Sprott School of Business
Carleton University

TIM Technology Innovation Management

Carleton University

Quantum Technology Business Seminar

Do you need a cat to understand how quantum computing works? A brief intro to the key concepts.

Invited Speaker: Dr. Khaled Mnaymneh, NRC Canada
9:00am-10:30am

Moderated by Stoyan Tanev & David Hudson
TIM Program, Sprott School of Business, Carleton University

Technology Innovation Management Program (TIM)

Sprott School of Business

Carleton University | Ottawa, Canada

Carleton University | Sprott School of Business

https://carleton.ca/tim/quantum-projects-in-tim/

Quantum Projects in TIM | Quantum Technology Workshops | Master Degrees Explore Quantum Business Opportunities

Quantum Technologies for Business Seminars

Explore Quantum Business Opportunities

by Sharing Knowledge/ Exchanging Ideas/ Engaging in Partnerships

Hosted by: Technology Innovation Management (TIM) Program, Sprott School of Business, Carleton University at CU@Kanata, 350 Legget Drive, Suite 101

Moderated by: Stoyan Tanev & David Hudson (TIM/Sprott/Carleton); Khaled Mnaymneh (NRC); Martin Laforest (Quantacet); Louise Davey (LDIQ)

Masters in TIM Pathways

Master of Technology

MTECH is a project-based degree offers an opportunity for students to apply their technical knowledge to solve real-world problems

Master of Entrepreneurship

MENT is a project-based program that focuses on improving the health of new companies or new lines of business

Master of Digital Transformation & Entrepreneurship

MDTE is a project-based program that enables aspiring young professionals to acquire skills and competences needed to lead digital transformation initiatives

Master of Applied Business Analytics

MABA is a project-based program that targets individuals who want to specialize in the application of advanced business analytics to solve technology problems

Master of Science

MSc degree is thesis-based. Students undertake original research to address a highly relevant technology management issue under the supervision of an experienced faculty member

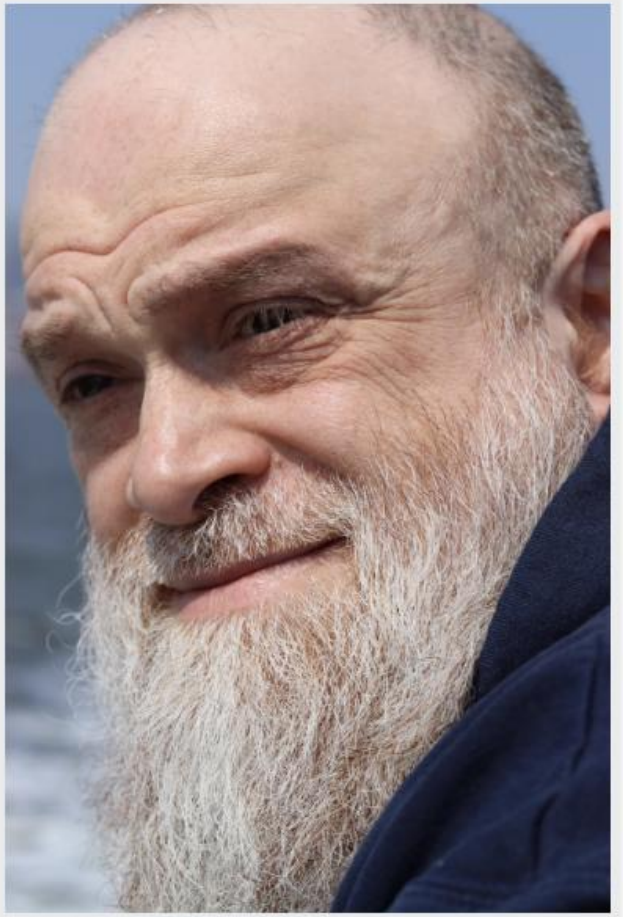
Khaled Mnaymneh

Roles and responsibilities

Khaled Mnaymneh leads strategic quantum, nanotechnology, and advanced materials development for the Government of Canada. His work spans foundational physics, device engineering, and national capability building. He drives research on quantum measurement, quantum–classical interfaces, nanofabrication, photonics, and semiconductor materials that enable next-generation sensors, networks, and information systems.

Khaled advises senior leadership on where Canada should invest, how to build sovereign capability in quantum and nanofabrication, and how to translate advanced materials research into practical technologies. He builds partnerships across academia, industry, and government, shaping programs that connect deep scientific insight to real-world platforms.

In the lab, he advances quantum devices, phononics, photonics, and nanoscale fabrication workflows, while mentoring researchers and developing new processes and infrastructure. He links fundamental science with actual technology development and helps guide NRC's national strategy in quantum and nanotech.



Khaled Mnaymneh

Senior Research Officer
Quantum and Nanotechnologies

TIM SHOWCASE

Thursday May 7th, 2026

8:00AM-1:00PM

Richcraft Hall

- Engage with talented students and alumni
- Discover groundbreaking projects
- Connect with faculty and thought leaders
- Network with top innovation leaders

REGISTER TODAY

Interested in attending?
Contact: **Dan Premachuk**
(dan.premachuk@carleton.ca)

Sprott School of Business
Carleton University

TIM
Technology Innovation Management

Do you need a cat to understand Quantum Mechanics?

A brief history of key concepts

Dr Khaled Mnaymneh, PEng

WHAT NRC DOES

Delivering Value to Canada in Two Ways

12 research centres performing research and technical services with partners:

DIGITAL TECHNOLOGIES	• Digital Technologies
EMERGING TECHNOLOGIES	• Metrology • Herzberg Astronomy and Astrophysics • Quantum and Nanotechnologies • Canadian Photonics Fabrication Centre
ENGINEERING	• Construction • Energy, Mining and Environment • Ocean, Coastal and River Engineering
LIFE SCIENCES	• Aquatic and Crop Resource Development • Human Health Therapeutics • Medical Devices
TRANSPORTATION AND MANUFACTURING	• Aerospace • Automotive and Surface Transportation

National program:

The Industrial Research Assistance Program (IRAP) provides a comprehensive suite of innovation services and funding to help drive SME growth and stimulate wealth creation in Canada.

NRC Strategic Priorities

2024-2029 Strategic Plan

Key research, innovation and organizational priorities of importance to us and Canadians

Mechanisms of Collaboration

CSTIP Programs

Grants and contributions to bring together academia, industry and government to attain critical mass to deliver technological breakthroughs

Collaboration Centres

Co-location of NRC researchers and infrastructure with academia to foster joint research and training opportunities for young scientists

Technical Services

Providing services and access to facilities to support business innovation. Include testing, prototyping, demonstrations, calibration and more

International Projects

Collaboration to advance R&D, train new talent, leverage investments and facilitate knowledge exchange with allies

Other Collaborations

- Joint calls for projects with co-funding
- Unfunded collaborator on projects
- Professional services
- HQP exchange

Our Role to Support the National Quantum Strategy

"Funding, de-risking and creating supportive policy frameworks for emerging technologies, convening and coordinating, procuring goods and services, and serving as a research partner."

The NRC supports all Canadian strategies on quantum

- NRC Quantum R&D Initiative ($9.0M)
- NRC Challenge Programs ($50.0M)

NRC funded initiatives

National Metrology Institute Initiatives

nmiQ

Canadian Quantum Strategies

NRC Quantum + Portfolio

COLLABORATION R&D PROGRAMS

- Small teams and Ideation projects
- High-throughput and Secure Networks
- Quantum Sensors
- Applied Quantum Computing
- Quantum InterNetworking (NEW)

RESEARCH CENTRES

- Quantum & Nanotechnologies Research Centre
- Metrology Research Centre
- Digital Technologies

BUSINESS INNOVATION

- Canadian Photonics Fabrication Centre
- Industrial Research Assistance Program

COLLABORATION CENTRE

- Joint Centre for Extreme Photonics

Illustration: Weirdness of Quantum

- Mach-Zehender Interferometer

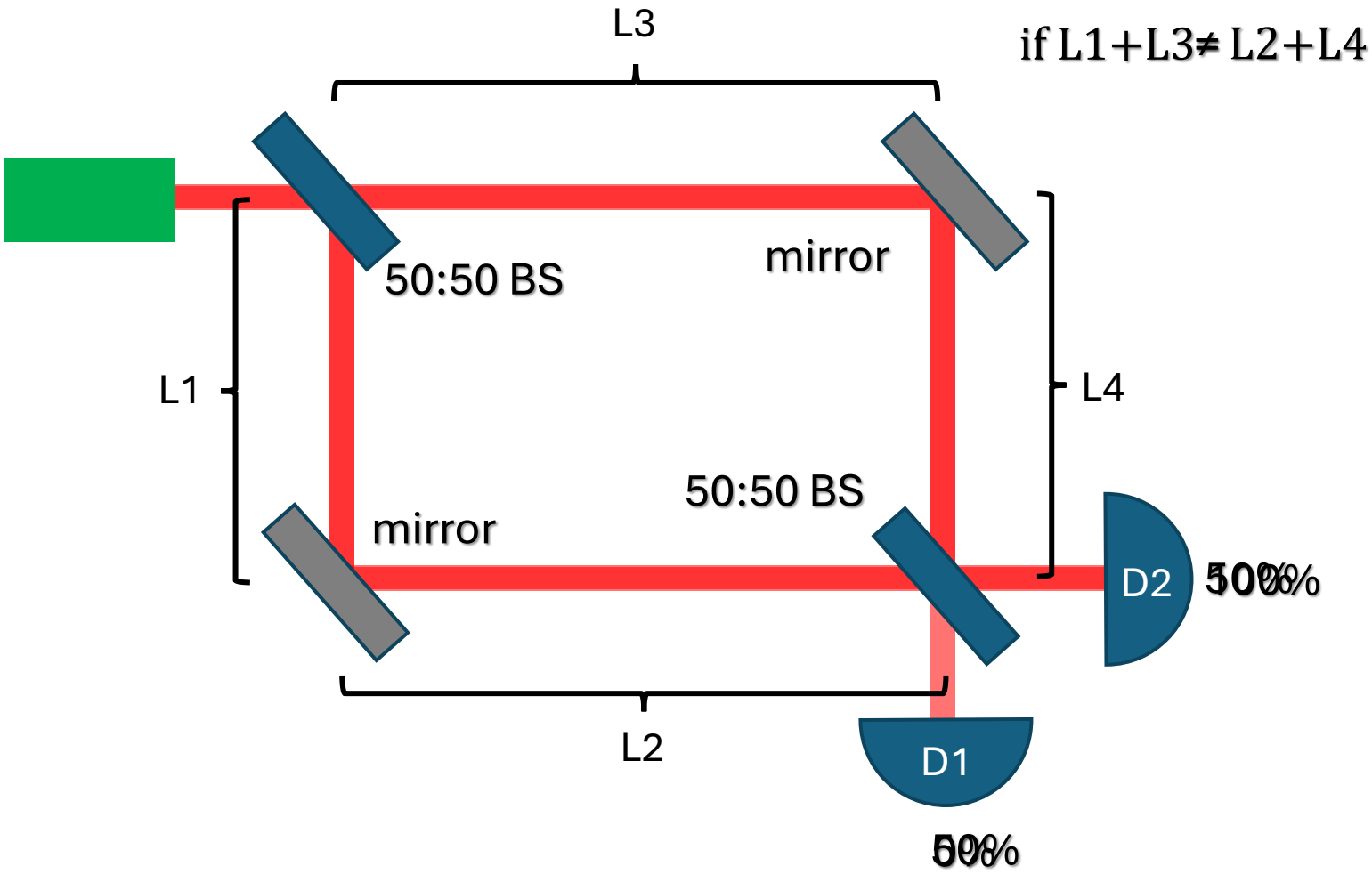
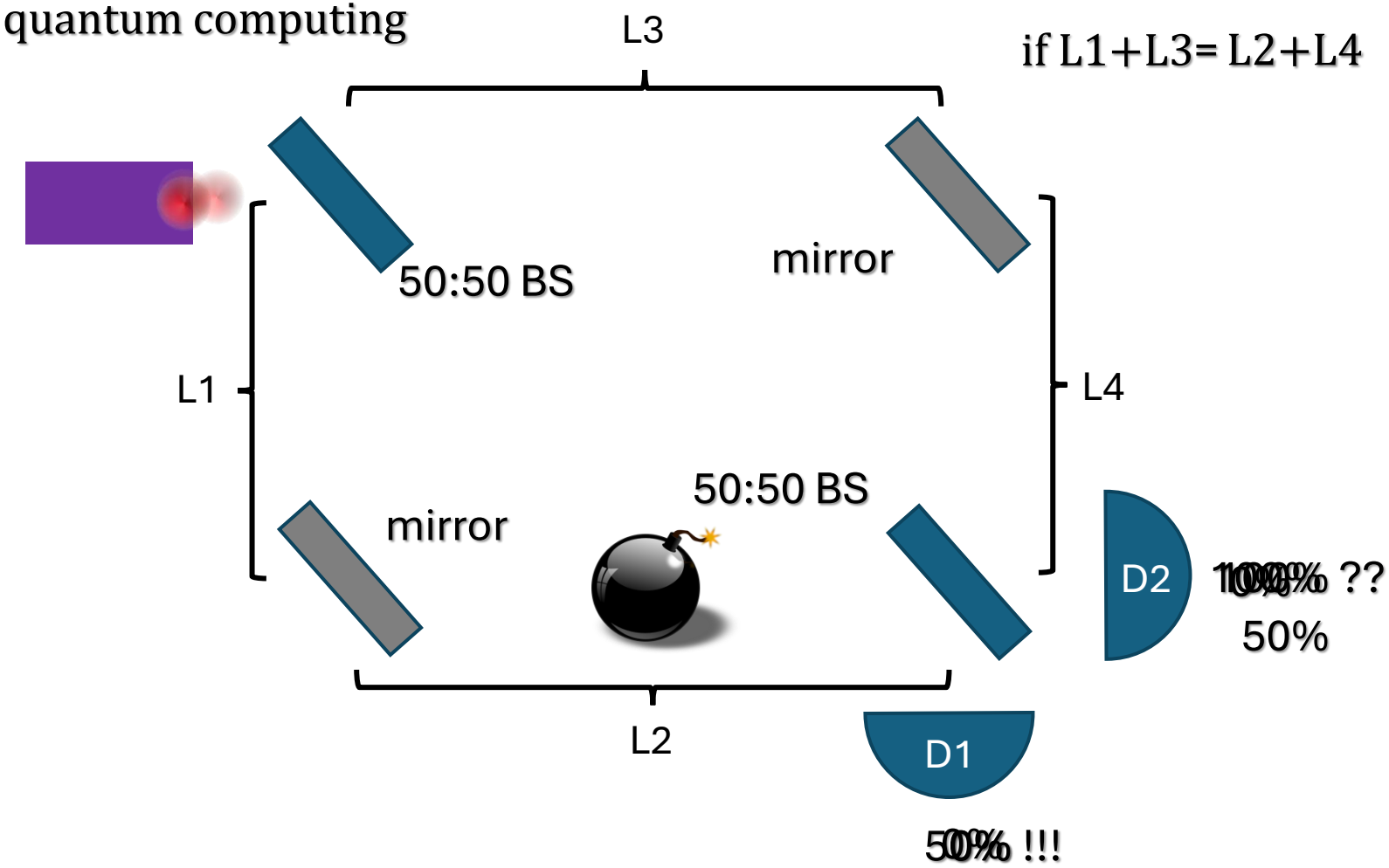


Illustration: Weirdness of Quantum – Single Photons

- access to counterfactual realities
- essence of quantum computing



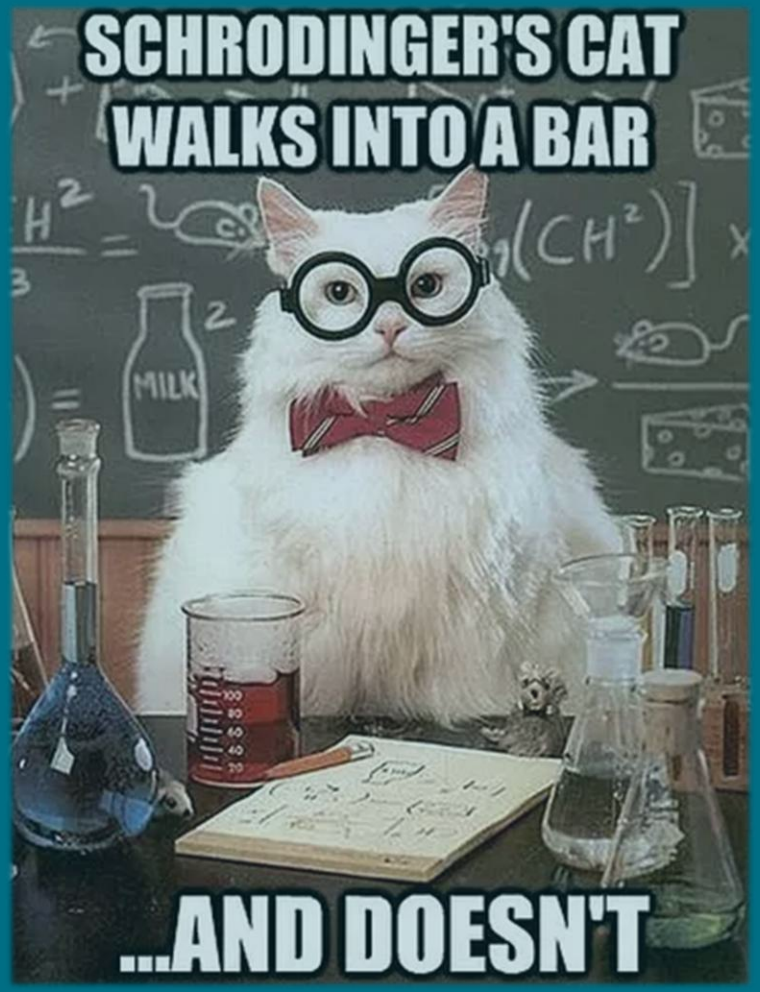
Back to the Cat … Contents

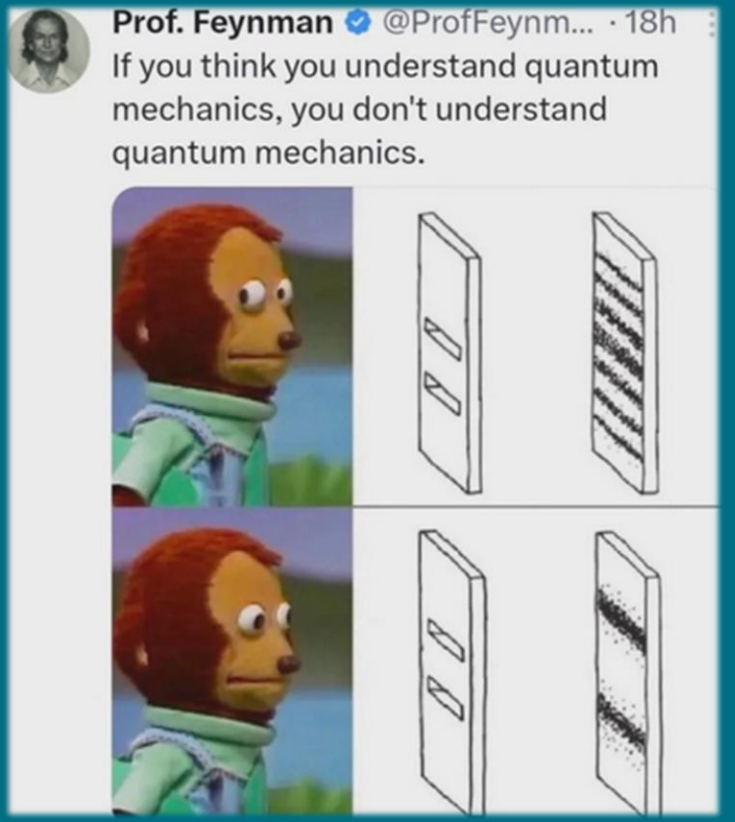
1) What is quantum?
   - randomness
   - entanglement

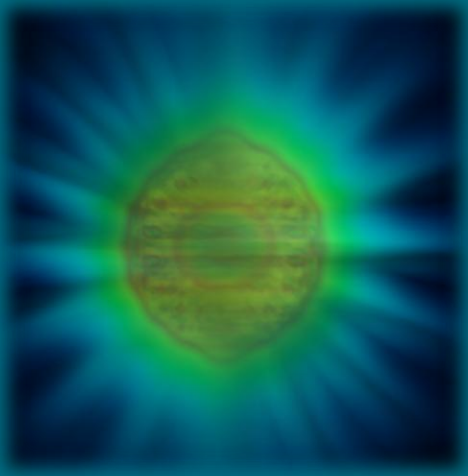
2) What is computing?
   - the Church-Turing Thesis

3) What is quantum computing?
   - the qubit
   - teleportation
   - BB84 (Charles Bennett and Gilles Brassard in 1984)

What is quantum?







What is Quantum? – It's Atomic Physics

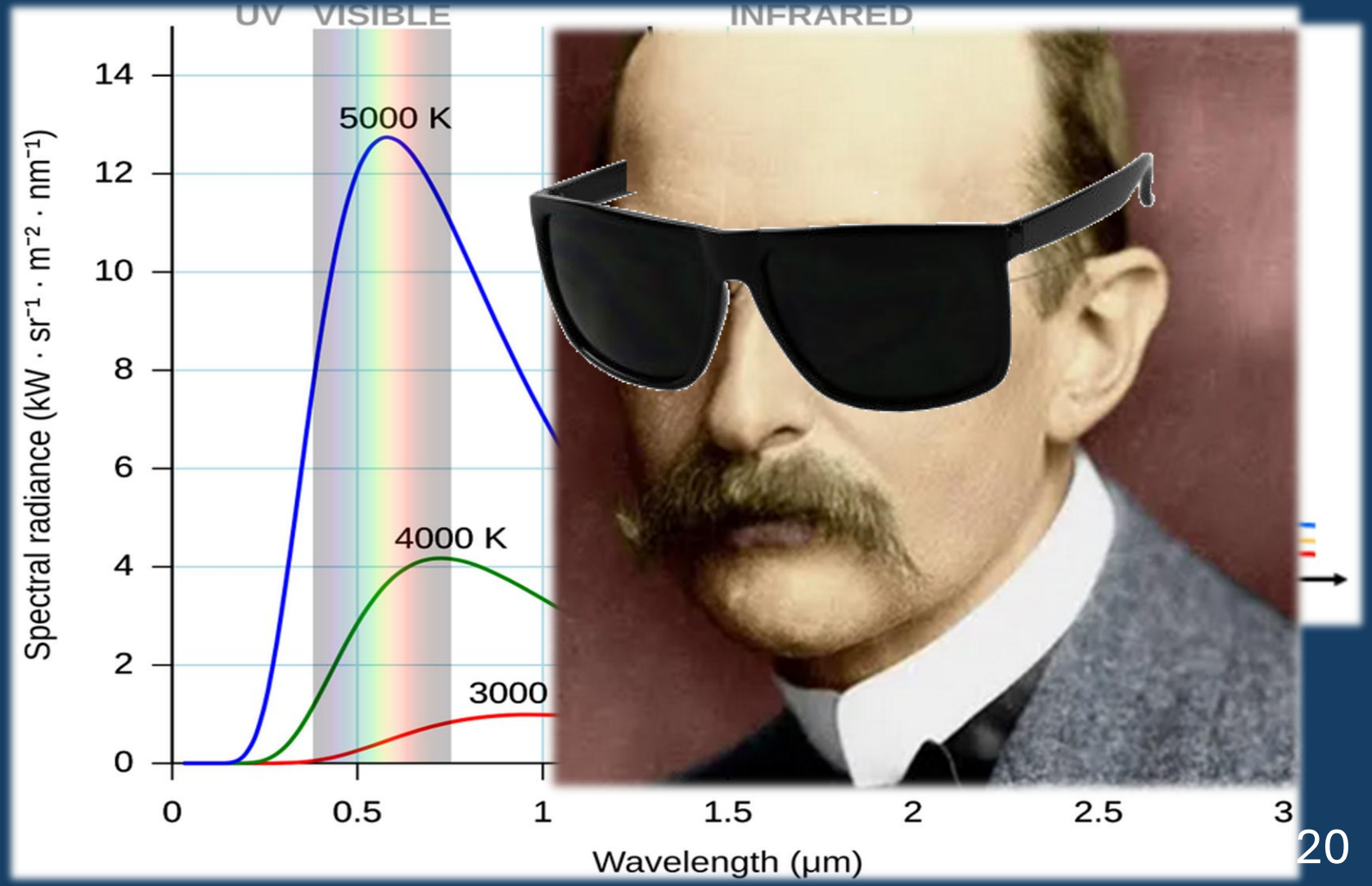
- it's what atoms do ...
- more importantly, is that the laws "down there" are "weird"
- like being Alice in Wonderland
- can we bring those laws back up to where we live and use them to process information?

What is Quantum? – It's blackbody radiation

- how did "quantum" get kicked off **...**
- it got Kirchhoff'ed! **...** Gustav Robert Kirchhoff:
- he studied the **solar atmosphere**
- a property of all bodies and refers to the perfect emission and absorption of heat and light – blackbody radiation
- before we looked down, we looked up **...** the sun
- this led to a **very very very very** important curve **...**

What is Quantum? – It's the Ultraviolet Catastrophe

- black body curve
- Wein's law
- very hard to derive it
- lead to the ultraviolet catastrophe
- problem until this guy came along ...



What is Quantum? – It's Planck's Constant

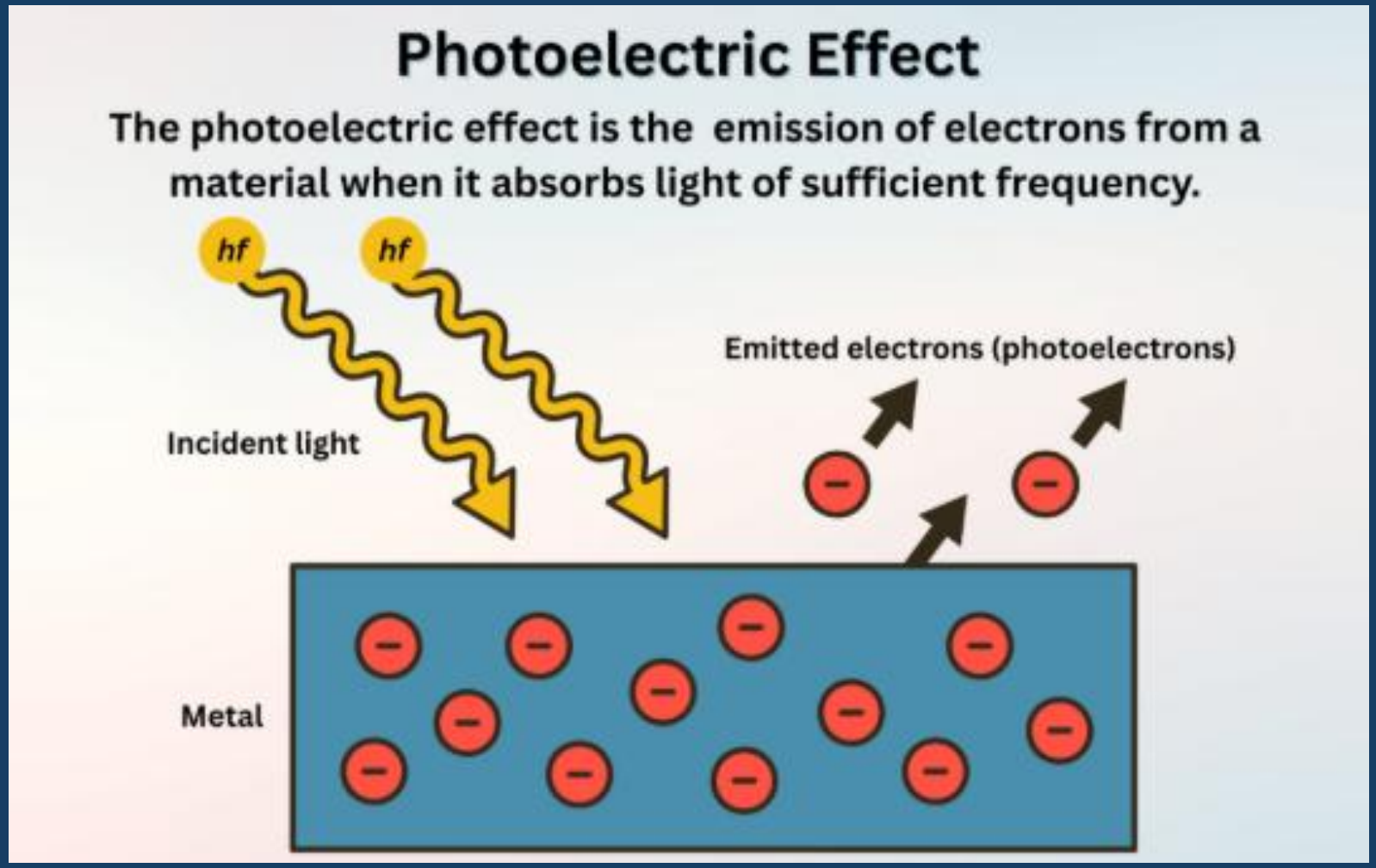
- Planck couldn't derive that pesky "-1" in the denominator ...
- only when he assumed energy was not continuous but arrived in discrete packets did the math give him that "-1"
- the famous constant was born ... Planck's Constant ...

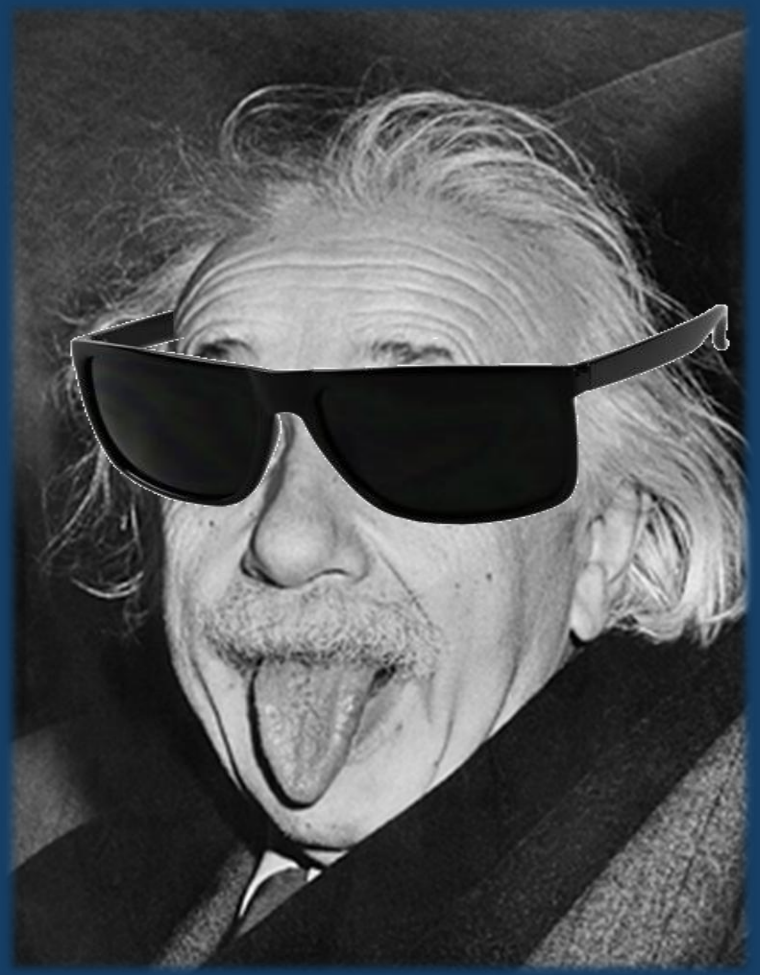
$$E = \hbar\omega$$

before quantum

$$U = \frac{b}{\exp\,(1/a'T)\,-\,1}$$

What is Quantum? – It's the Photoelectric Effect



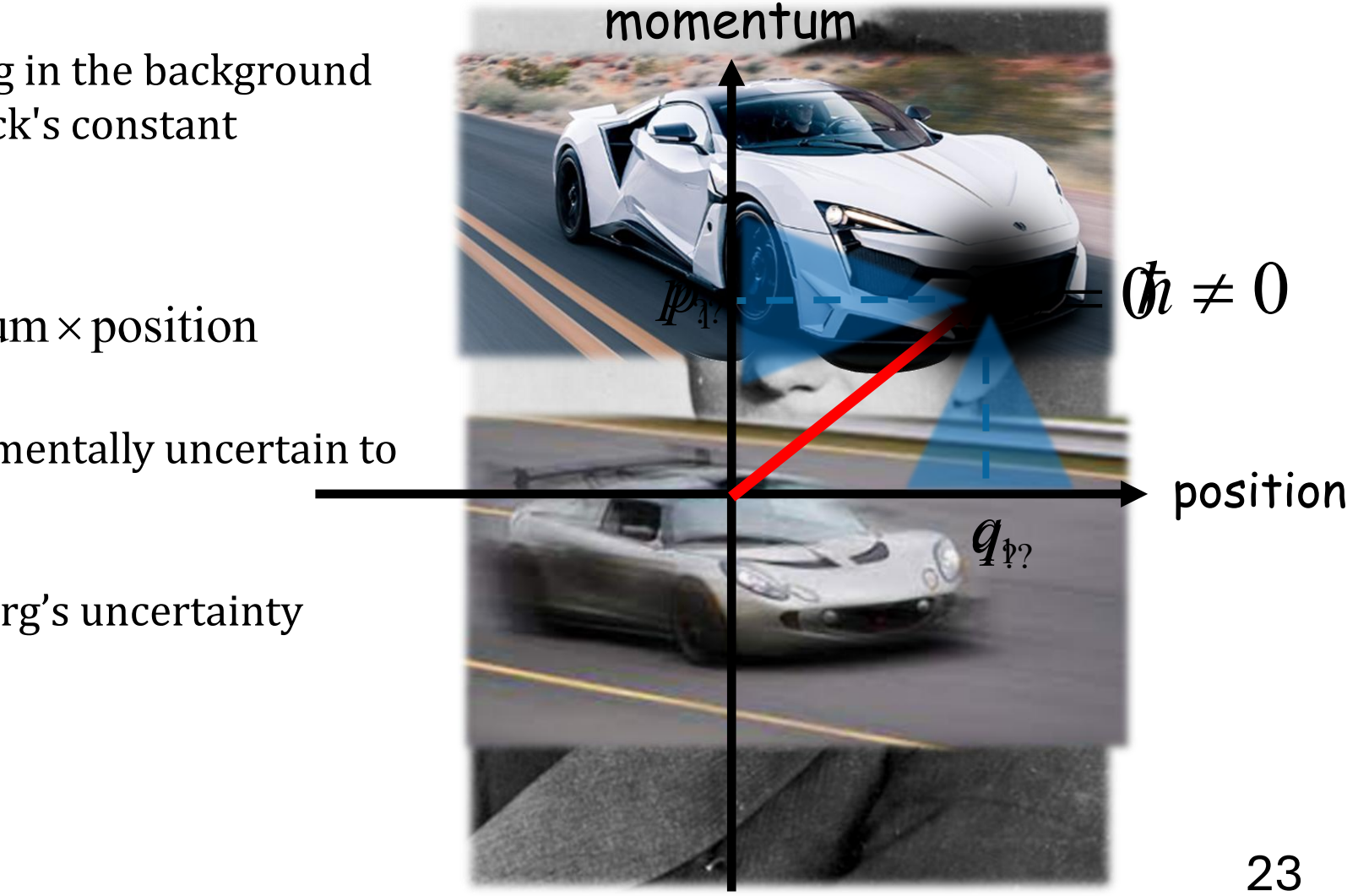


What is Quantum? – Heisenberg's Uncertainty Principle

- however, something was brewing in the background because of the discovery of Planck's constant
- its unit ...

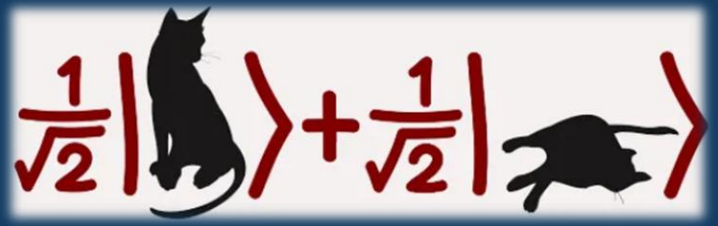
$$[h] = \text{energy} \times \text{time} = \text{momentum} \times \text{position}$$

- it implied that reality was fundamentally uncertain to reality!
- this was the essence of Heisenberg's uncertainty principle
- he got the Nobel prize too ...

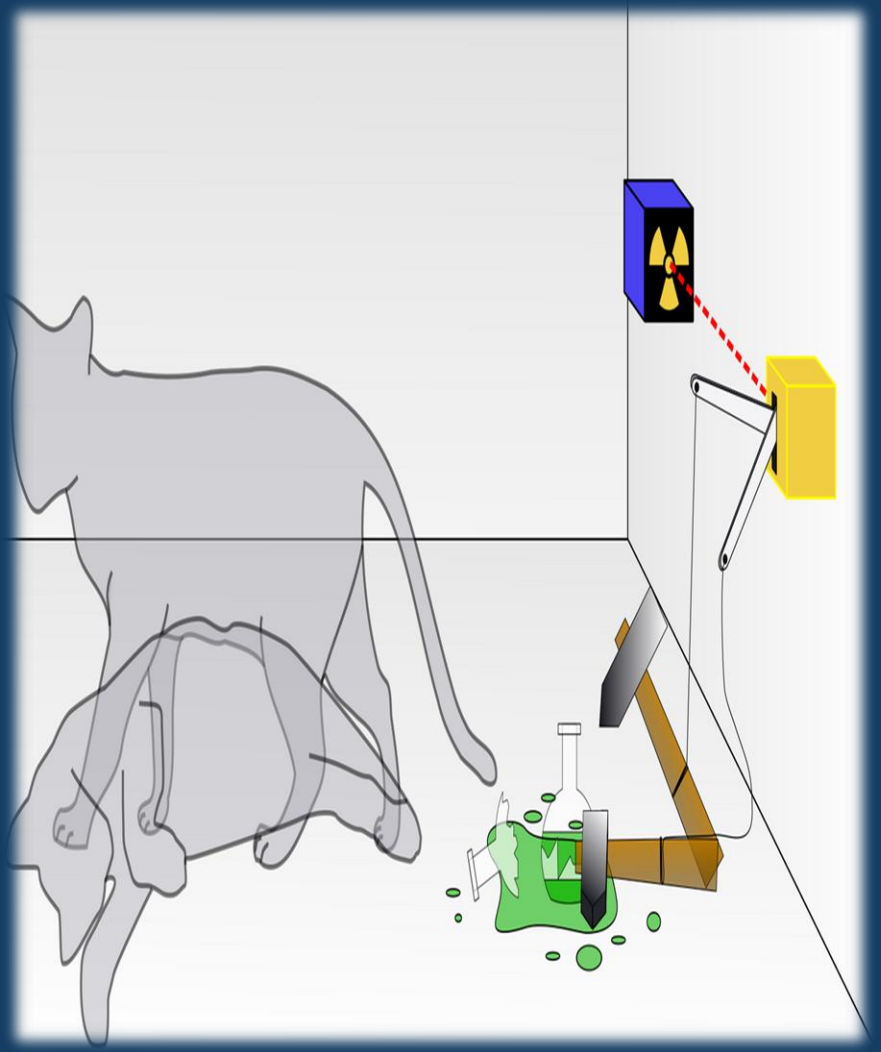


What is Quantum? – It's Superposition

- Schrodinger tried to bring back a sense of determinacy with his wave mechanics
- however, atomic transitions were still seen to be fundamentally random:
- **"If I had known that we were not going to get rid of this damned quantum-jumping, I never would have had anything to do with quantum theory!"**
- this brings us to his cat ...



natural parallelism



What is Quantum? – It's Randomness

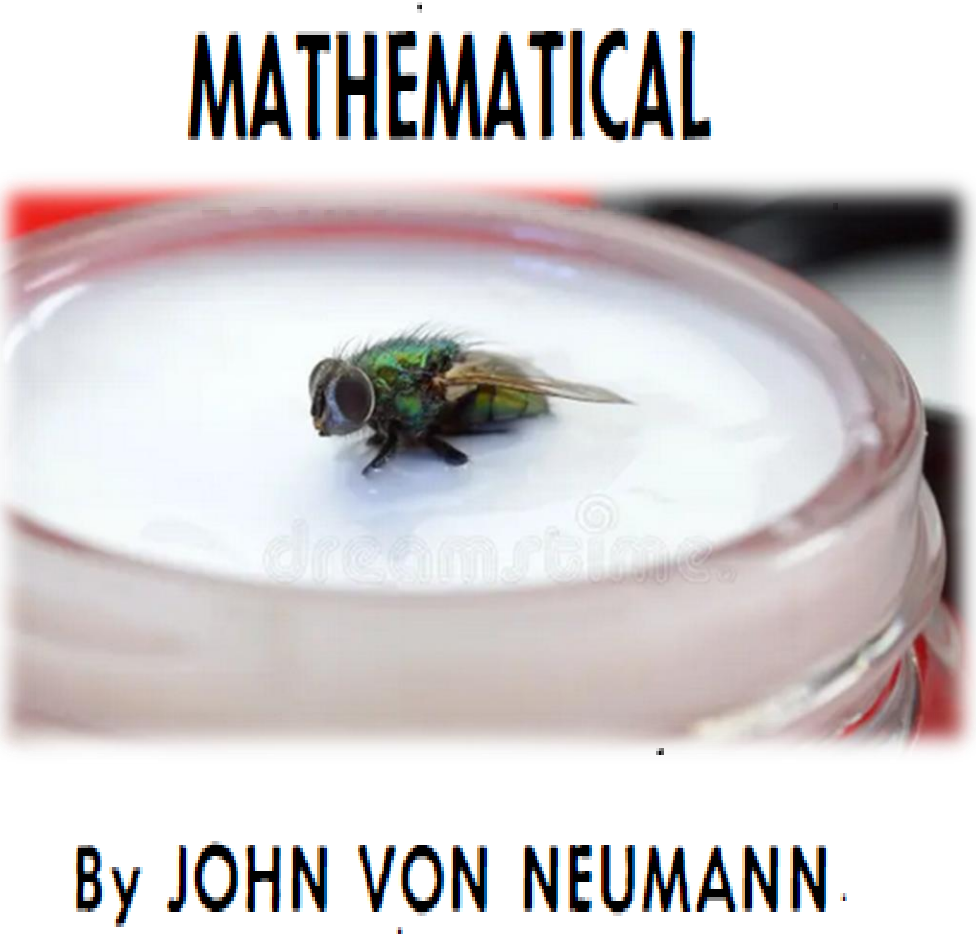
- two extremely important concepts that contribute to quantum computing are:

    1. sum over histories – real, physical parallel processing – calculations with many worlds

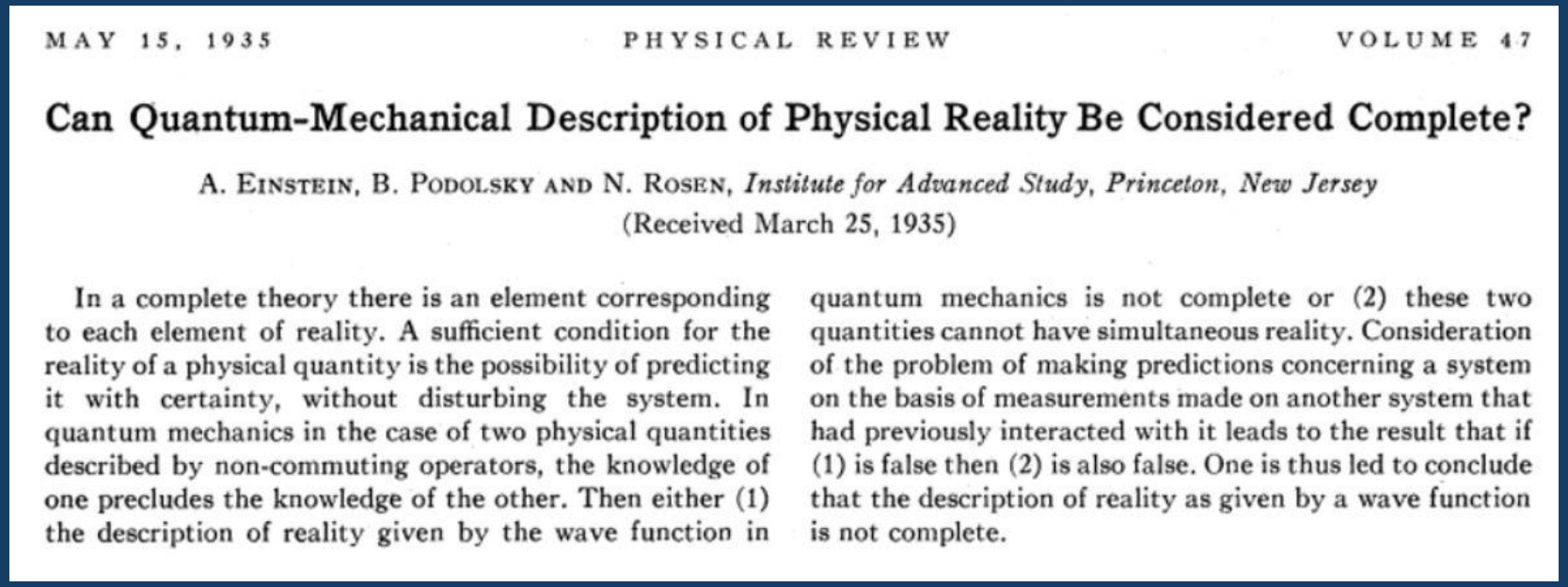
    2. randomness ...

- in 1931, world-renowned mathematician John von Neumann proved that hidden variables do not exist

- this was the fly in Einstein's ointment ..



What is Quantum? – It's Entanglement



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)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

- compelled Einstein to write his famous 1935 EPR paper
- while trying to disprove quantum theory as a complete theory, he inadvertently provided the basis for entanglement! (poor Einstein!)
- the third ingredient for quantum computing!

What is Computing? – It's an entscheidungsproblem!

- first analog computer (2nd century BC)
- modern age ushered in by Alan Turing

230 A. M. TURING [Nov. 12,

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

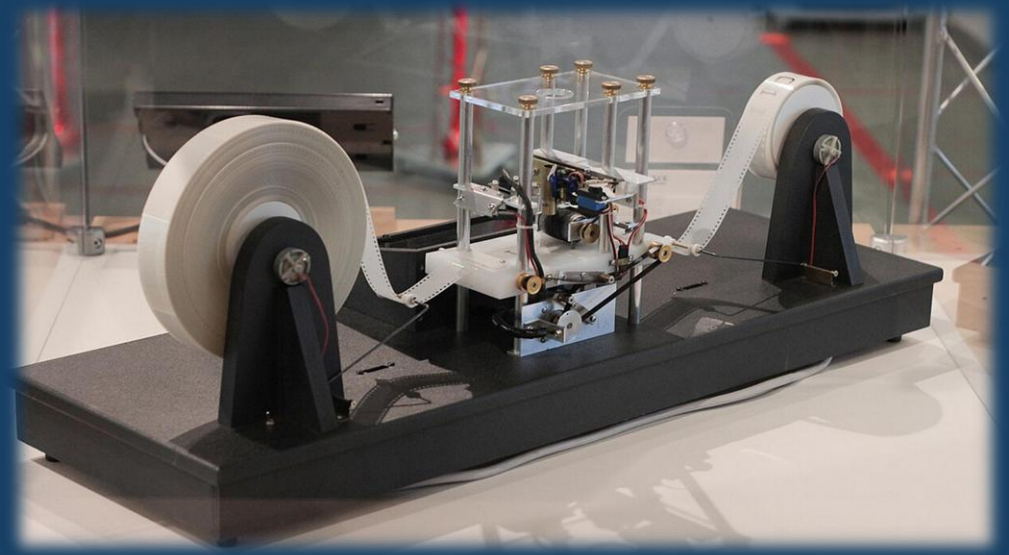
[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means.

- entscheidungsproblem: an algorithm that takes any logical statement as input and correctly determines its validity in a finite number of steps

What is Computing? – It's a Turing machine

- Turing developed an abstract notion of what we now call a programmable computer – model for computation known as the TURING MACHINE



- infinite strip of tape extending to the left and right, divided into little squares (cells)
- each square holds a symbol: 0, 1 or blank
- head: looks at one cell at a time;
  - it can: read the symbol OR write a symbol OR move left or right

- simple rule example: if you see a 1 and you're in state A -> write 0, move right and go to state B

What is Computing? – It's the Church-Turing Thesis

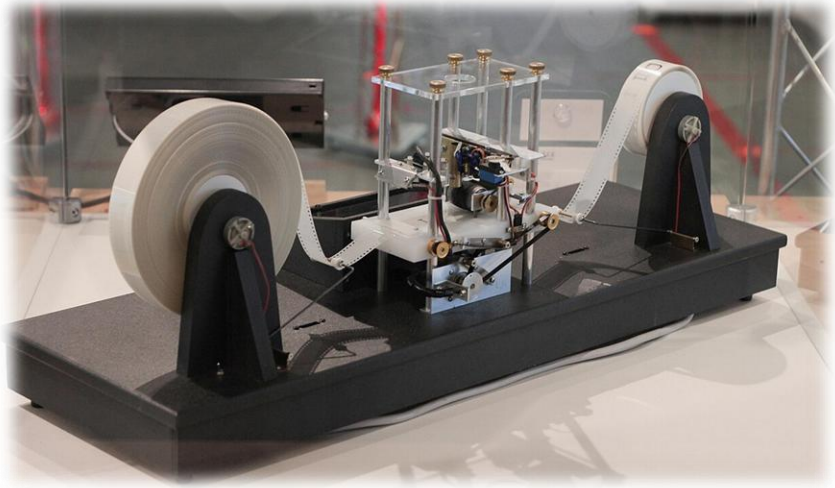
- Led to the Church-Turing thesis:

  "any algorithmic process can be simulated efficiently using a Turing machine"

- **but is this true?**

- **turns out analog computers can solve problems believed to have no solution on a Turing machine!**

- **however, noise kills this advantage**



What is Computing? – Randomized algorithm?!

- this means effect of noise must be taken into account in evaluating efficiency!
- but wait ... we have a new challenger to the Church-Turing thesis
- the randomized algorithm (Robert Solovay and Volker Stressen – mid-1970s)
- Solovay-Stessen test for primeness used randomness as an essential part of the algorithm!
- no deterministic test is known to do this ...

What is Quantum Computing?

- challenge appears to be easily resolved by simply modifying the Church-Turing thesis:

  "any algorithmic process can be simulated efficiently using a probabilistic Turing machine"

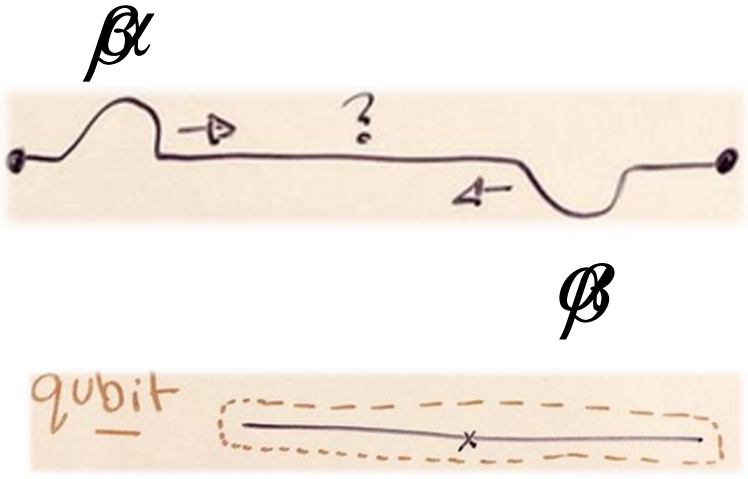
- really? we gonna keep doing this?
- no
- maybe ...
- the birth of quantum computing
- in 1985, David Deutsch asked whether the laws of physics could be used to derive an even stronger version of the Church-Turing thesis

- because the laws of physics are ultimately quantum mechanical, Deutsch was naturally led to consider computing devices based upon the principle of quantum mechanics

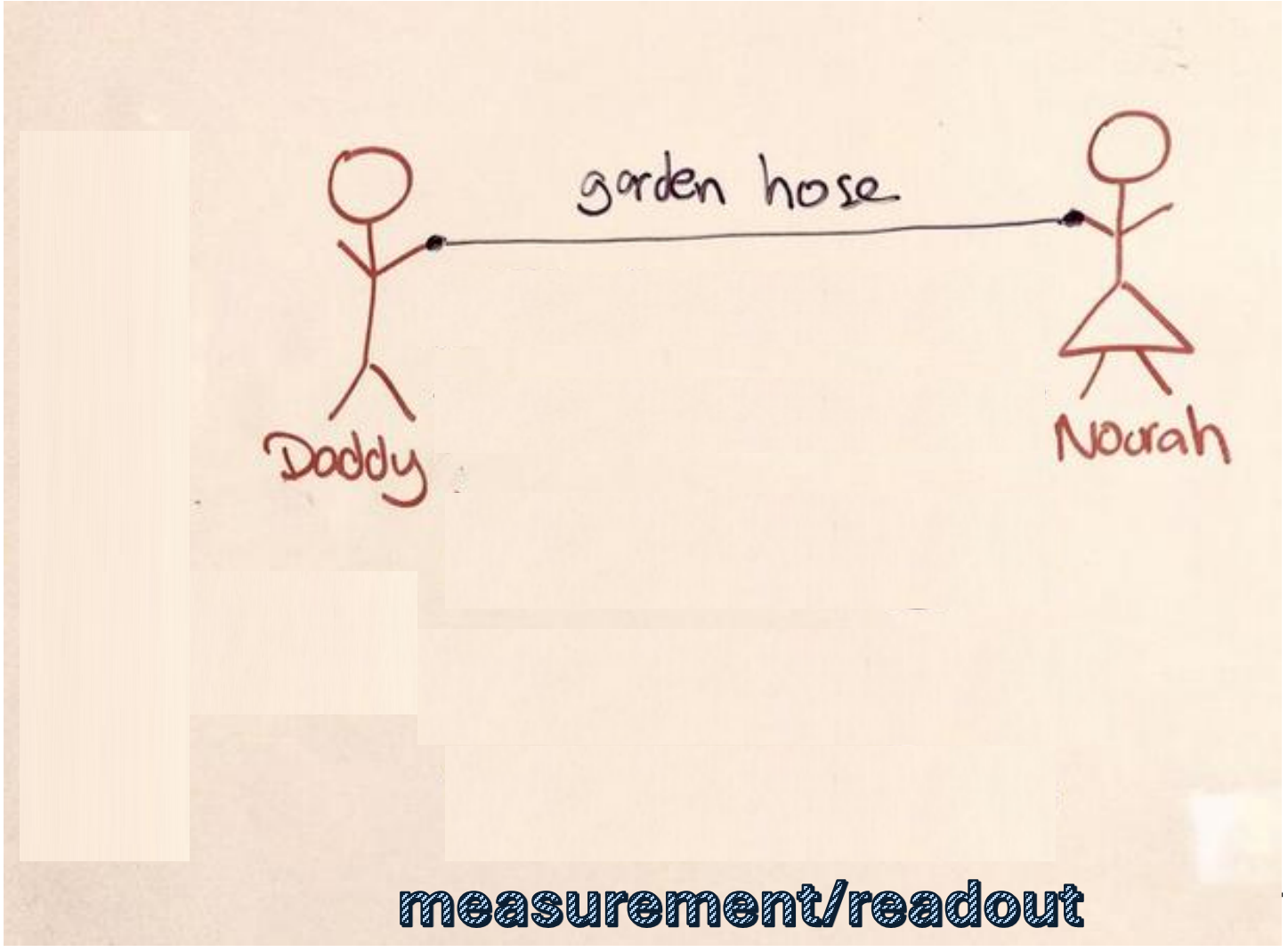
What is Quantum Computing? – It's qubits!

- **the qubit …**

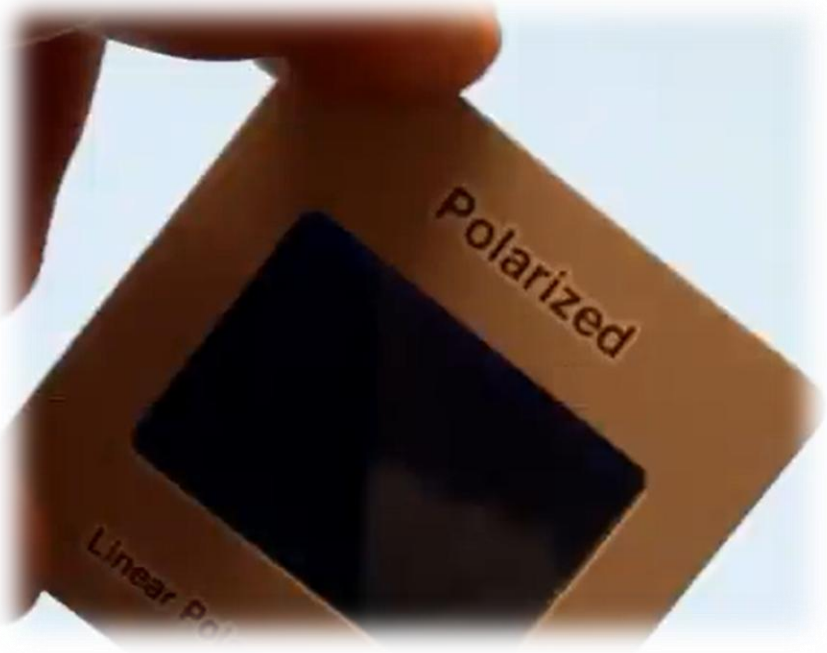
$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$



$$X \equiv \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}. \qquad X \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \beta \\ \alpha \end{bmatrix}.$$



What is Quantum Computing? – It's qubit manipulation



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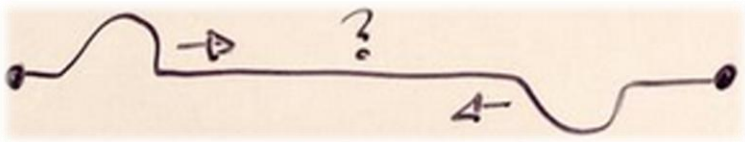

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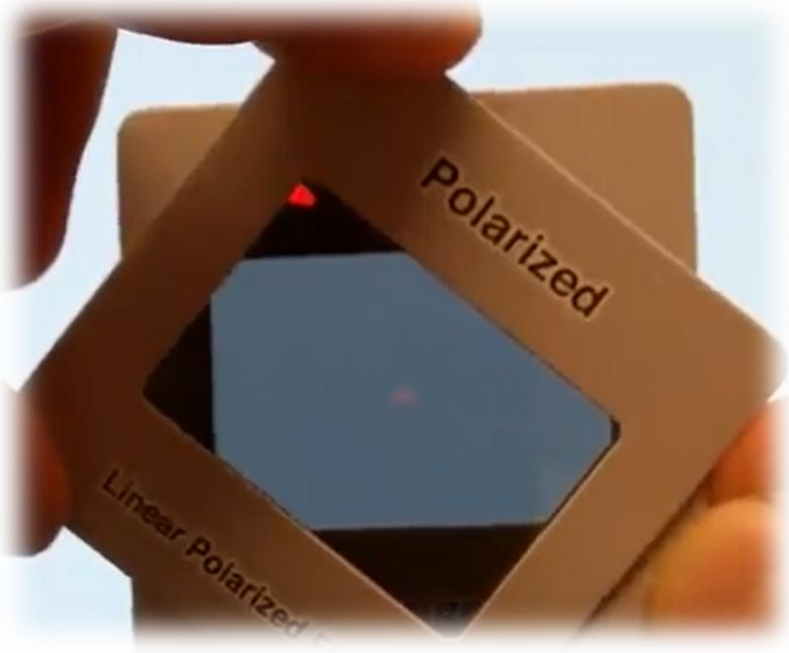

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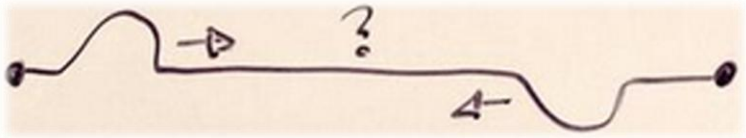

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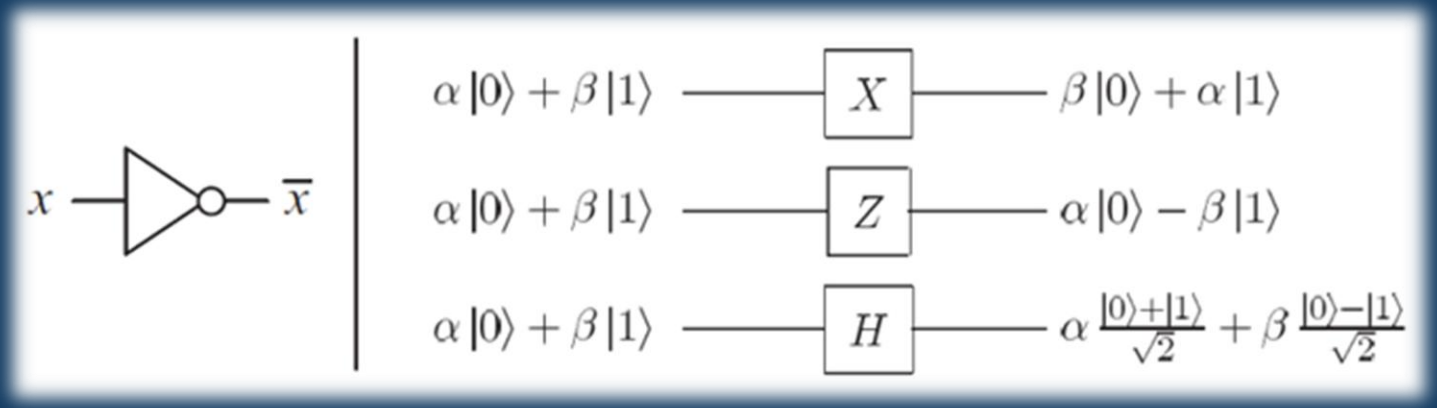
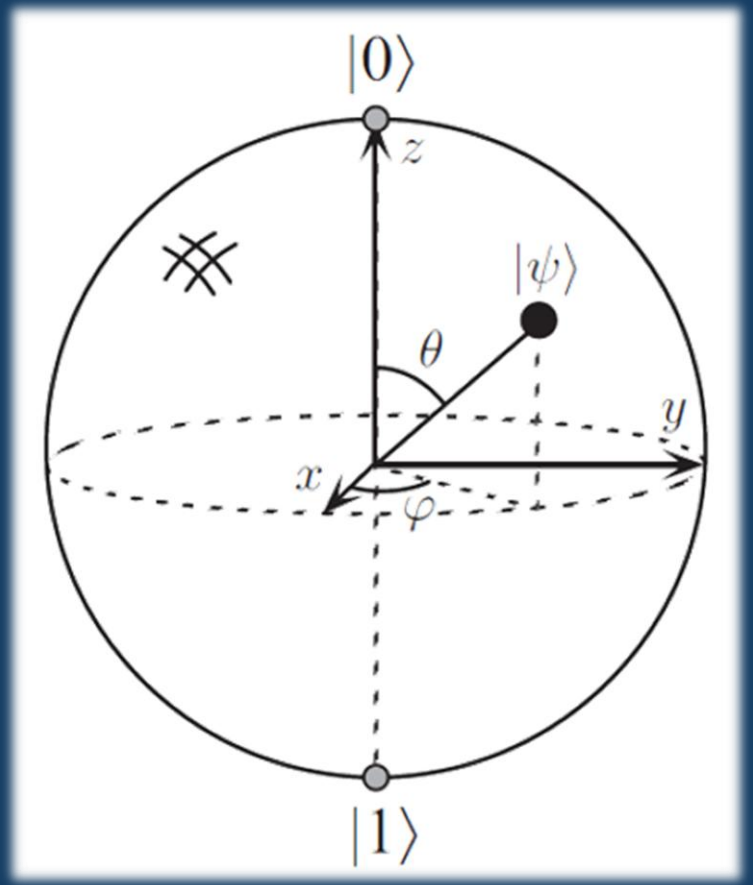
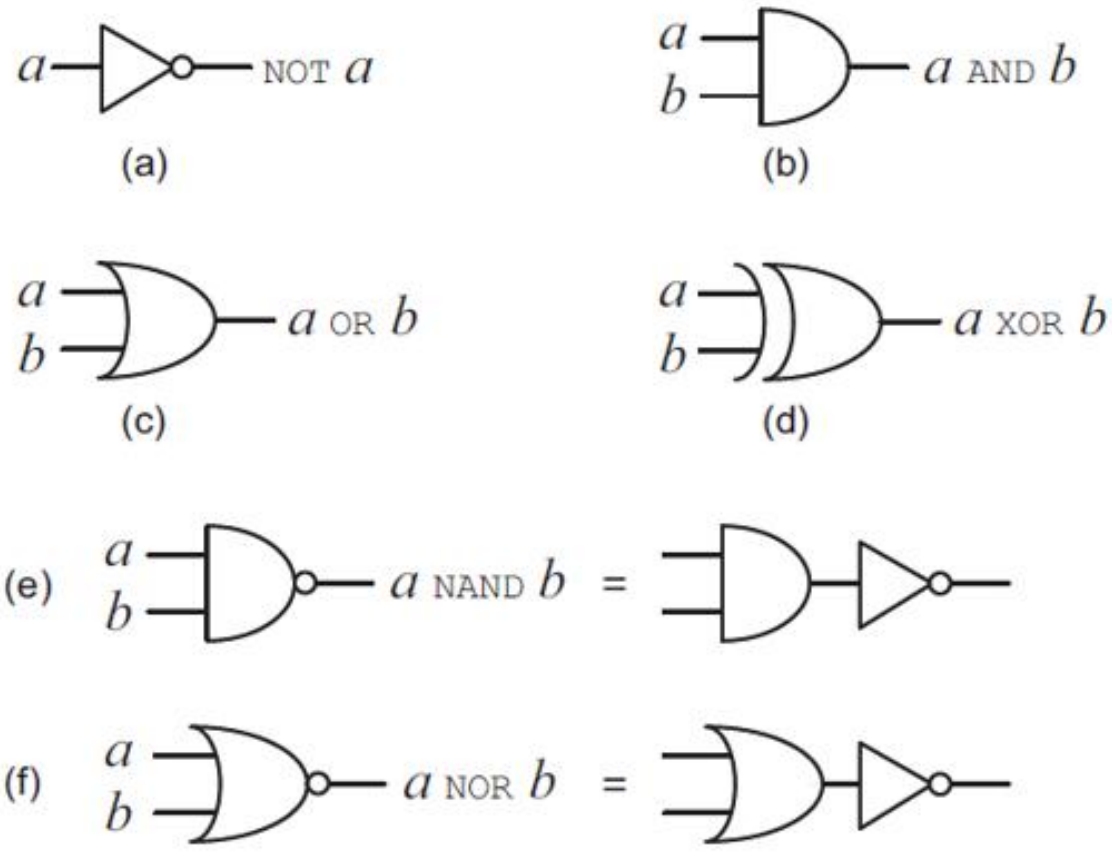
What is Quantum Computing? – Qubit operations

- the Block sphere ...
- easy way to follow manipulations of the state via “gates”



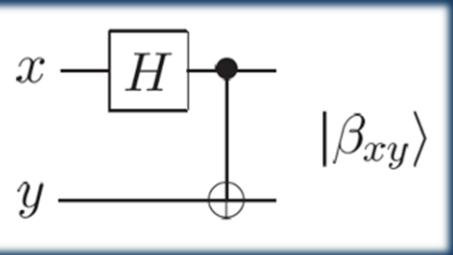


What is Quantum Computing? – It's entangling …



What is Quantum Computing? – Bell states!

- Bell states



In	Out
$\|00\rangle$	$(\|00\rangle + \|11\rangle)/\sqrt{2} \equiv \|\beta_{00}\rangle$
$\|01\rangle$	$(\|01\rangle + \|10\rangle)/\sqrt{2} \equiv \|\beta_{01}\rangle$
$\|10\rangle$	$(\|00\rangle - \|11\rangle)/\sqrt{2} \equiv \|\beta_{10}\rangle$
$\|11\rangle$	$(\|01\rangle - \|10\rangle)/\sqrt{2} \equiv \|\beta_{11}\rangle$

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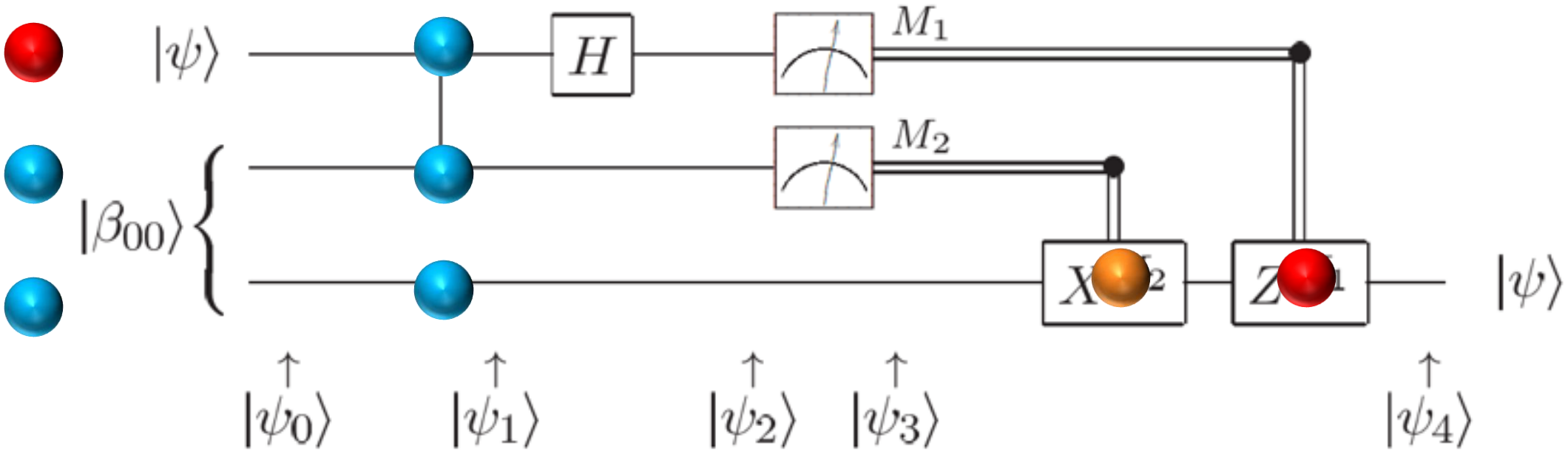
ON THE EINSTEIN PODOLSKY ROSEN PARADOX*

J. S. BELL†

Department of Physics, University of Wisconsin, Madison, Wisconsin

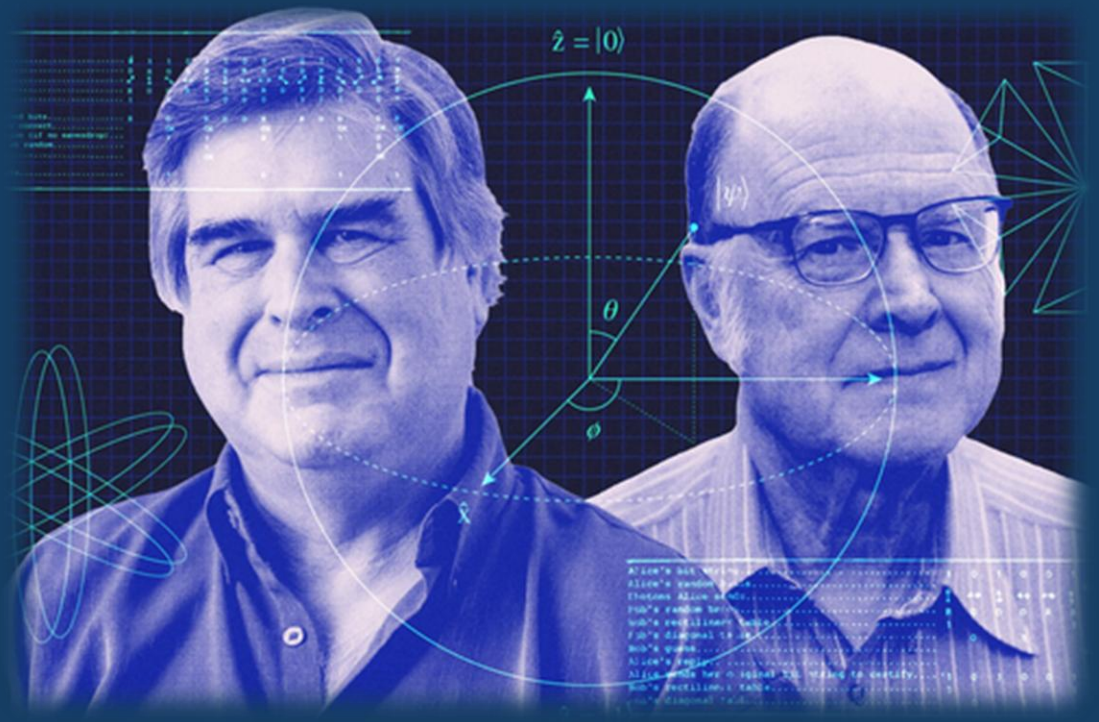
(*Received 4 November 1964*)

What is Quantum Computing? – It's teleportation



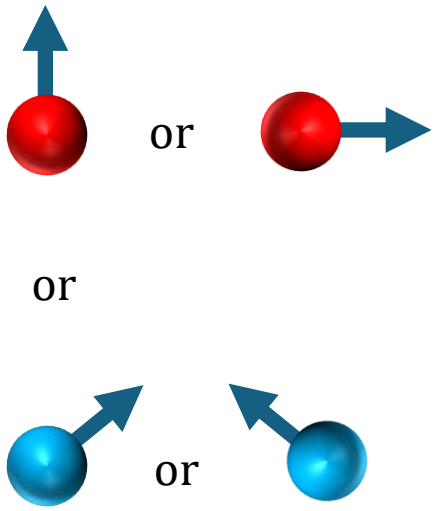
What is Quantum Computing? – BB84

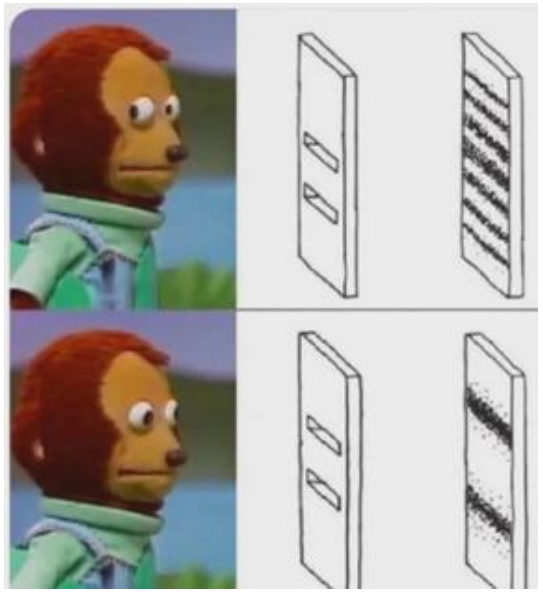
- in 1984 Gilles Brassard (a Canadian – yay!) and Charles Bennet showed that security need not rely on computational assumptions, but can instead be enforced by the structure of physical law itself
- they were award the Turing Award (the Nobel of Computer Science)
- what is BB84?

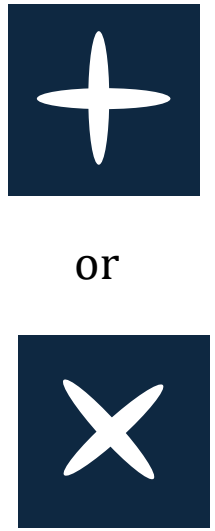


What is Quantum Computing? – Nature hacking us …

ALICE







BOB

- Alice and Bob publicly announce their bases only
- Eve tries to copy the photons or tries to observe which photon
- Nature: pope, can't copy (no cloning theorem) and can't observe without changing the state
- Alice and Bob talk statistics, if Eve around statistics different than from when she's not - abort
- Nature keep only the cases where their bases matched
- Alice gives Bob the raw key to unlock encrypted data

Conclusions – Take away of key concepts

- superpositions – ability to process different “realities” at once
- randomness – key to solving problems more efficiently
- entanglement – access to manipulations that are independent of space and time
- elegant physics
- but daunting (but worthwhile) engineering
- business case – win-win ...
- so is a cat necessary?
- Absolutely!

Is everything you heard today correct?

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Original Paper

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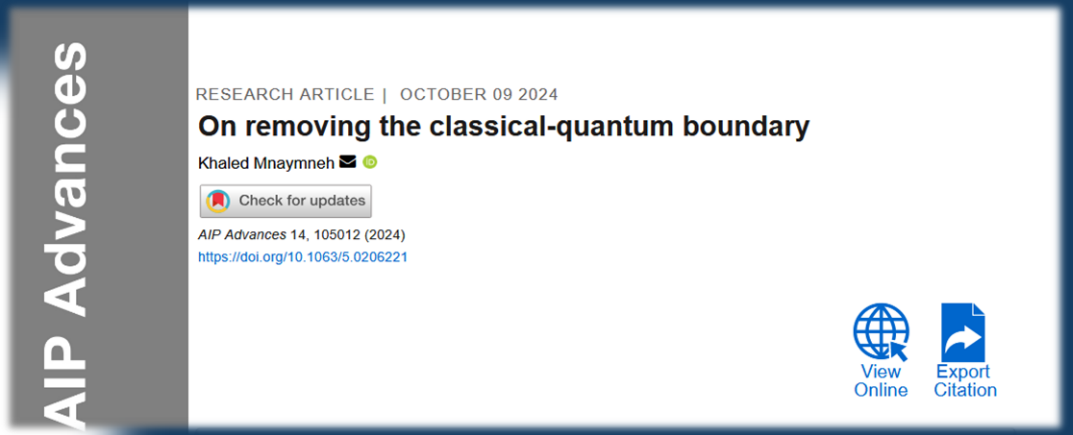

- third paper: Is quantum computing different in galaxy far far away? Connecting Planck's constant to the Cosmological constant …

Thank you for your attention!