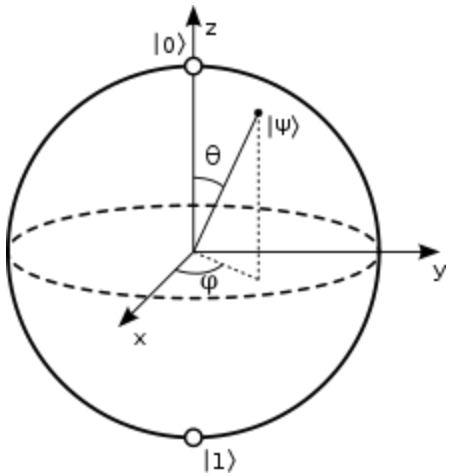
Intro to Quantum Computing

Introduction



Slides from Georgios Stamouli

Administrative info

- Instructor: Menica Dibenedetto
- Tutor: Shi Qiu shi.qiu@maastrichtuniversity.nl
- Communication: domenica.dibenedetto@maastrichtuniversity.nl
- Office: C4.032
- Office hours: by appointment (for small questions: open door -> please do come in!)

Administrative info

- 17 appointments (lectures/tutorials/Q&A)
- Broadly split into four themes:
  - Mathematics of Qbits
  - Quantum Entanglement & Bell's Inequalities
  - Quantum Logic and Circuits
  - Quantum Algorithms, Protocols and Applications (Cryptography etc.)
- Final Exam: Closed book, for 100% of the final grade.
- Periodically a set of exercises.

Knowledge

- Desired prior Knowledge:
  - Very good knowledge of *Linear Algebra* (we will cover the basic tools in a vocabulary appropriate for manipulating Qbits but you should already be familiar with concepts of Vector Spaces, Bases, Orthogonality, Inner Products, Linear Transformations etc.)
- Algorithmic thinking will help you (but it is not strictly necessary)
- *No prior knowledge of Quantum Physics is assumed. We will build all concepts (Superposition, Entanglement, etc.) from first principles.*

Sources

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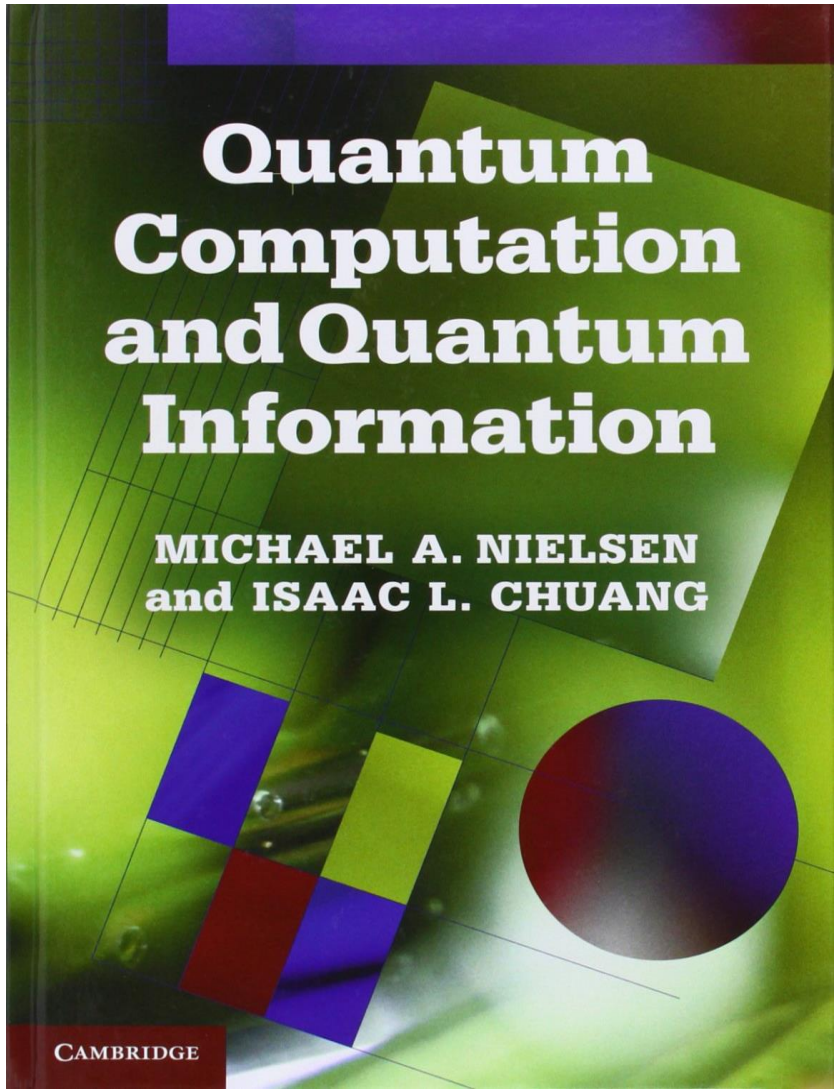
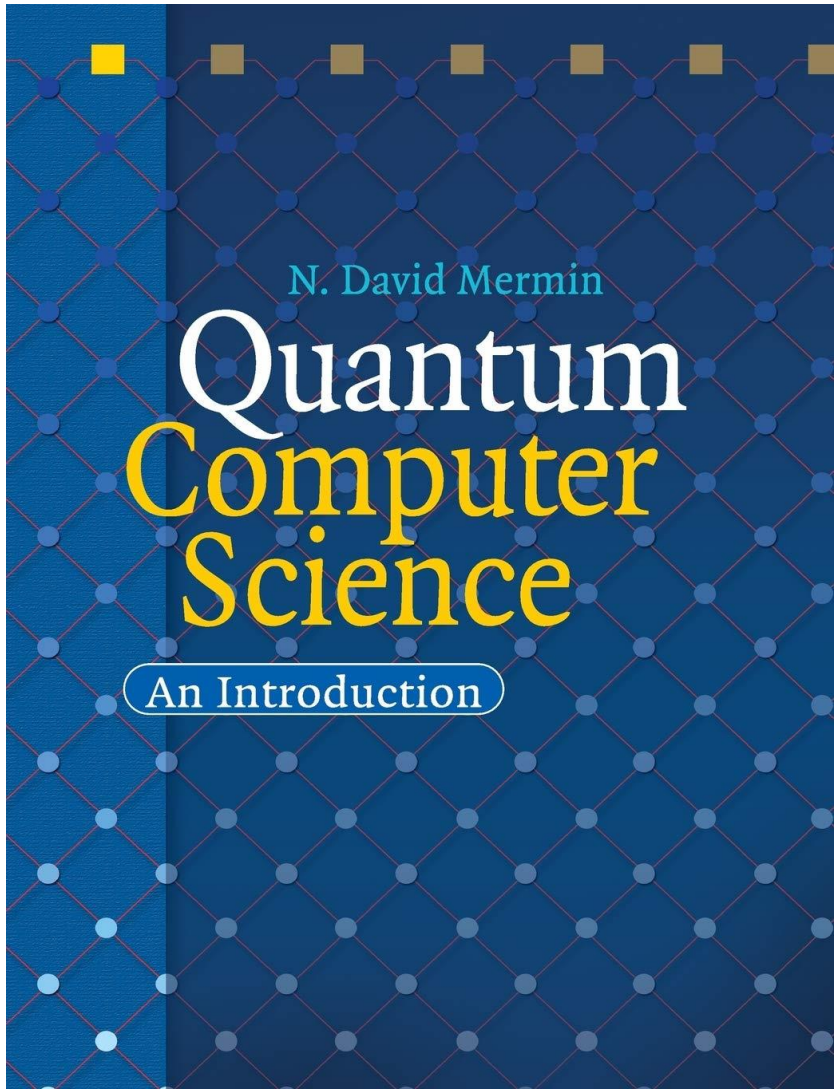

Quantum Computation and Quantum Information
MICHAEL A. NIELSEN and ISAAC L. CHUANG
CAMBRIDGE

Sources



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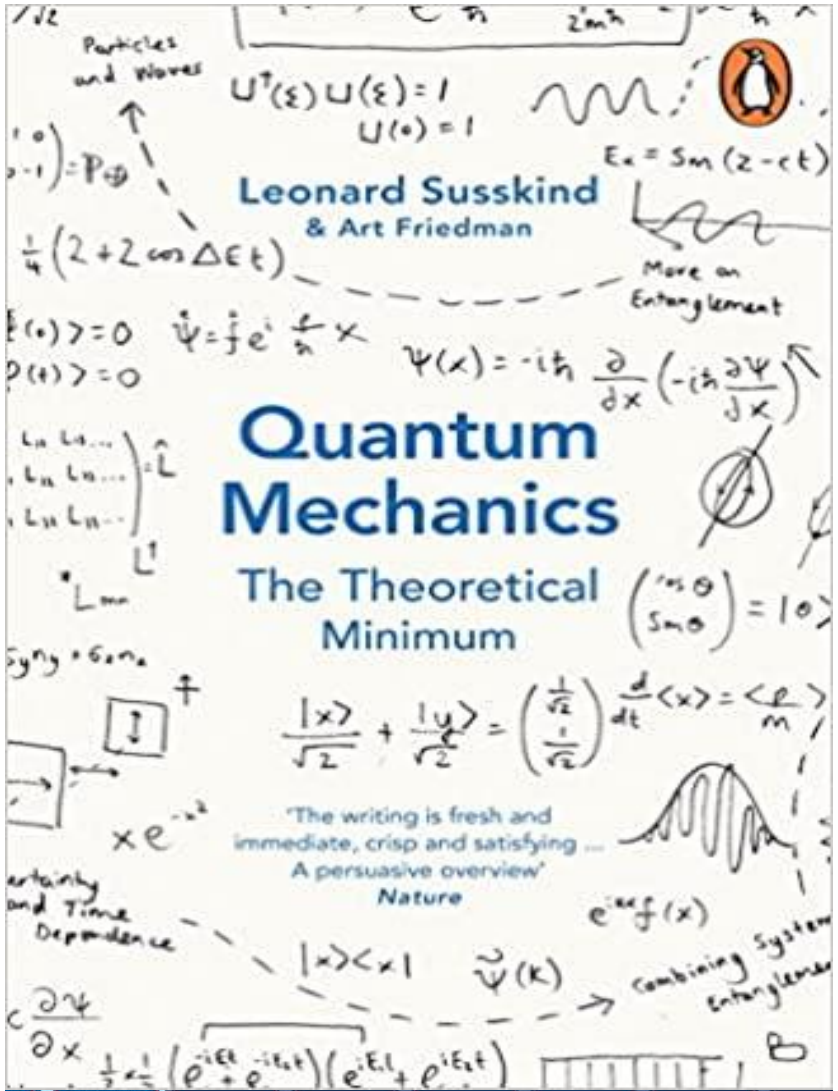
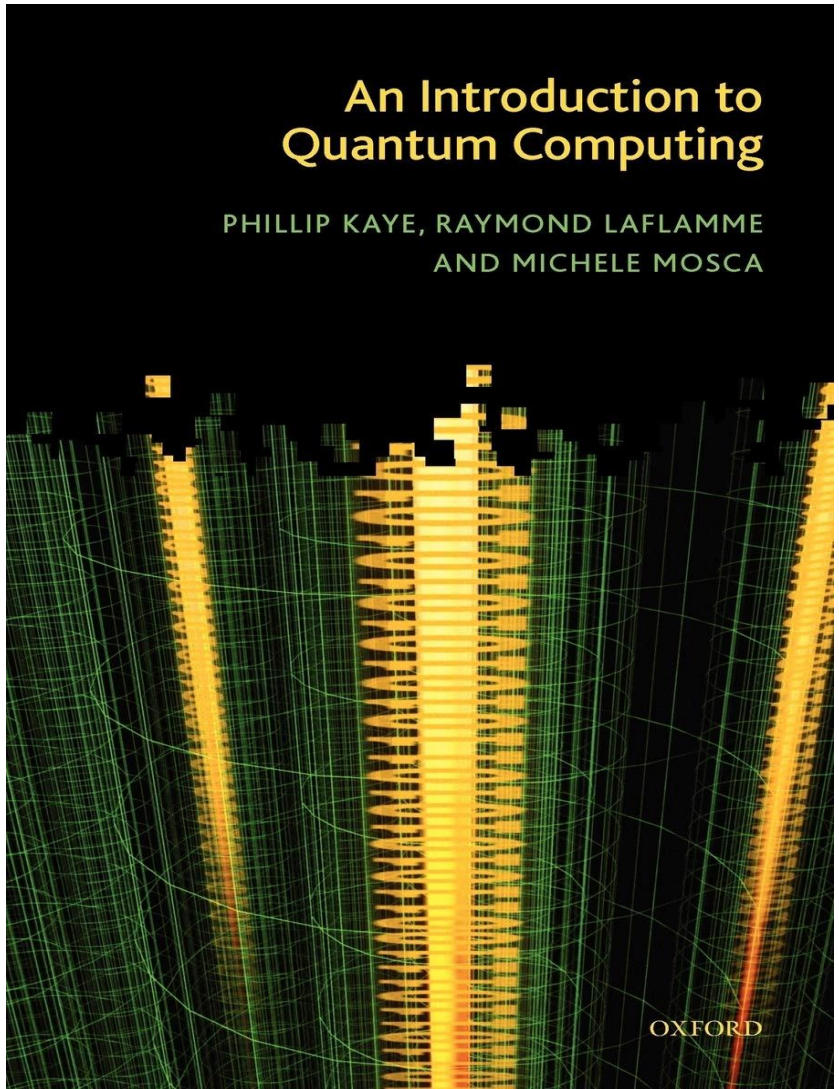
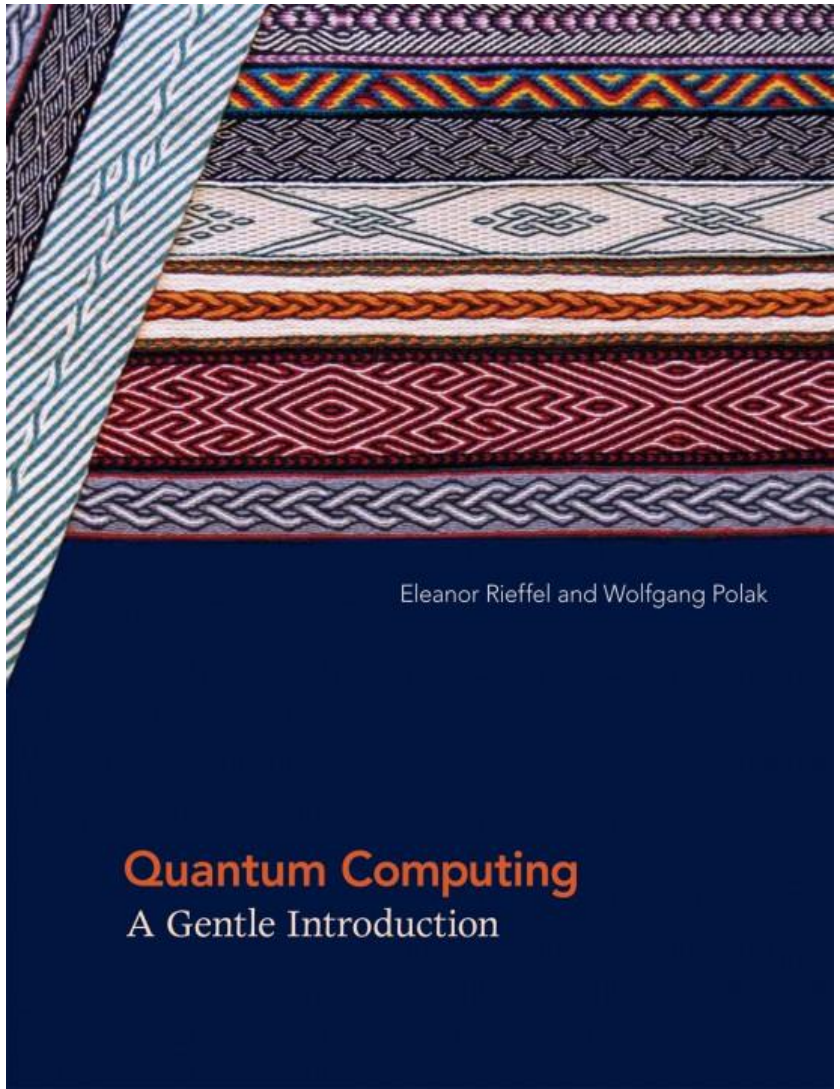

Particles and Waves
Leonard Susskind
& Art Friedman
More on Entanglement
Quantum Mechanics
The Theoretical Minimum
'The writing is fresh and immediate, crisp and satisfying ... A persuasive overview'
Nature
Combining Systems

Sources


An Introduction to
Quantum Computing
PHILLIP KAYE, RAYMOND LAFLAMME
AND MICHELE MOSCA
OXFORD

Sources


Eleanor Rieffel and Wolfgang Polak
Quantum Computing
A Gentle Introduction

What this course is about

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- Potential Applications.

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And to convince you that Quantum theory and computing is not that difficult

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- Quantum hardware.

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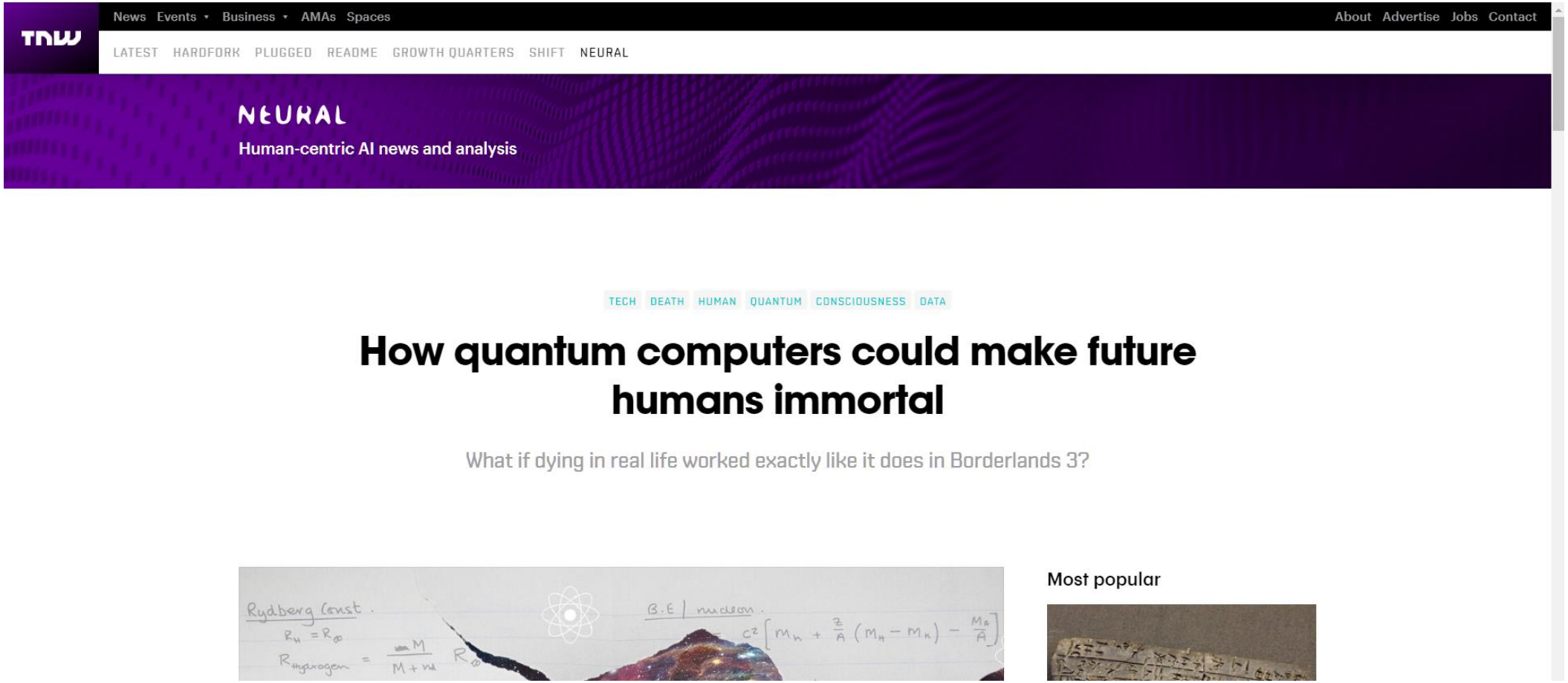

What fancy things?

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Quantum Supremacy & AI, with Stephen Fry.
527K views • 11 months ago

Pindex

How **Quantum** AI could help you live to 200, like a bowhead whale. Google's **quantum** supremacy news opens exciting doors.

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Efficient algorithm design is *independent* of underlying model of computation.

QC - Motivation

Classical computing (based on TM model of computation) does not seem able to efficiently simulate ***Quantum Mechanics***.

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Deutsch: Can we justify Church-Turing thesis using laws of physics?

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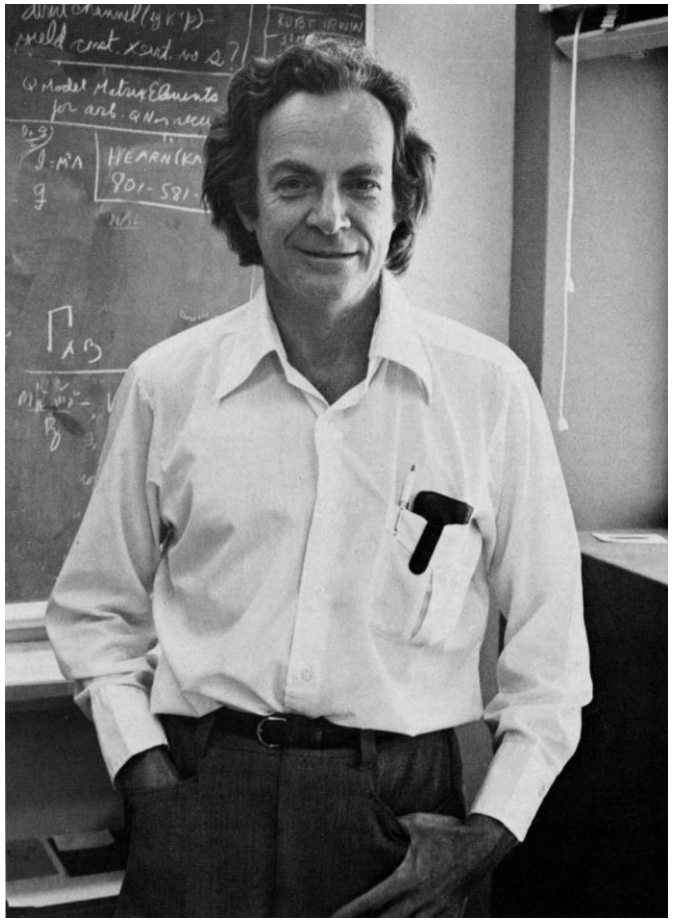
Violation of strong Church-Turing Thesis!

So…what is QC?



. . . trying to find a computer simulation of physics seems to me to be an excellent program to follow out. . . . the real use of it would be with quantum mechanics. . . . Nature isn't classical , dammit. . . and if you want to make a simulation of Nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.

Richard Feynman

So…what is QC?

The theory of computation has traditionally been studied almost entirely in the abstract, as a topic in pure mathematics. This is to miss the point of it. Computers are physical objects, and computations are physical processes.
What computers can or cannot compute is determined by the laws of physics alone, and not by pure mathematics.

David Deutsch

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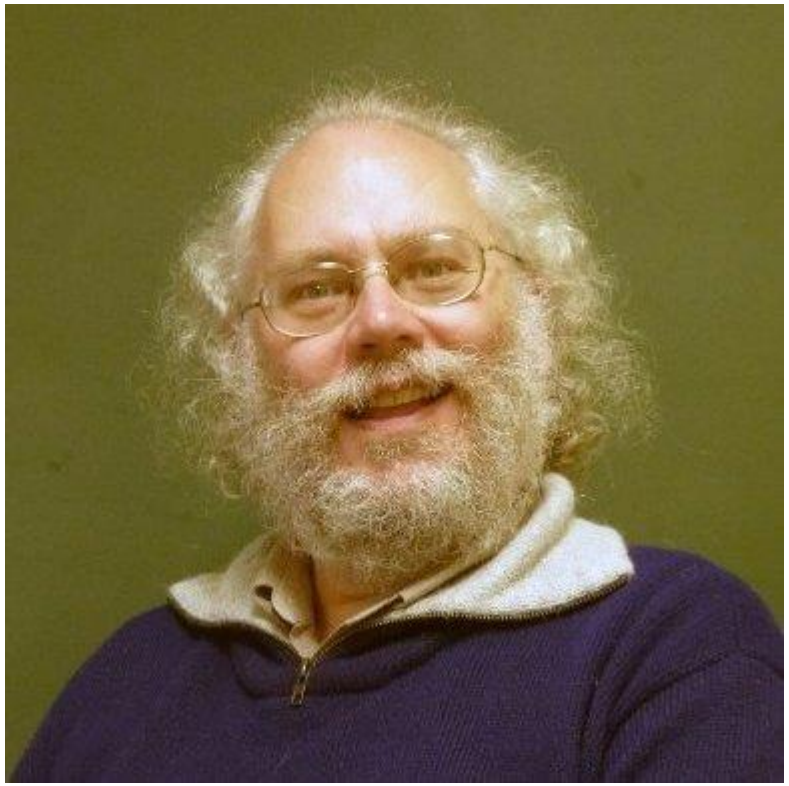

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- Many applications (Cryptography, etc.)

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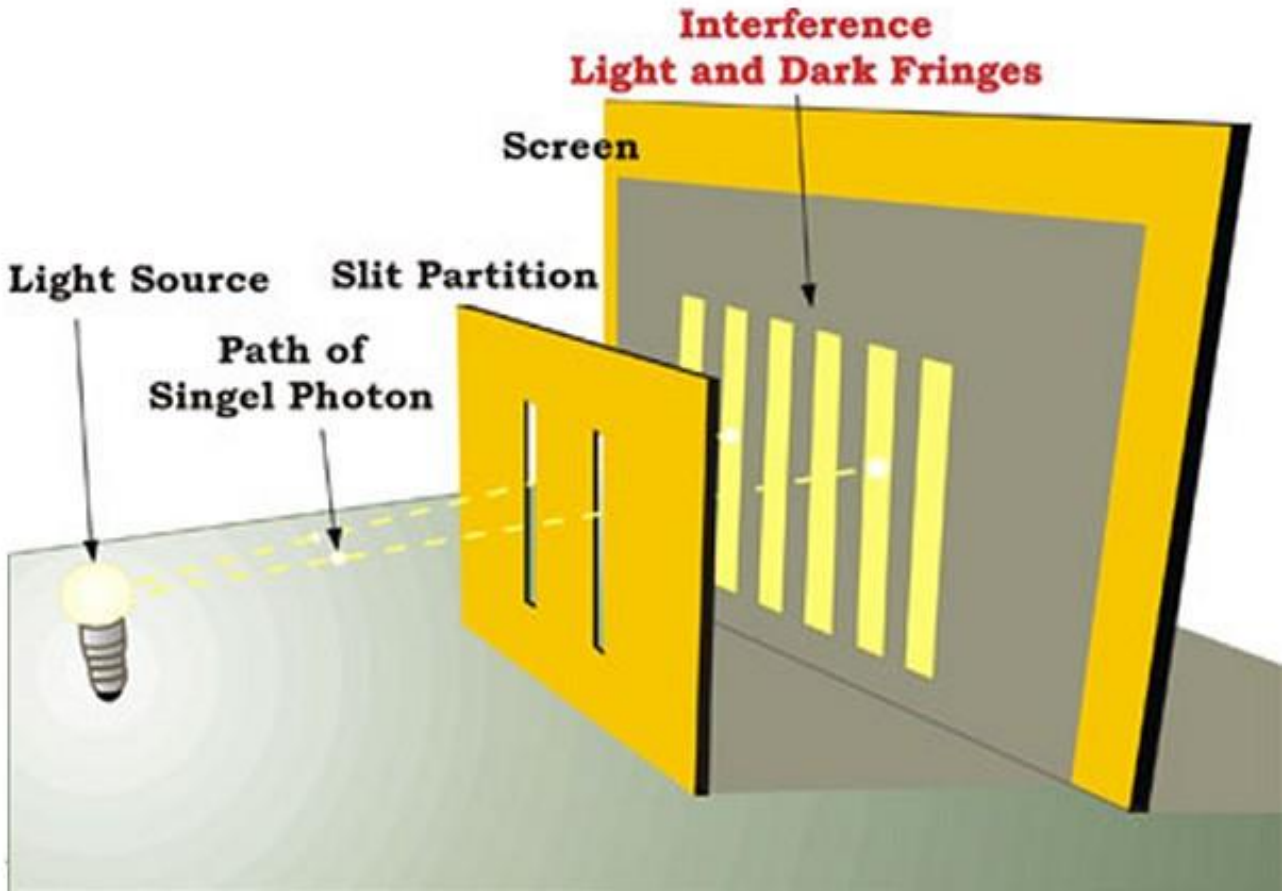
- And the nature of the new basic “carrier” of information (**Qbit**)

A bit of Physics: The Double Slit Experiment



- Source: https://www.physicsoftheuniverse.com/

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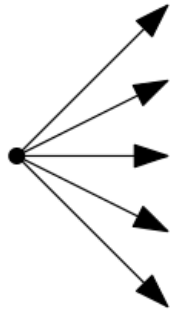

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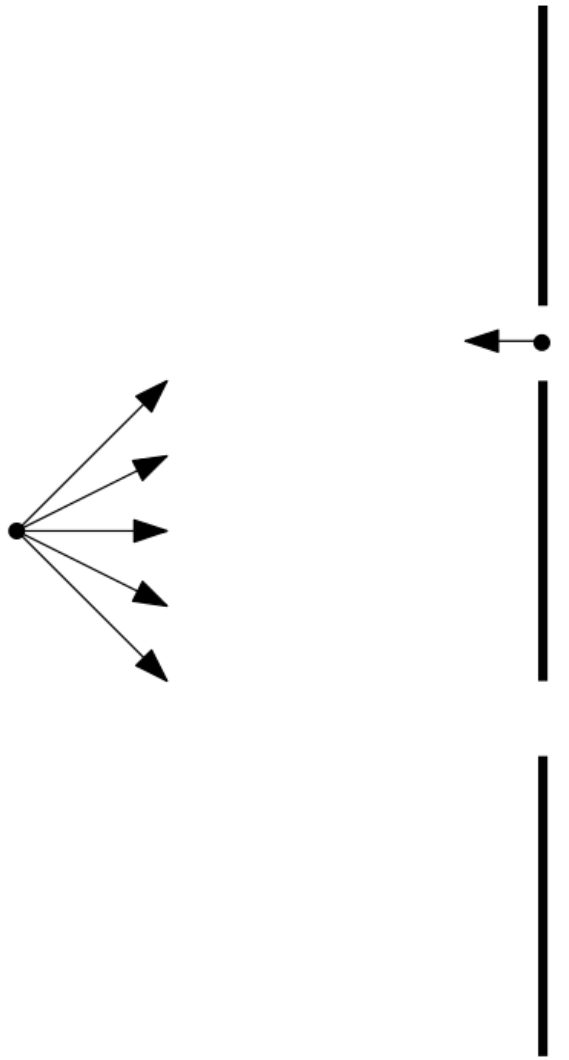

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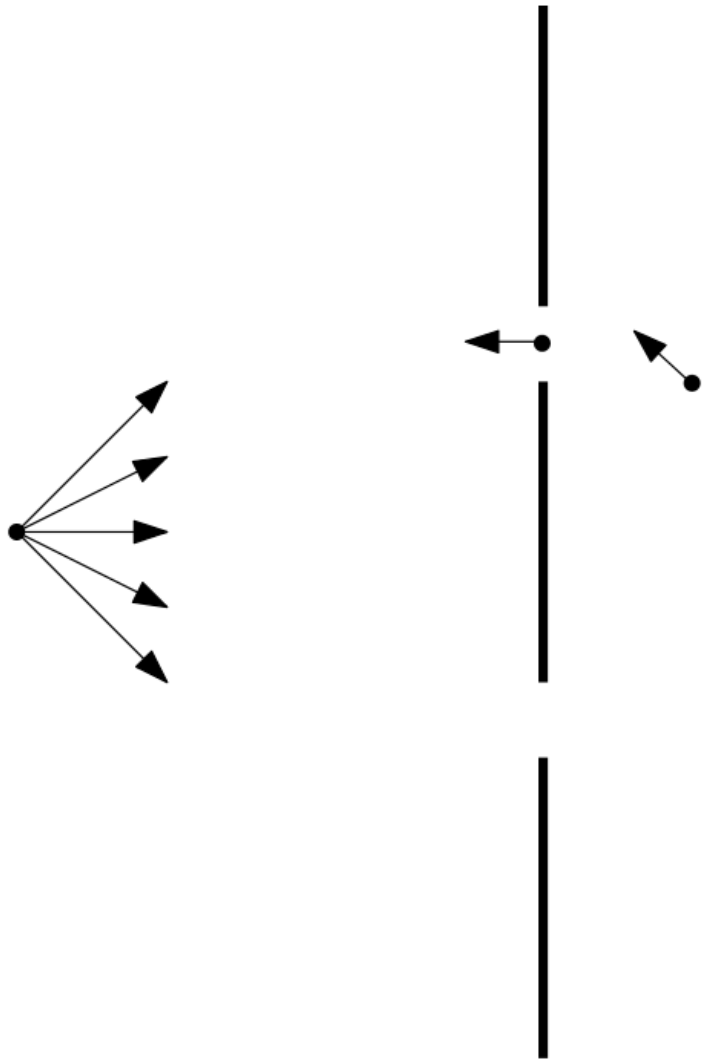

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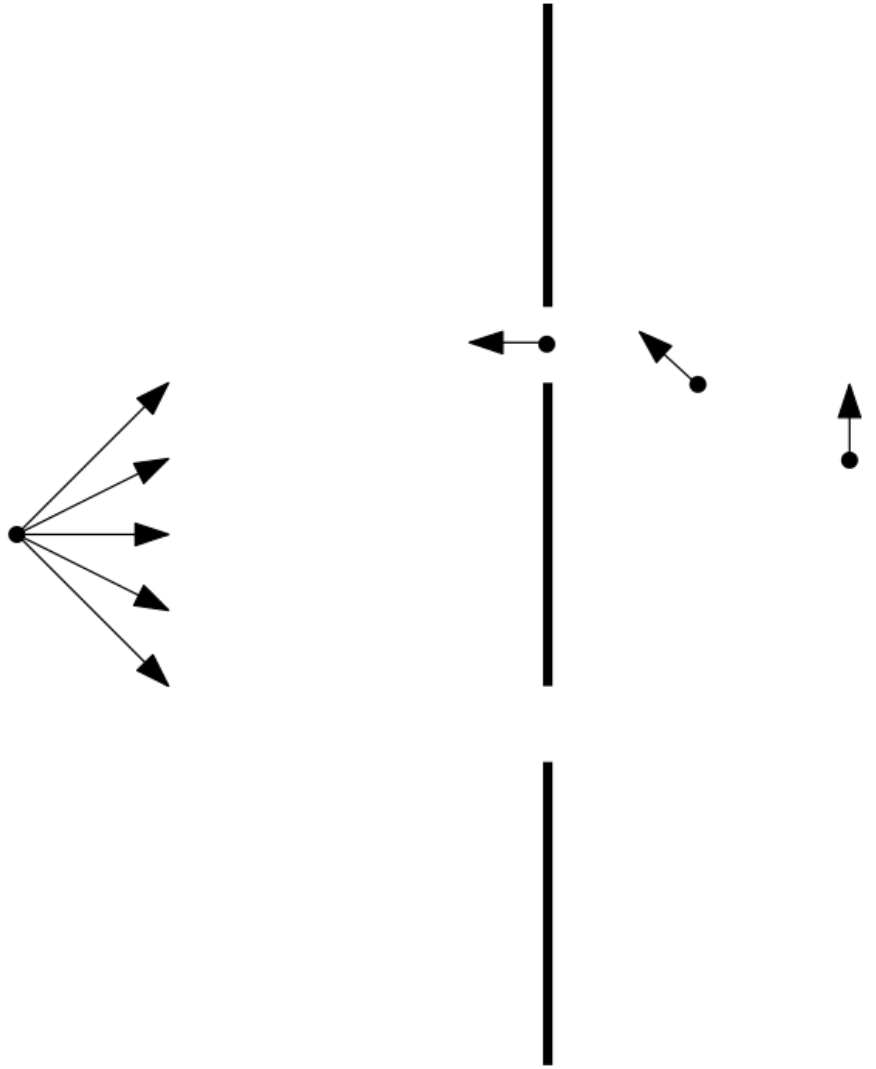

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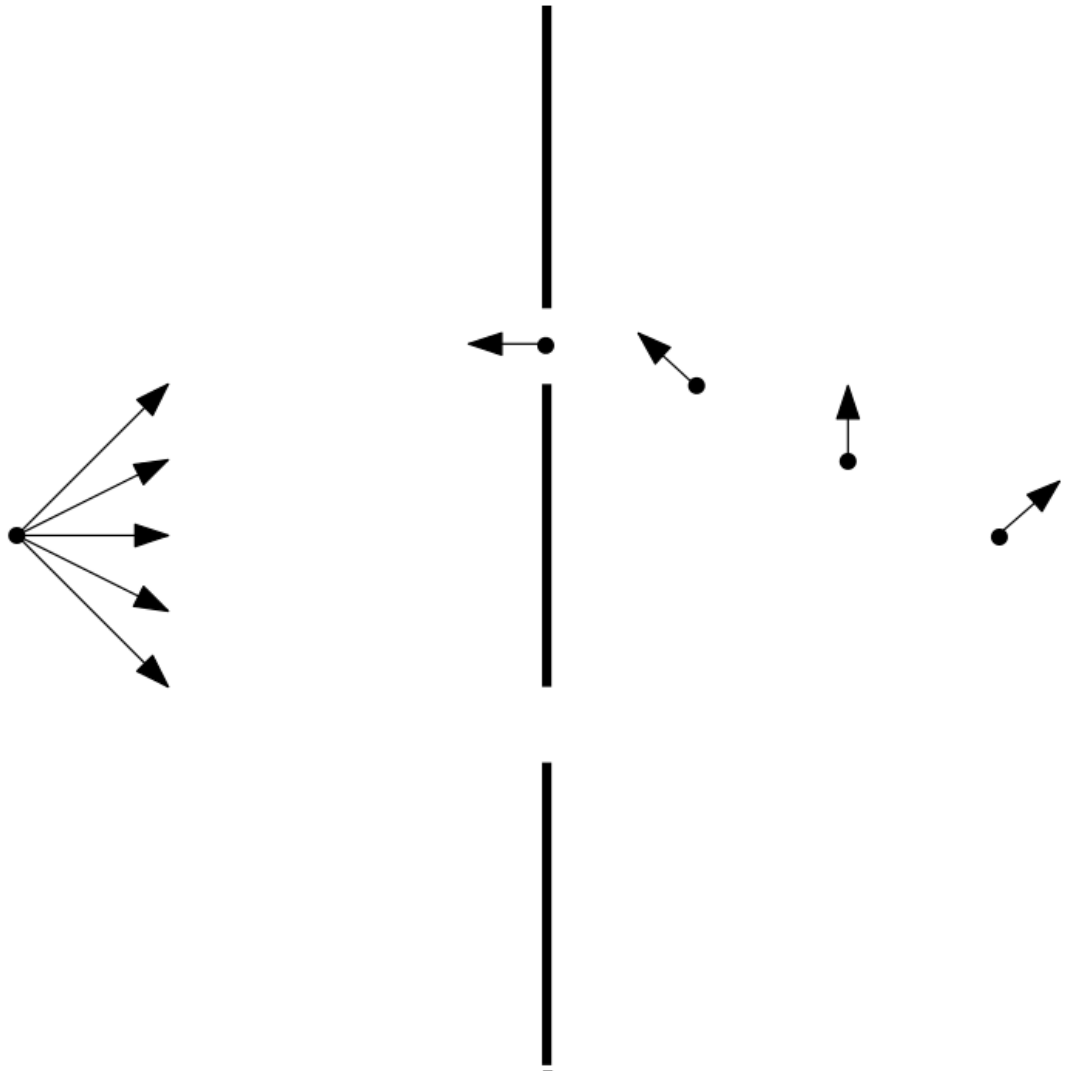

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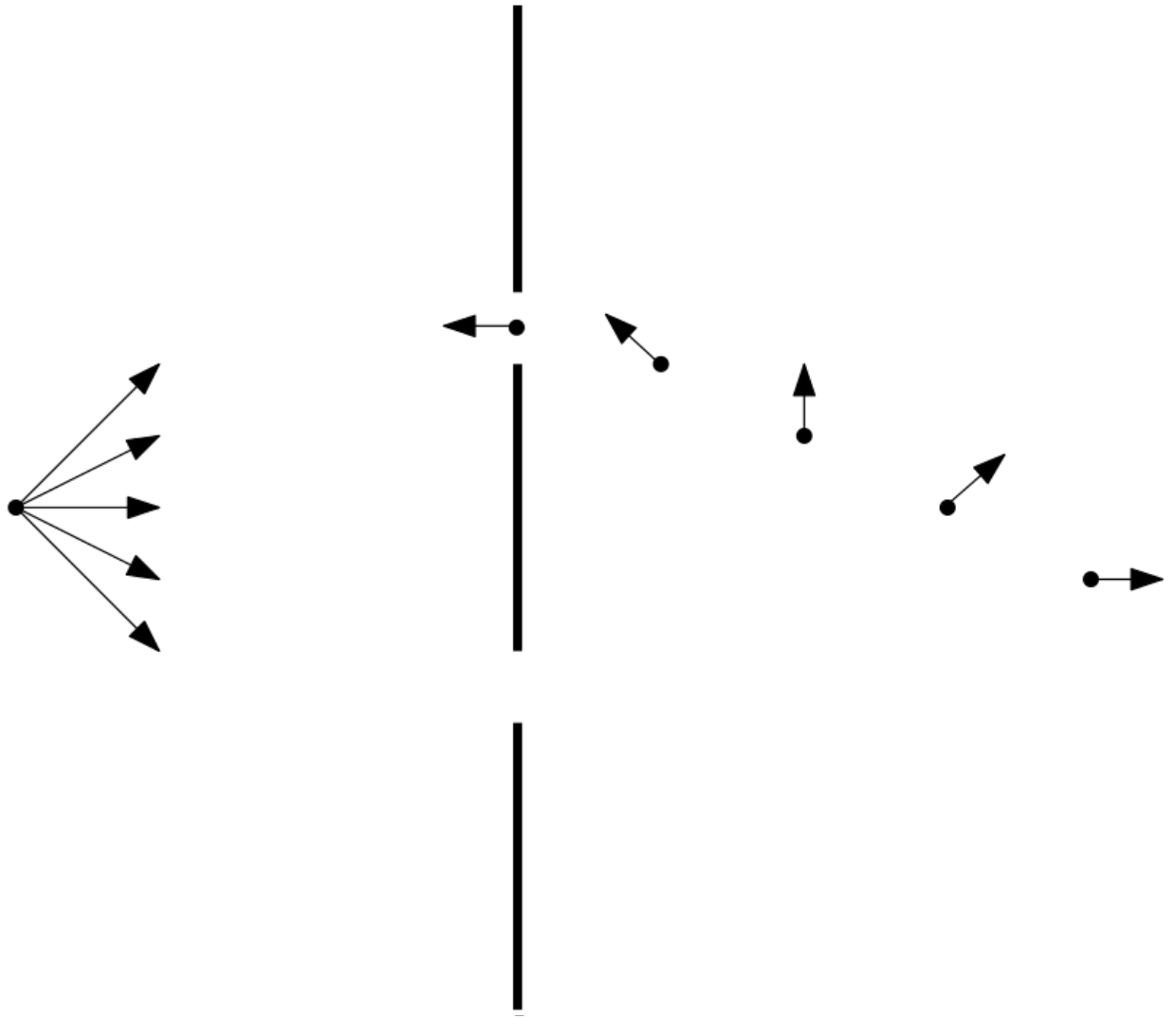

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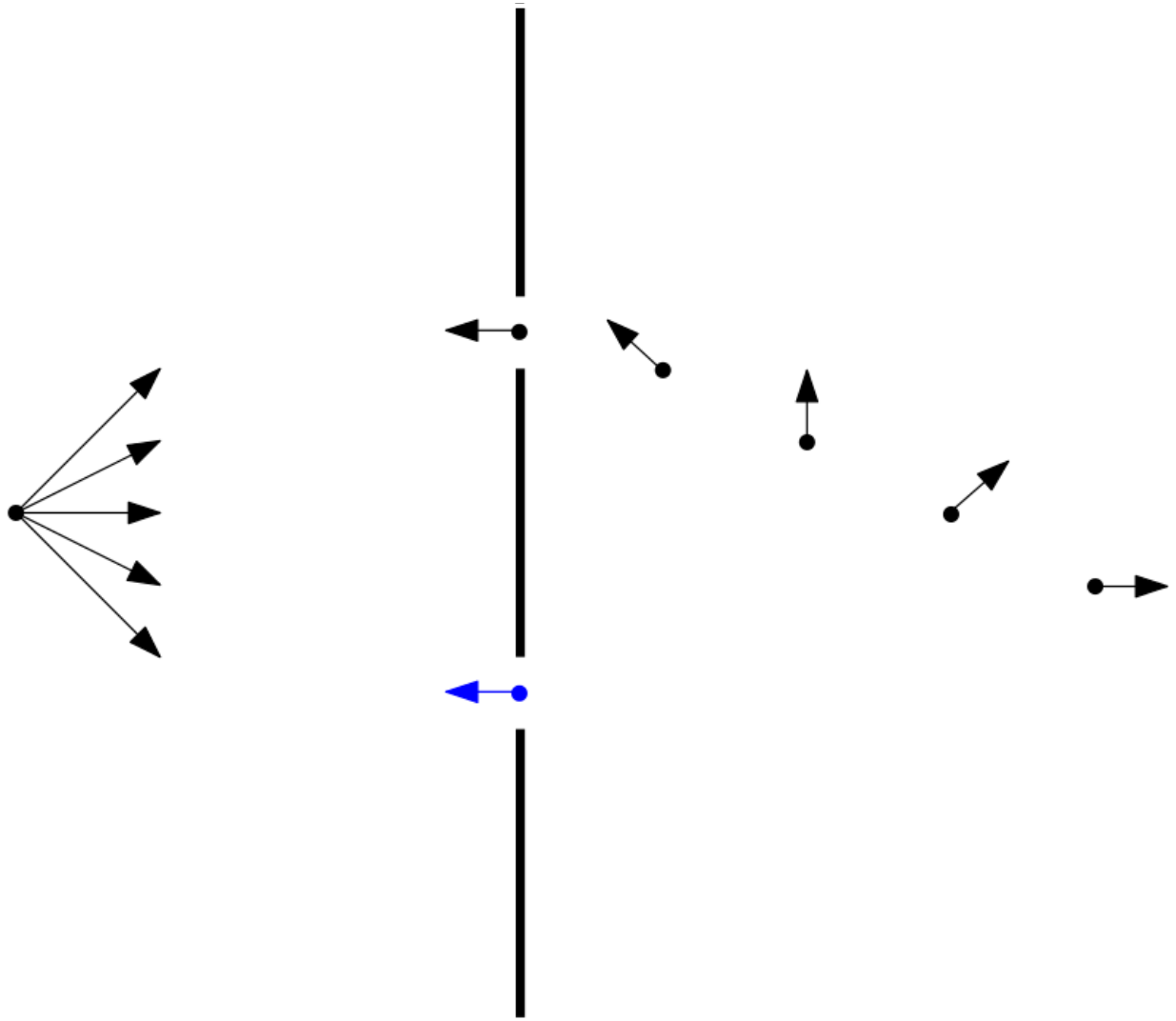

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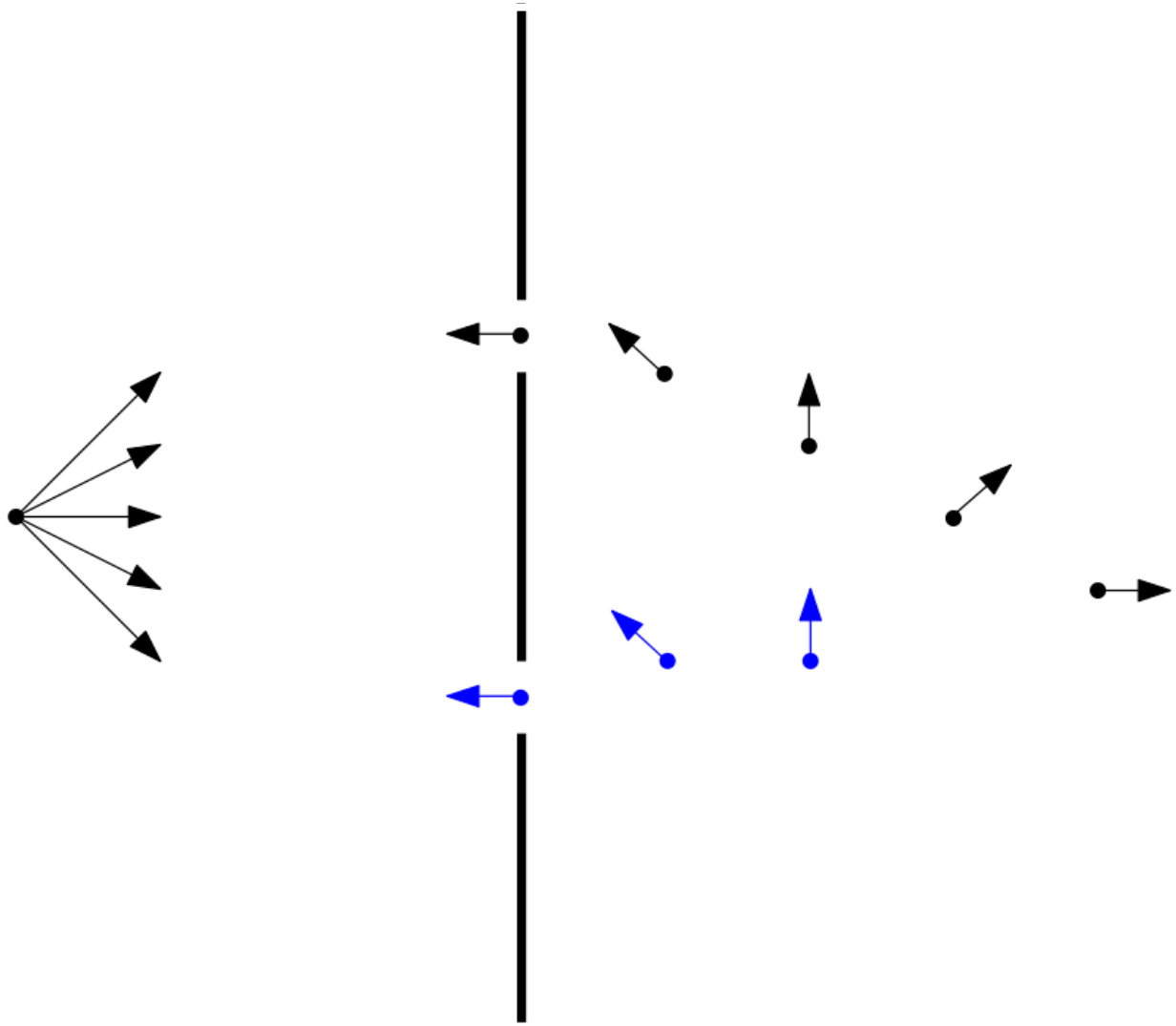

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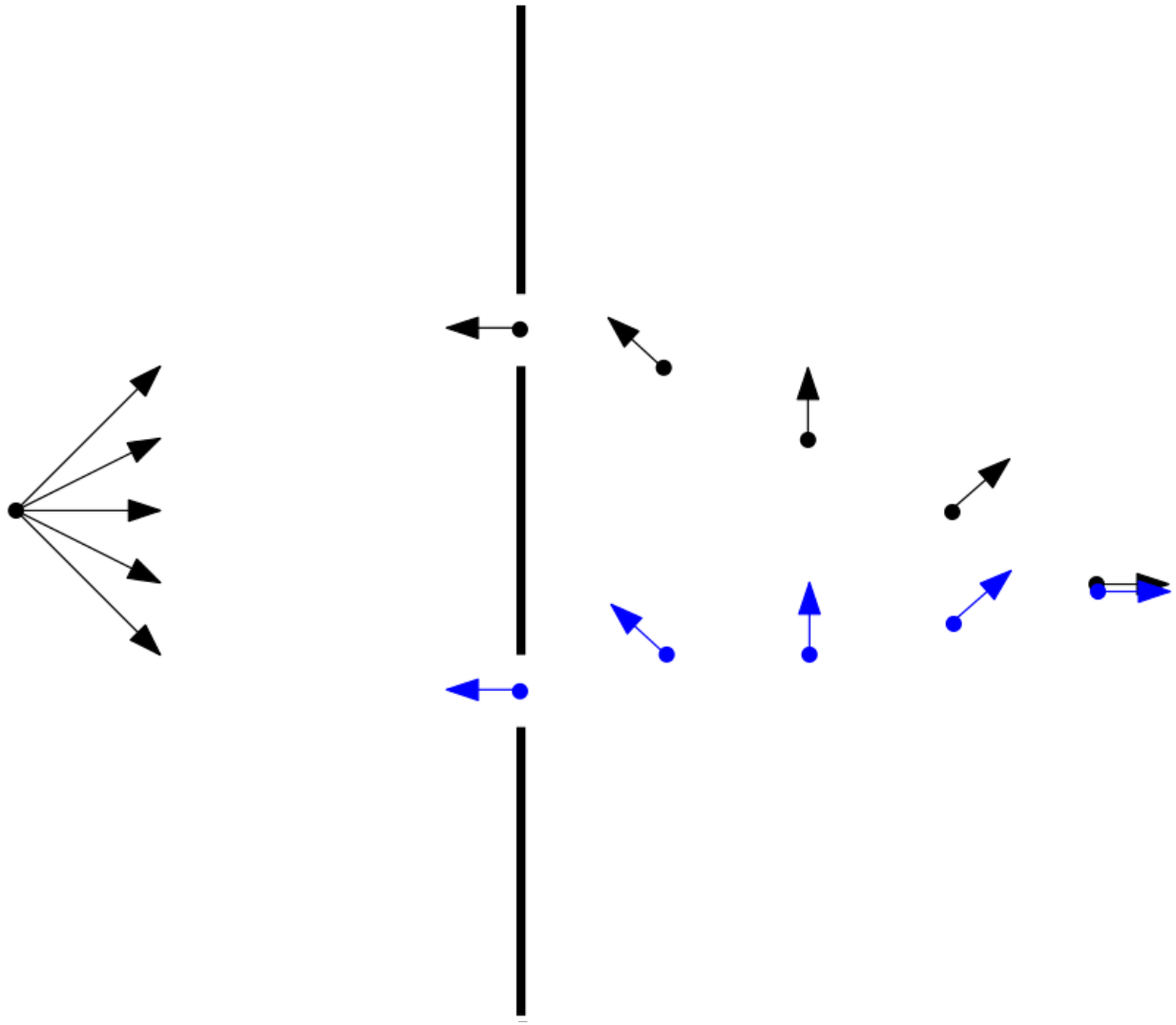

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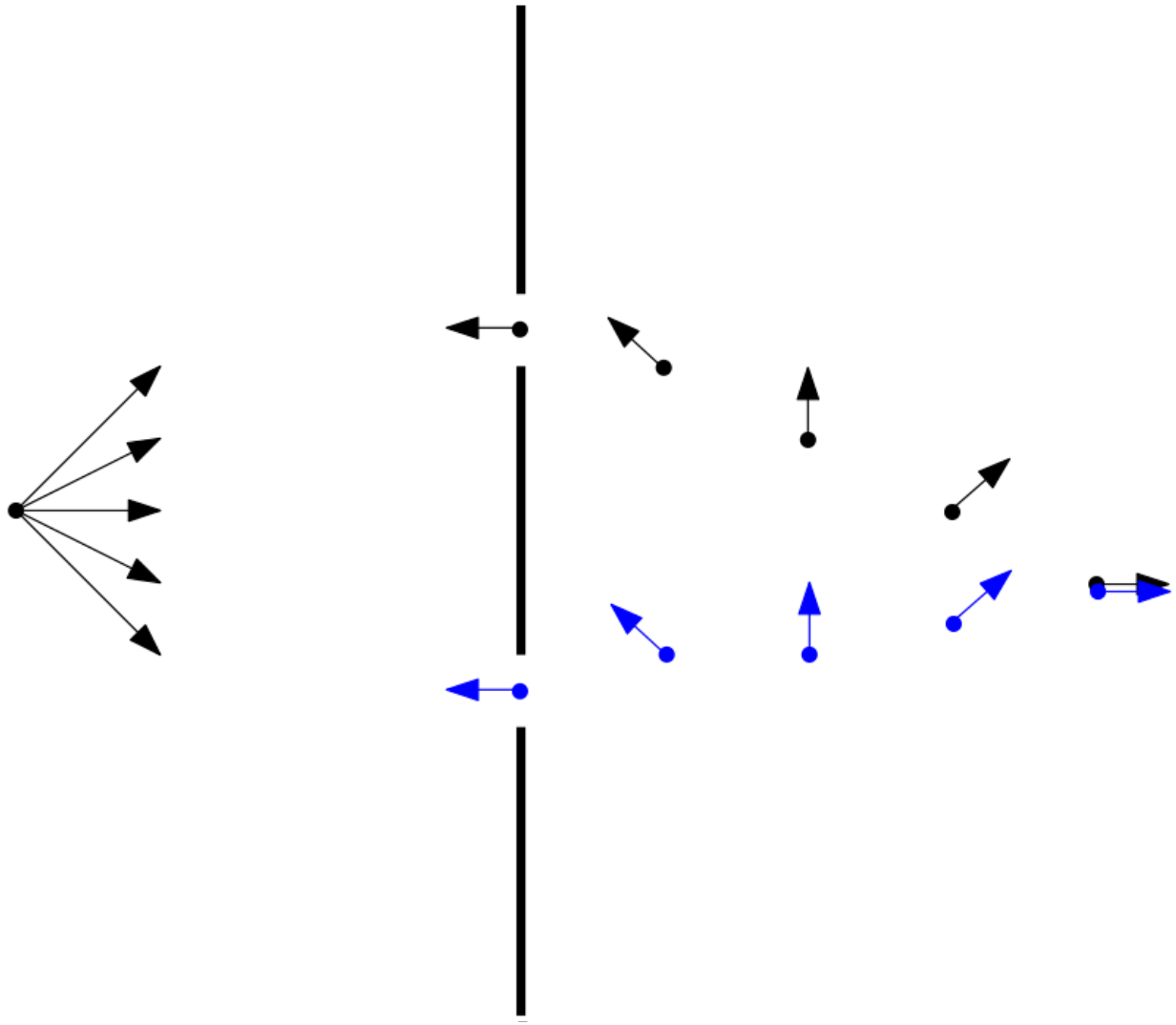

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Interference!

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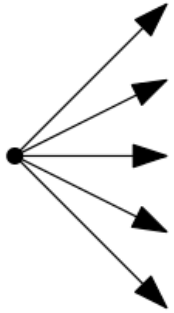

- ***Destructive***

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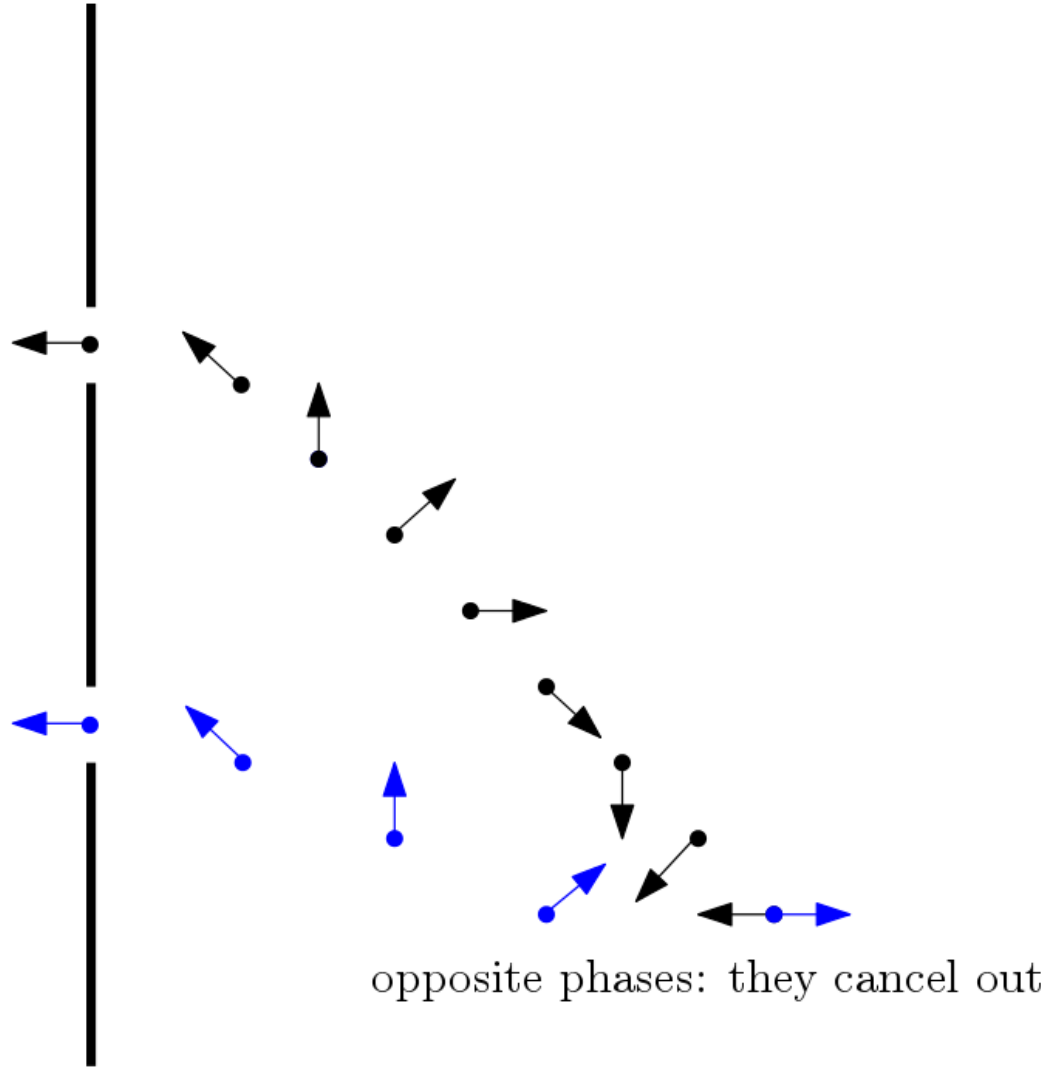
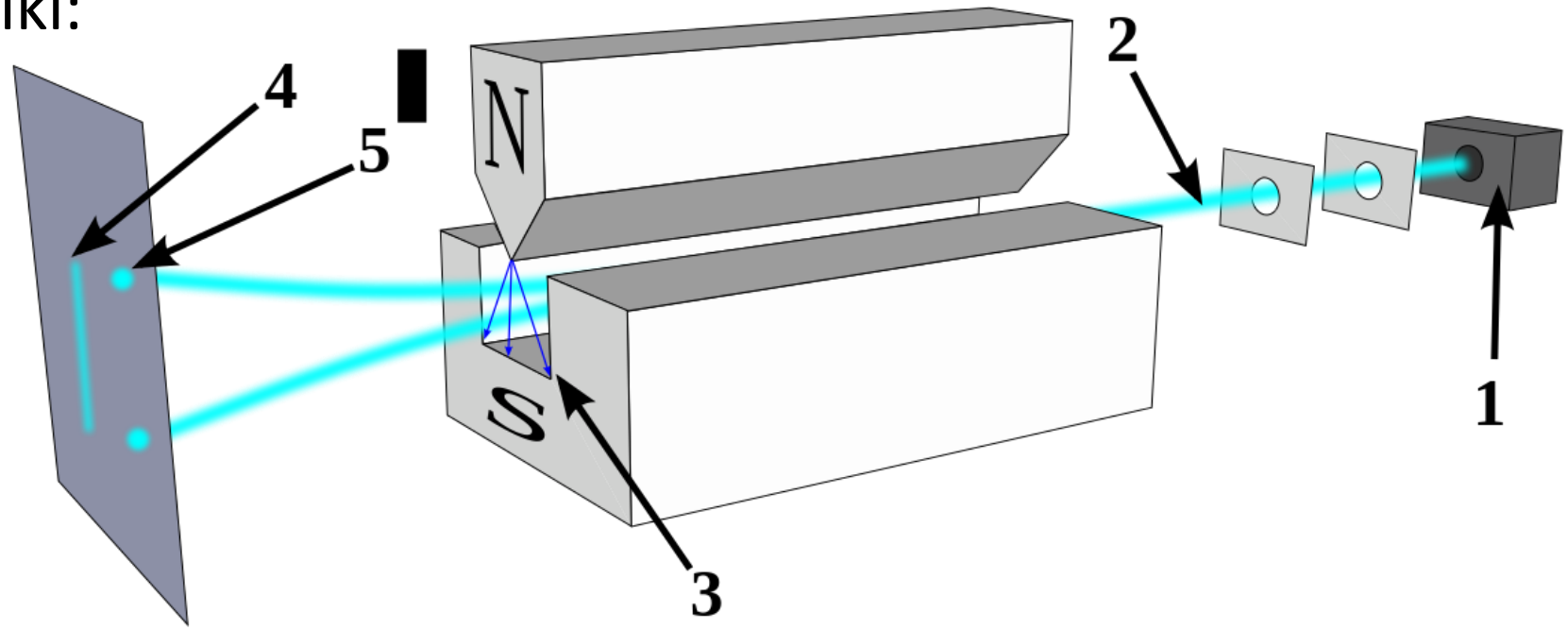


The Stern-Gerlach Experiment

- From wiki:



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- Classical physics say that none of them should be deflected at all!

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- A Qbit can also be in a ***coherent superposition of both***!

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$$|\boldsymbol{s}\rangle = \boldsymbol{\alpha}\ |\uparrow\rangle + \boldsymbol{\beta}\ |\downarrow\rangle$$

- Such that $\boldsymbol{\alpha^2 + \beta^2 = 1}$.
- This intuitively means that if we observe s we will see ↑ spin with *probability* $\boldsymbol{\alpha^2}$ and ↓ spin with *probability* $\boldsymbol{\beta^2}$.

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- Such "forbidden" computational paths cancel out!

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- The numbers α, β can be any numbers (reals, negative, complex).
- They are called the ***amplitudes*** of the corresponding state.
- Then we don't we describe the quantum state as simply

$$|\boldsymbol{s}\rangle = \boldsymbol{\alpha^2}\ |\uparrow\rangle + \boldsymbol{\beta^2}\ |\downarrow\rangle?$$

- If we allow amplitudes to be negative, then we allow ***negative interference*** between different computational paths that lead to incorrect solutions!
- Such "forbidden" computational paths cancel out!
- We cannot do that with a classical computer!

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- These are the ***unitary operators*** (linear transformations that preserve the length of the vector).
- Such transformations are in the core of every quantum algorithm.
- And why complex numbers?
- That’s much more complicated question but fortunately we won’t need them ☺

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These can be represented in information theoretical terms by a qubit, and the operations thereon, and throughout this course we will see how these phenomena give rise to powerful quantum algorithms.