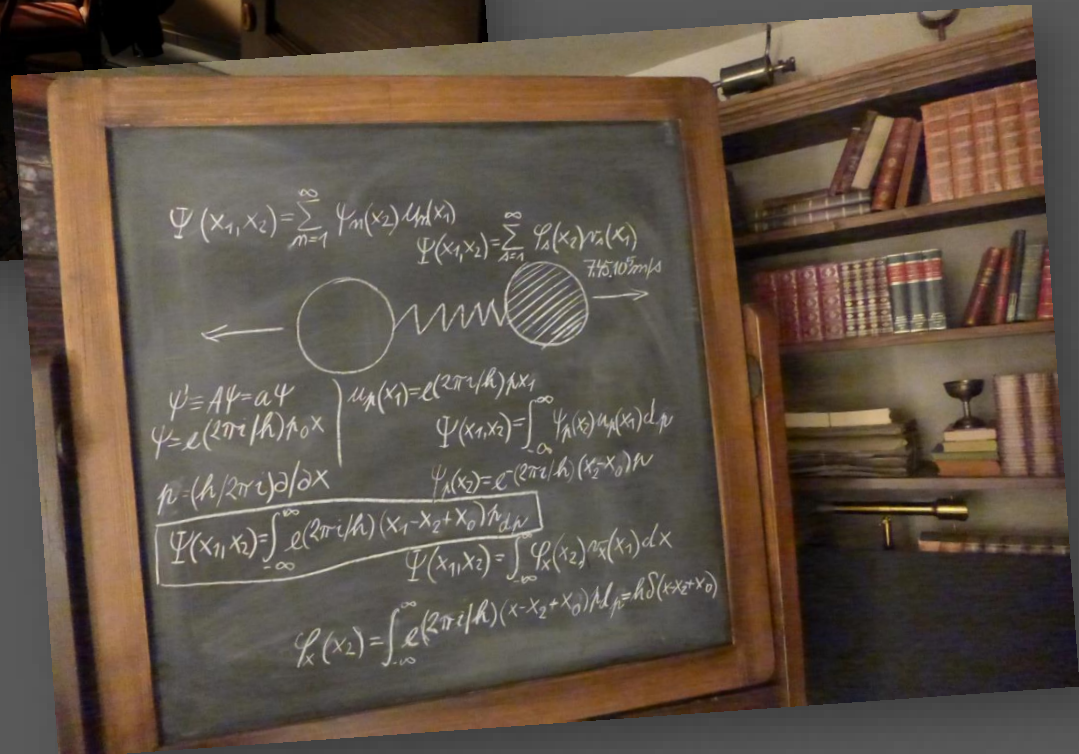
10cm

Puzzles, trickinesses, brain-twisters...

Einsten's home, Princeton 1935

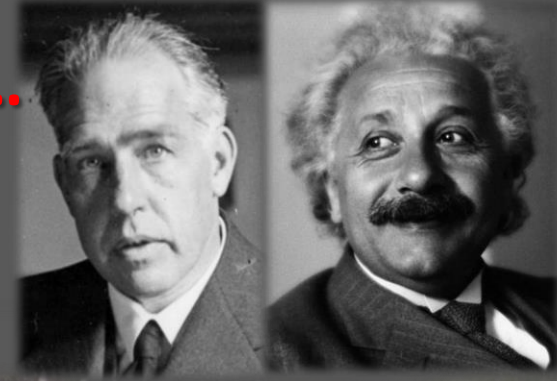


Einstein explains
Bohr the **idea of
the EPR paper** on
incompleteness of
quantum theory



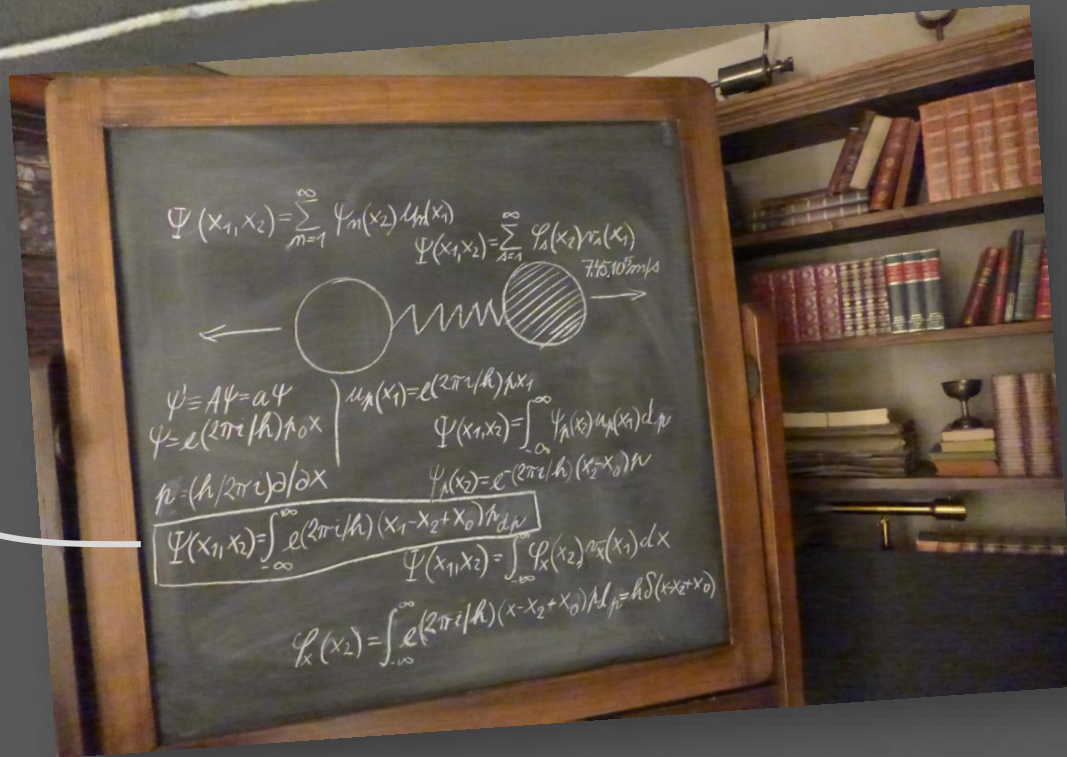
Puzzles, trickinesses, brain-twisters...

Einsten's home, Princeton 1935



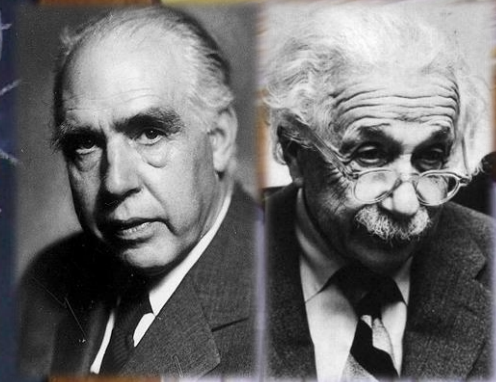
$$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} e^{(2\pi i/\hbar)(x_1 - x_2 + x_0)p} \nu dp$$

Einsten explains Bohr the **idea of the EPR paper** on incompleteness of quantum theory



Puzzles, trickinesses, brain-twisters...

Einsten's office, Princeton 1951



$$\Psi(1,2) = f(1)f(2) \frac{1}{\sqrt{2}} (u_+(1)u_-(2) - u_-(1)u_+(2))$$

$$U(1,2) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & ++ \\ 0 & -- \\ 1 & +- \\ 1 & -+ \end{pmatrix}$$

$$P(1,2) = \frac{1}{2} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

$$P(2) = \text{Tr}^{(1)} P(1,2) = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

$$q^2 = \frac{\hbar}{m^2} \text{Im} \frac{(\Psi(1,2), \vec{D}_2 \Psi(1,2))}{(\Psi(1,2), \Psi(1,2))}$$

$$= \frac{|f_+(1)|^2 |f_-(2)|^2 + |f_-(1)|^2 |f_+(2)|^2}{|f_+(1)|^2 |f_-(2)|^2 + |f_-(1)|^2 |f_+(2)|^2}$$

Diagrams showing spin and space components:

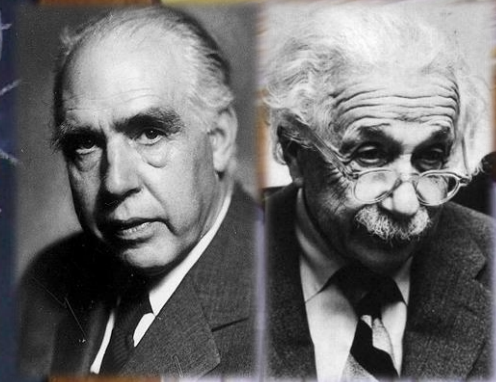
- Spin: u_+ , u_-
- Space: f_+ , f_-
- Labels: 1 , 2 , $+$, $-$, \times

Einsten and Bohr have a **quarrel** about quantum theory



Puzzles, trickinesses, brain-twisters...

Einsten's office, Princeton 1951



Spin formulation of EPR

$$\Psi(1,2) = f(1)f(2) \frac{1}{\sqrt{2}} (u_+(1)u_-(2) - u_-(1)u_+(2))$$

↑ → ← +
z | B₁ |
space spin u(1,2)

Bohr: Density matrix approach

Spin:

$$u(1,2) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & ++ \\ 0 & -- \\ 1 & +- \\ 1 & -+ \end{pmatrix}$$

$$\rho(1,2) = \frac{1}{2} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & -\frac{1}{2} \\ 0 & 0 & -\frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{matrix} ++ \\ -- \\ +- \\ -+ \end{matrix}$$

$$\rho(2) = \text{Tr}^{(1)} \rho(1,2) = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \begin{matrix} + \\ - \end{matrix}$$

Einstein: Bohmian interpretation

$$\frac{1}{\sqrt{2}} (f_+(1)f_-(2)u_+(1)u_-(2) - f_-(1)f_+(2)u_-(1)u_+(2))$$

$$\Rightarrow \frac{\hbar}{m^2} \text{Im} \frac{(\Psi(1,2) \nabla_2 \Psi(1,2))}{(\Psi(1,2), \Psi(1,2))}$$

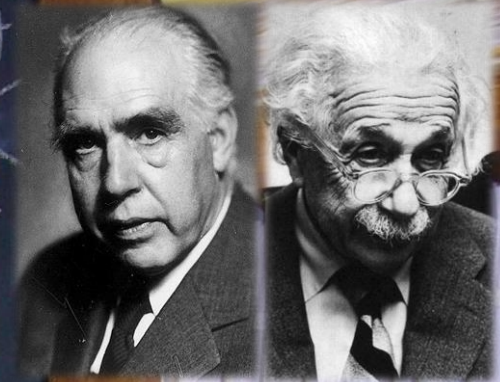
$$= \frac{|f_+(1)|^2 |f_-(2)|^2 + |f_-(1)|^2 |f_+(2)|^2}{|f_+(1)|^2 |f_-(2)|^2 + |f_-(1)|^2 |f_+(2)|^2}$$

Einstein and Bohr have a **quarrel about quantum theory**



Puzzles, trickinesses, brain-twisters...

Einsten's office, Princeton 1951



Spin formulation of EPR

$$\Psi(1,2) = f(1)f(2) \frac{1}{\sqrt{2}} (u_+(1)u_-(2) - u_-(1)u_+(2))$$

space spin $u(1,2)$

Bohr: Density matrix approach

Spin:

$$u(1,2) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{matrix} ++ \\ -- \\ +- \\ -+ \end{matrix}$$

$$\rho(1,2) = \frac{1}{2} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{matrix} ++ \\ -- \\ +- \\ -+ \end{matrix}$$

$$\rho(2) = \text{Tr}^{(1)} \rho(1,2) = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

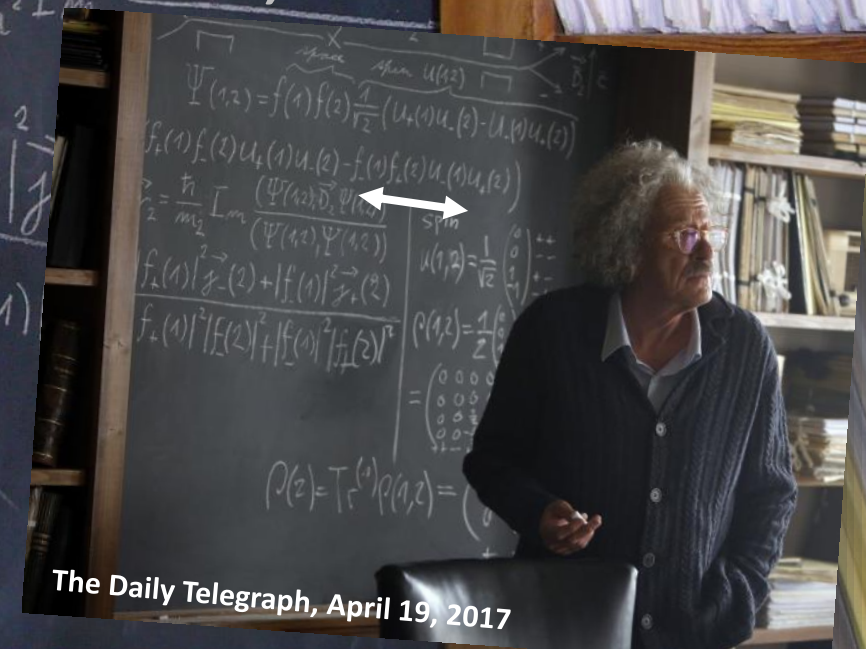
Einstein: Bohmian interpretation

$$\frac{1}{\sqrt{2}} (f_+(1)f_-(2)u_+(1)u_-(2) - f_-(1)f_+(2)u_-(1)u_+(2))$$

$$\dot{q}^2 = \frac{\hbar}{m^2} \nabla \cdot (\Psi(1,2), \vec{\nabla}_2 \Psi(1,2))$$

$$= \frac{|f_+(1)|^2}{|f_+(1)|^2}$$

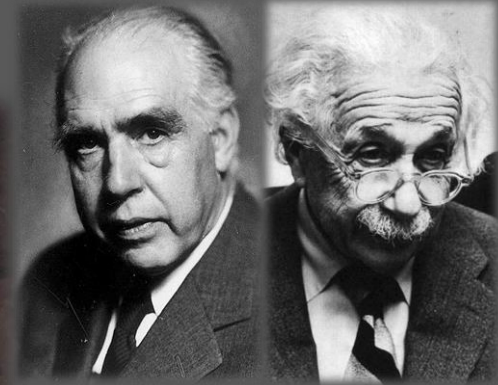
Einstein and Bohr have a **quarrel about quantum theory**



The Daily Telegraph, April 19, 2017

Puzzles, trickinesses, brain-twisters...

Einsten's office, Princeton 1955



Dies mach k abgeleitet

$$\frac{1}{2} [(-U_{i,s}^s + \gamma_{i,s}^s)_{,ll} + U_{k,s,k,i}^s - U_{i,s,kk}^s] + (U_{i,k,l}^l + \frac{1}{2} \gamma_{i,k}^k)_{,ll} = 0$$

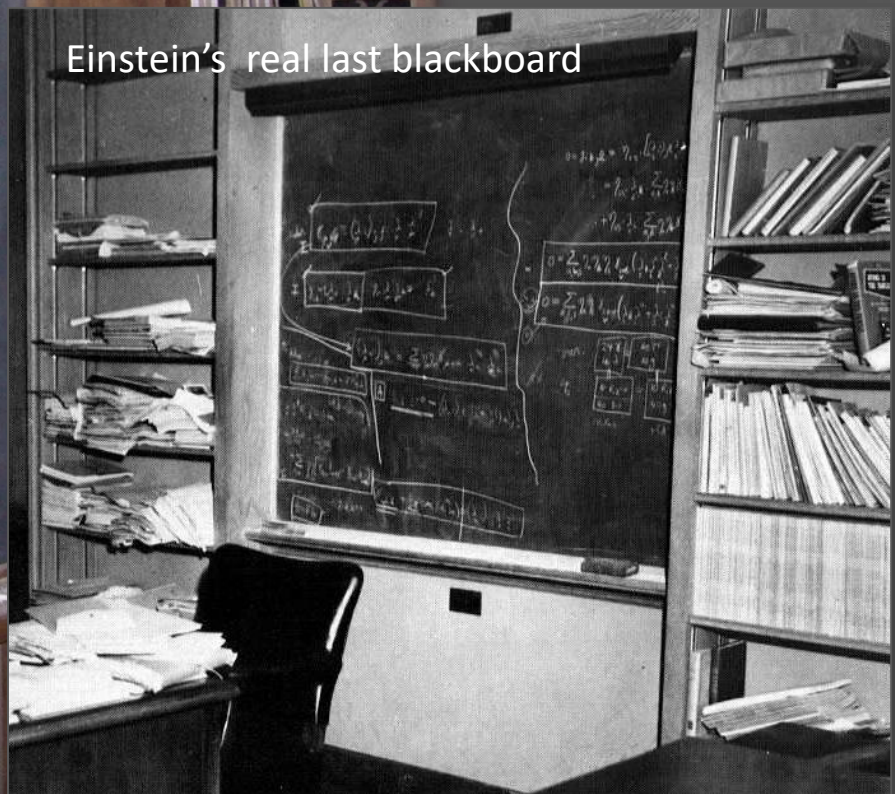
Für die Gleichungen erster Näherung mit dieser Formel ist die Identität $U_{k,i}^s = 0$ als strenge Feldgl., so reduziert sich dies zu

$$\gamma_{i,s,ll}^s + \frac{1}{2} \gamma_{l,k,l}^k + U_{i,k,l,k}^l = 0 \quad \left| \begin{array}{l} \gamma_{i,k}^k = \gamma_{i,l}^l \\ U_{i,k,l,k}^l = U_{i,l,k,k}^k \end{array} \right.$$

Es ergibt sich die Gleichung

$$\frac{1}{2} \gamma_{i,s,ll}^s - \frac{1}{2} \gamma_{l,k,l}^k + (U_{i,l}^l + U_{i,k}^k)_{,k} = 0$$

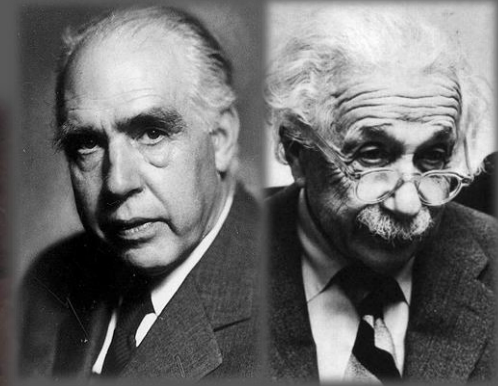
Bohr notices a mistake — **wrong third derivative** — on Einstein's blackboard



Einstein's real last blackboard

Puzzles, trickinesses, brain-twisters...

Einsten's office, Princeton 1955



Albert Einstein Archives, The Hebrew University of Jerusalem
Archival Call Number 3-12

Dies nach k abgeleitet

$$\frac{1}{2} [(-U_{i,s}^s + g_{i,s}^{i,s})_{,ll} + U_{k,s,k,i}^s - U_{i,s,kk}^s] + (U_{i,k,e}^e)_{,k} + \frac{1}{2} (g_{i,s}^{i,k})_{,kk} = 0$$

Für die Gleichungen erster Näherung ist dies eine Identität. Hat man $U_{k,s}^s = 0$ als strenge Feldgl., so reduziert sich dies zu

$$g_{i,s,ell}^{i,s} + \frac{1}{2} g_{l,kk}^{i,k} + U_{i,k,e}^e = 0$$

Im zweiten Näherung genau ist hier

Dies nach k abgeleitet

$$\frac{1}{2} (-g_{i,ee}^{i,k} + U_{k,s,i}^s + g_{s,i}^{k,s} - U_{i,s,k}^s - g_{i,s,k}^{i,s}) + U_{i,k,e}^e$$

$$\equiv \frac{1}{2} (-g_{i,ee}^{i,k} + g_{e,i}^{k,e} - g_{e,k}^{i,i})$$

Dies nach k abgeleitet

$$\frac{1}{2} [(-U_{i,s}^s + g_{i,s}^{i,s})_{,ee} + U_{k,s,k,i}^s - U_{i,s,kk}^s] + (U_{i,k,e}^e)_{,k} + \frac{1}{2} (g_{i,s}^{i,k})_{,kk} = 0$$

Für die Gleichungen erster Näherung ist dies eine Identität. Hat man $U_{k,s}^s = 0$ als strenge Feldgl., so reduziert sich dies zu

$$-\frac{1}{2} g_{i,ee}^{i,s} + \frac{1}{2} g_{e,k,e}^{i,k} + U_{i,k,e}^e = 0$$

Das zweite Näherung genau ist hier

$$g_{i,e}^{i,k} = -g_{i,e}^{i,k} \quad | \quad U_{i,k,e}^e = U_{i,s}^s + U_{s,k}^s$$

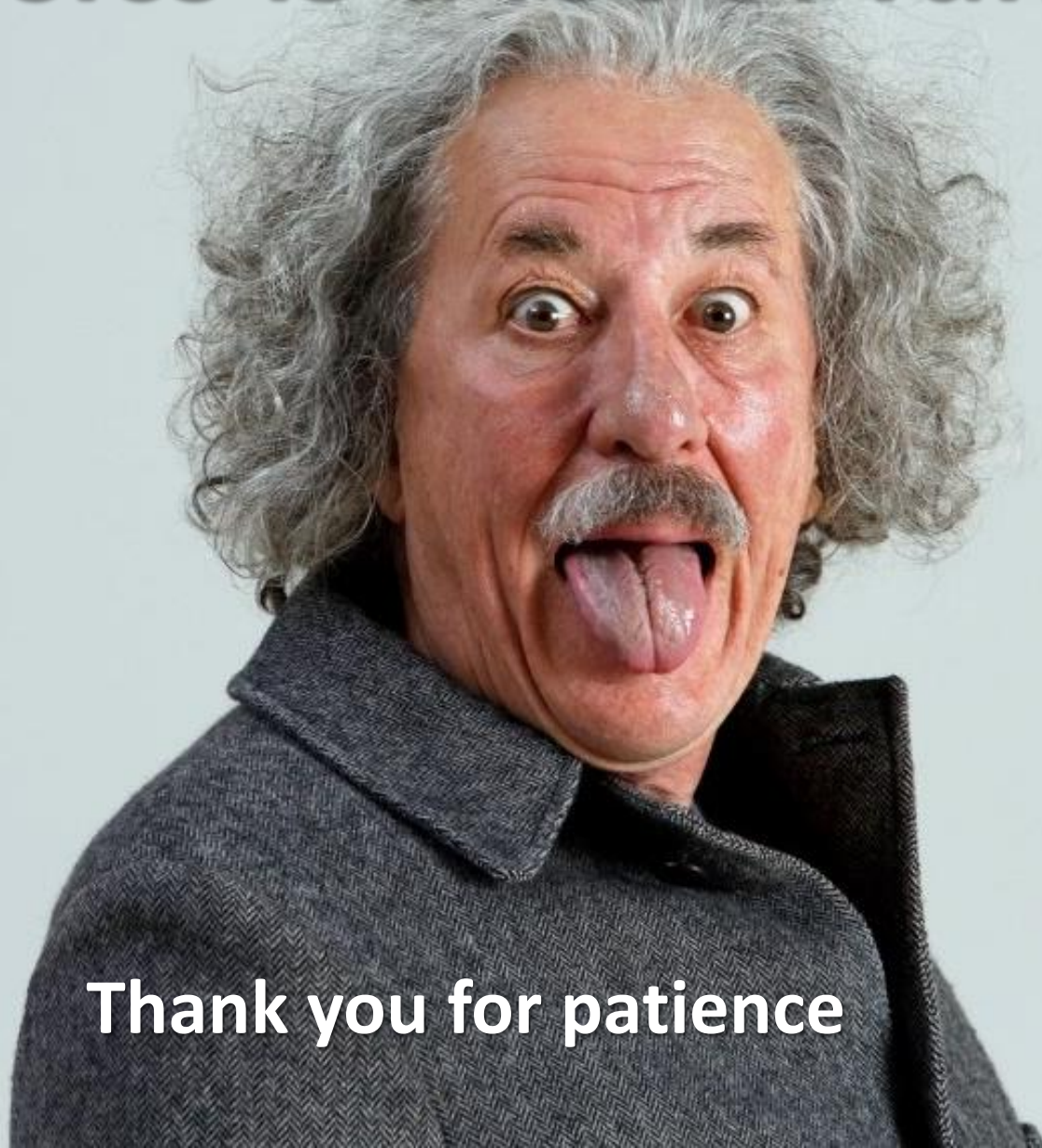
Es ergibt sich also die Gleichung

$$\frac{1}{2} g_{i,ee}^{i,s} - \frac{1}{2} g_{e,k,e}^{i,k} + (U_{i,s}^s + U_{s,k}^s)_{,k} = 0$$

Bohr notices a mistake – wrong third derivative – on Einstein's blackboard

Courtesy: Jiří Podolský

Physics is a lot of fun !



Thank you for patience