PHYS 407/507 & CS 495 - Introduction to Quantum Computing

Term: Spring 2026
Meetings: Tuesday & Thursday 17:00-18:15
Location: Room 117 Wishnick Hall
Video: All sessions recorded for online viewing

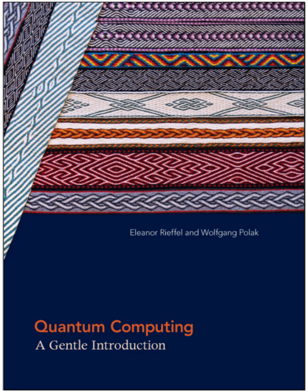
Instructor: Carlo Segre
Office: 166D/172 Pritzker Science
Phone: 312.567.3498
email: segre@illinoistech.edu

Resources: *Quantum Computing: A Gentle Introduction*, E. Rieffel & W. Polak (MIT Univ Press, 2011)

Introduction to Classical and Quantum Computing, T. Wong (Rooted Grove, 2022)

Quirk: A drag-and-drop quantum circuit simulator, Craig Gidney

Web Site: http://phys.iit.edu/~segre/phys407/26S



Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.
5. Use the concept of quantum entanglement to develop quantum algorithms.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.
5. Use the concept of quantum entanglement to develop quantum algorithms.
6. Clearly describe the techniques of quantum error correction and fault tolerance.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.
5. Use the concept of quantum entanglement to develop quantum algorithms.
6. Clearly describe the techniques of quantum error correction and fault tolerance.
7. Build quantum algorithms using Quirk.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.
5. Use the concept of quantum entanglement to develop quantum algorithms.
6. Clearly describe the techniques of quantum error correction and fault tolerance.
7. Build quantum algorithms using Quirk.
8. Demonstrate the programming of a quantum computer using Python.

Course objectives for PHYS 407/507 & CS 495

1. Clearly describe the building blocks of quantum computing.
2. Apply tools of quantum computing to manipulate qubits.
3. Clearly describe the fundamental hardware used to realize quantum computers.
4. Clearly describe the purpose and realization of quantum gates.
5. Use the concept of quantum entanglement to develop quantum algorithms.
6. Clearly describe the techniques of quantum error correction and fault tolerance.
7. Build quantum algorithms using Quirk.
8. Demonstrate the programming of a quantum computer using Python.
9. Successfully program an agreed-upon quantum algorithm on an IBM quantum computer.

Course syllabus

- Homework Assignments

Course syllabus

- Homework Assignments
- Qiskit Progress Reports

Course syllabus

- Homework Assignments
- Qiskit Progress Reports
- Midterm Exams – Online, handwritten uploads to Canvas

Course syllabus

- Homework Assignments
- Qiskit Progress Reports
- Midterm Exams – Online, handwritten uploads to Canvas
- Final Exam – Presentations on research articles
  - Choose a recent research article which features a synchrotron technique
  - Get approval before starting
  - Timetable will be posted

Course syllabus

- Homework Assignments
- Qiskit Progress Reports
- Midterm Exams – Online, handwritten uploads to Canvas
- Final Exam – Presentations on research articles
  - Choose a recent research article which features a synchrotron technique
  - Get approval before starting
  - Timetable will be posted
- Final project - programming a quantum algorithm
  - Start thinking about a suitable project right away
  - Make proposal and get approval before starting

Course grading

PHYS 407 & CS 495

PHYS 507

Course grading

PHYS 407 & CS 495

30% – Homework assignments

PHYS 507

20% – Homework assignments

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

30% – Final presentation

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

20% – Final presentation

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

30% – Final presentation

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

20% – Final presentation

20% – Final project

Course grading

PHYS 407 & CS 495

30% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

30% – Final presentation

Grading scale

A	–	88%	to	100%
B	–	75%	to	88%
C	–	62%	to	75%
D	–	50%	to	62%
E	–	0%	to	50%

PHYS 507

20% – Homework assignments
Weekly, due at beginning of class
Turned in via Canvas

40% – Exams

20% – Final presentation

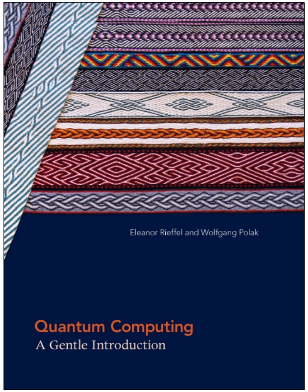
20% – Final project

Grading scale

A	–	88%	to	100%
B	–	75%	to	88%
C	–	0%	to	75%

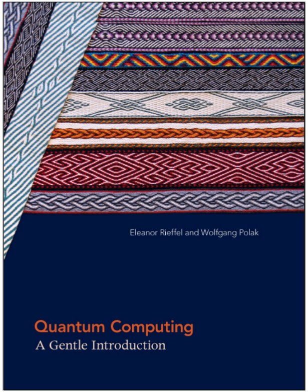
Topics to be covered (chapter titles)

1. Quantum building blocks



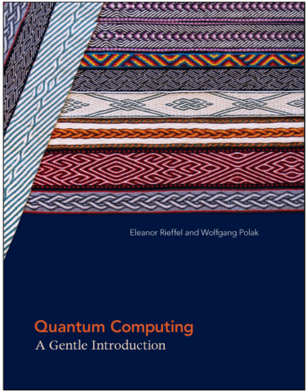
Topics to be covered (chapter titles)

1. Quantum building blocks
2. Quantum algorithms



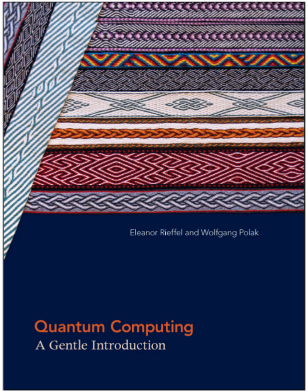
Topics to be covered (chapter titles)

1. Quantum building blocks
2. Quantum algorithms
3. Entangled subsystems and robust computation



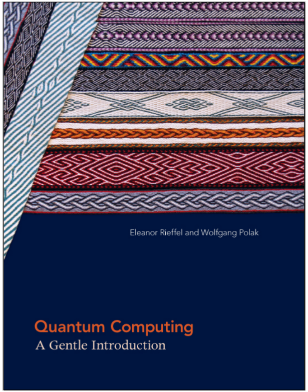
Topics to be covered (chapter titles)

1. Quantum building blocks
2. Quantum algorithms
3. Entangled subsystems and robust computation
4. Quantum computing hardware



Topics to be covered (chapter titles)

1. Quantum building blocks
2. Quantum algorithms
3. Entangled subsystems and robust computation
4. Quantum computing hardware
5. Other topics as appropriate



Why study quantum computing?

Quantum computing is one part of a broader field called quantum information science which has revolutionized cryptography and secure communications

Why study quantum computing?

Quantum computing is one part of a broader field called quantum information science which has revolutionized cryptography and secure communications

Quantum computing can provide solutions to problems that are computationally expensive using digital computers

Why study quantum computing?

Quantum computing is one part of a broader field called quantum information science which has revolutionized cryptography and secure communications

Quantum computing can provide solutions to problems that are computationally expensive using digital computers

Quantum computing error correction and fault tolerance has made the technology practical

Why study quantum computing?

Quantum computing is one part of a broader field called quantum information science which has revolutionized cryptography and secure communications

Quantum computing can provide solutions to problems that are computationally expensive using digital computers

Quantum computing error correction and fault tolerance has made the technology practical

Companies are beginning to build practical quantum computers with many qubits

Why study quantum computing?

Quantum computing is one part of a broader field called quantum information science which has revolutionized cryptography and secure communications

Quantum computing can provide solutions to problems that are computationally expensive using digital computers

Quantum computing error correction and fault tolerance has made the technology practical

Companies are beginning to build practical quantum computers with many qubits

Quantum computing is becoming interesting to a number of fields outside physics and could be even more relevant in the near future

Today's outline - January 13, 2026

Today's outline - January 13, 2026

- Quantum fundamentals

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra
- Quantum postulates

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra
- Quantum postulates
- Quantum key distribution

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra
- Quantum postulates
- Quantum key distribution

Reading Assignment: Reiffel: 2.4-2.5; 3.1 Wong: 2.2.2-2.4.3; 4.2.1-4.2.2

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra
- Quantum postulates
- Quantum key distribution

Reading Assignment: Reiffel: 2.4-2.5; 3.1 Wong: 2.2.2-2.4.3; 4.2.1-4.2.2

Homework Assignment #01:
due Thursday, January 22, 2026

Today's outline - January 13, 2026

- Quantum fundamentals
- Superposition
- Dirac notation
- Qubits & linear algebra
- Quantum postulates
- Quantum key distribution

Reading Assignment: Reiffel: 2.4-2.5; 3.1 Wong: 2.2.2-2.4.3; 4.2.1-4.2.2

Homework Assignment #01:
due Thursday, January 22, 2026

Homework Assignment #02:
due Tuesday, February 03, 2026

Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

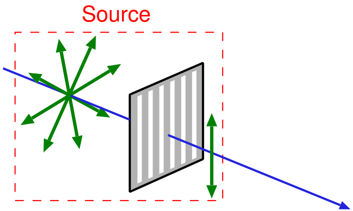
A simple example of such a system is the polarization of a photon

Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

A simple example of such a system is the polarization of a photon

Consider an unpolarized beam of light from a laser pointer prepared in the vertical polarization by a filter



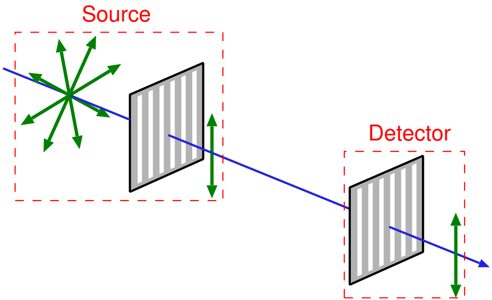
Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

A simple example of such a system is the polarization of a photon

Consider an unpolarized beam of light from a laser pointer prepared in the vertical polarization by a filter

A detector for the vertical state will detect the full beam intensity,



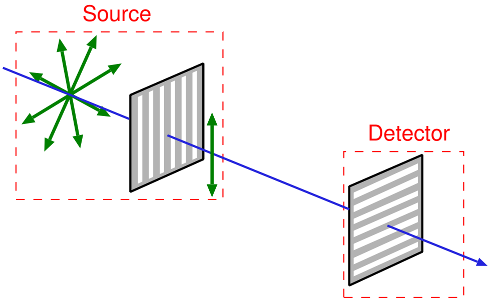
Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

A simple example of such a system is the polarization of a photon

Consider an unpolarized beam of light from a laser pointer prepared in the vertical polarization by a filter

A detector for the vertical state will detect the full beam intensity, A detector for the horizontal state will detect nothing



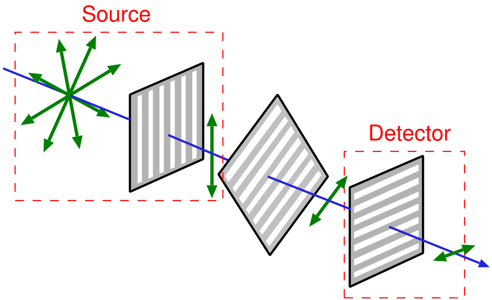
Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

A simple example of such a system is the polarization of a photon

Consider an unpolarized beam of light from a laser pointer prepared in the vertical polarization by a filter

A detector for the vertical state will detect the full beam intensity, A detector for the horizontal state will detect nothing



If a tilted polarizer is placed in between, the horizontal detector now measures a smaller, but non-zero, value

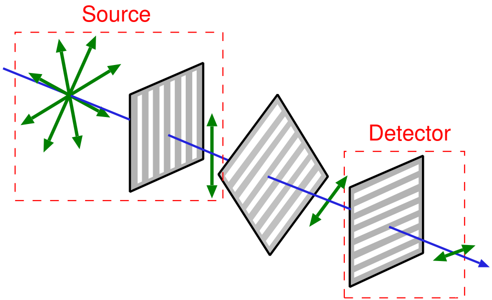
Quantum mechanics fundamentals

A quantum computer is built of qubits which consist of physical systems which have two measureable states

A simple example of such a system is the polarization of a photon

Consider an unpolarized beam of light from a laser pointer prepared in the vertical polarization by a filter

A detector for the vertical state will detect the full beam intensity, A detector for the horizontal state will detect nothing



If a tilted polarizer is placed in between, the horizontal detector now measures a smaller, but non-zero, value

Because photons are quantum particles, this effect works even for single photons with the measuring a fraction of the photons to be horizontal

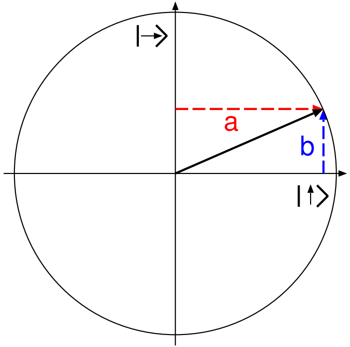
Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|{\uparrow}\rangle$ and $|{\rightarrow}\rangle$ states

$$|v\rangle = a|{\uparrow}\rangle + b|{\rightarrow}\rangle,$$



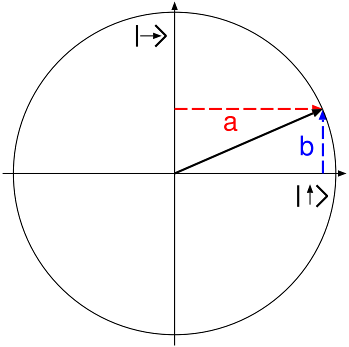
Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

$$|v\rangle = a|\uparrow\rangle + b|\rightarrow\rangle,$$

The amplitudes a and b are complex constants such that the state is normalized

$$|v|^2 \equiv 1$$



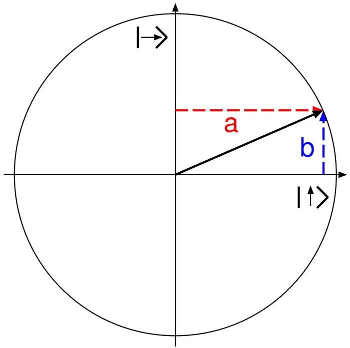
Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

$$|v\rangle = a|\uparrow\rangle + b|\rightarrow\rangle,$$

The amplitudes a and b are complex constants such that the state is normalized

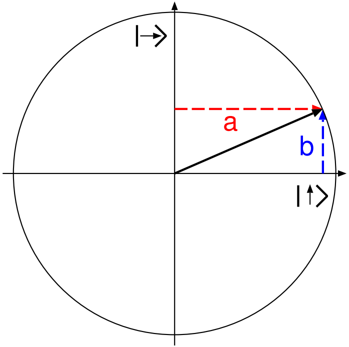
$$|v|^2 \equiv 1 \quad \longrightarrow \quad |a|^2 + |b|^2 = 1$$



Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

The amplitudes a and b are complex constants such that the state is normalized



$$|v\rangle = a|\uparrow\rangle + b|\rightarrow\rangle,$$

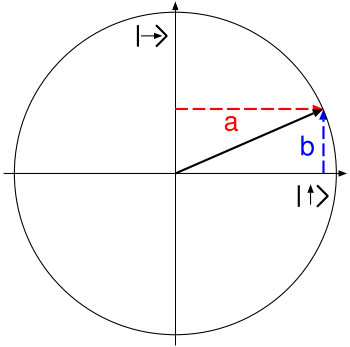
$$|v|^2 \equiv 1 \quad \longrightarrow \quad |a|^2 + |b|^2 = 1$$

$$a = |a|e^{i\alpha}, \quad b = |b|e^{i\beta}$$

Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|{\uparrow}\rangle$ and $|{\rightarrow}\rangle$ states

The amplitudes a and b are complex constants such that the state is normalized



$$|v\rangle = a|{\uparrow}\rangle + b|{\rightarrow}\rangle,$$

$$|v|^2 \equiv 1 \quad \longrightarrow \quad |a|^2 + |b|^2 = 1$$

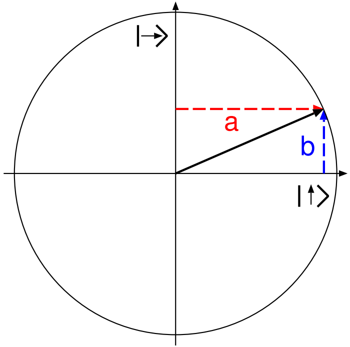
$$a = |a|e^{i\alpha}, \quad b = |b|e^{i\beta}$$

Suppose a photon in a general state $|v\rangle$ enters a detector whose direction is $|{\uparrow}\rangle$

Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

The amplitudes a and b are complex constants such that the state is normalized



$$|v\rangle = a|\uparrow\rangle + b|\rightarrow\rangle,$$

$$|v|^2 \equiv 1 \quad \longrightarrow \quad |a|^2 + |b|^2 = 1$$

$$a = |a|e^{i\alpha}, \quad b = |b|e^{i\beta}$$

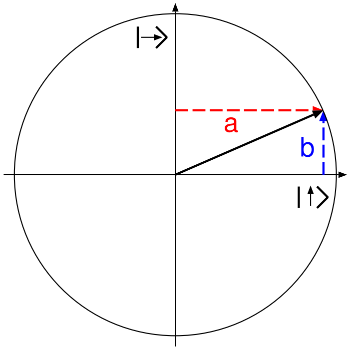
Suppose a photon in a general state $|v\rangle$ enters a detector whose direction is $|\uparrow\rangle$

The probability of detection is $|a|^2$ and the probability of absorption is $|b|^2$

Superposition of states

The state of a single photon can be represented by a generalized quantum superposition of the $|\uparrow\rangle$ and $|\rightarrow\rangle$ states

The amplitudes a and b are complex constants such that the state is normalized



$$|v\rangle = a|\uparrow\rangle + b|\rightarrow\rangle,$$

$$|v|^2 \equiv 1 \quad \longrightarrow \quad |a|^2 + |b|^2 = 1$$

$$a = |a|e^{i\alpha}, \quad b = |b|e^{i\beta}$$

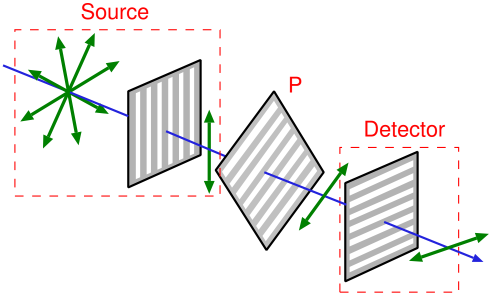
Suppose a photon in a general state $|v\rangle$ enters a detector whose direction is $|\uparrow\rangle$

The probability of detection is $|a|^2$ and the probability of absorption is $|b|^2$

This formalism allows us to describe the polarization experiment

Polarizer experiment

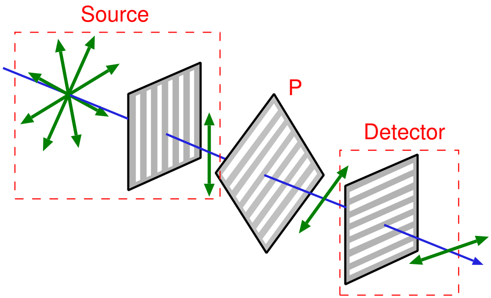
The photons that come from the source are in a state $|\uparrow\rangle$



Polarizer experiment

The photons that come from the source are in a state $|\uparrow\rangle$

In the axes of the polarizer *P* there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

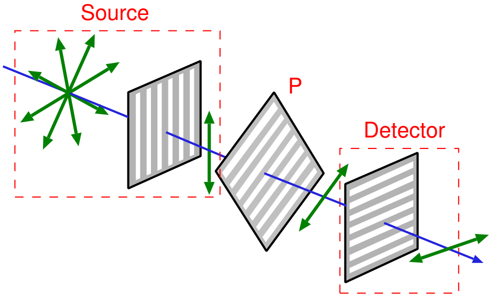


Polarizer experiment

The photons that come from the source are in a state $|\uparrow\rangle$

In the axes of the polarizer *P* there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

$$|\uparrow\rangle = \frac{1}{\sqrt{2}}|\nearrow\rangle + \frac{1}{\sqrt{2}}|\nwarrow\rangle$$



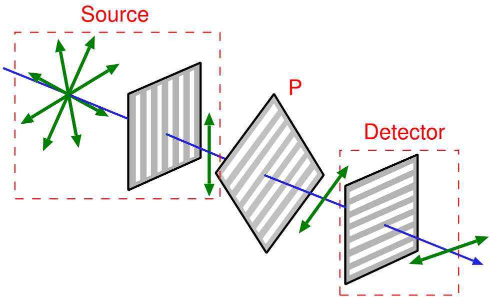
Polarizer experiment

The photons that come from the source are in a state $|\uparrow\rangle$

In the axes of the polarizer *P* there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

$$|\uparrow\rangle = \frac{1}{\sqrt{2}}|\nearrow\rangle + \frac{1}{\sqrt{2}}|\nwarrow\rangle$$

The photon thus has an 0.5 probability of passing through the polarizer and will then be in a state



Polarizer experiment

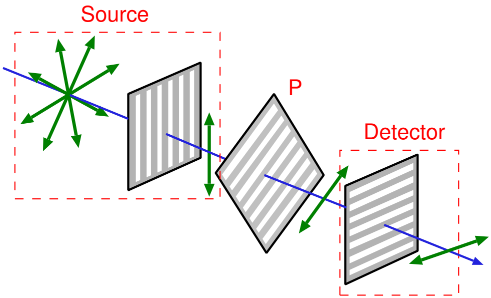
The photons that come from the source are in a state $|\uparrow\rangle$

In the axes of the polarizer P there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

$$|\uparrow\rangle = \frac{1}{\sqrt{2}}|\nearrow\rangle + \frac{1}{\sqrt{2}}|\nwarrow\rangle$$

The photon thus has an 0.5 probability of passing through the polarizer and will then be in a state

$$|\nearrow\rangle = \frac{1}{\sqrt{2}}|\uparrow\rangle + \frac{1}{\sqrt{2}}|\rightarrow\rangle$$

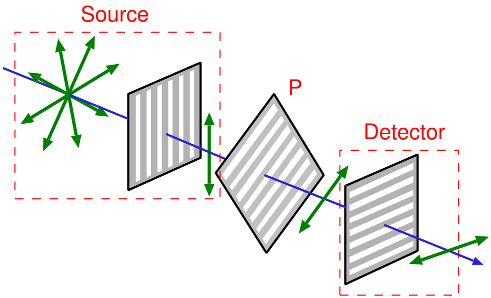


Polarizer experiment

The photons that come from the source are in a state $|\uparrow\rangle$

In the axes of the polarizer *P* there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

$$|\uparrow\rangle = \frac{1}{\sqrt{2}}|\nearrow\rangle + \frac{1}{\sqrt{2}}|\nwarrow\rangle$$



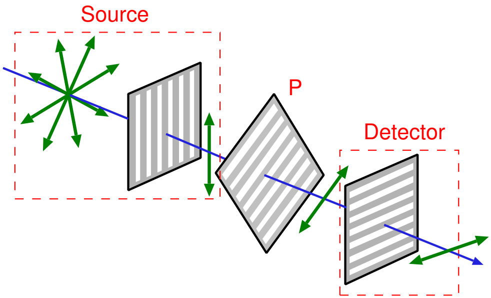
The photon thus has an 0.5 probability of passing through the polarizer and will then be in a state

$$|\nearrow\rangle = \frac{1}{\sqrt{2}}|\uparrow\rangle + \frac{1}{\sqrt{2}}|\rightarrow\rangle$$

Again there is only an 0.5 probability of the photon passing so an initial photon will have a probability of $0.5 \times 0.5 = 0.25$ of making it to the detector

Polarizer experiment

The photons that come from the source are in a state $|\uparrow\rangle$



In the axes of the polarizer *P* there are two possible states $|\nearrow\rangle$ and $|\nwarrow\rangle$ and the vertically polarized photon can be written as

$$|\uparrow\rangle = \frac{1}{\sqrt{2}}|\nearrow\rangle + \frac{1}{\sqrt{2}}|\nwarrow\rangle$$

The photon thus has an 0.5 probability of passing through the polarizer and will then be in a state

$$|\nearrow\rangle = \frac{1}{\sqrt{2}}|\uparrow\rangle + \frac{1}{\sqrt{2}}|\rightarrow\rangle$$

Again there is only an 0.5 probability of the photon passing so an initial photon will have a probability of $0.5 \times 0.5 = 0.25$ of making it to the detector

Quantum particles (and qubits) behave probabilistically

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle,$$

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac, or bra-ket, notation is used to describe quantum systems.

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac, or bra-ket, notation is used to describe quantum systems. The ket ($|x\rangle$) and bra ($\langle x|$) are used to represent a vector and its conjugate transpose respectively

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac, or bra-ket, notation is used to describe quantum systems. The ket ($|x\rangle$) and bra ($\langle x|$) are used to represent a vector and its conjugate transpose respectively

A complex vector space V is generated by a set of vectors, S, if every $|v\rangle \in V$ can be written as a complex linear superposition of the vectors in the set

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac, or bra-ket, notation is used to describe quantum systems. The ket ($|x\rangle$) and bra ($\langle x|$) are used to represent a vector and its conjugate transpose respectively

A complex vector space V is generated by a set of vectors, S, if every $|v\rangle \in V$ can be written as a complex linear superposition of the vectors in the set

$$|v\rangle = a_1|s_1\rangle + a_2|s_2\rangle + \cdots + a_n|s_n\rangle,$$

Dirac notation

Any two-state quantum system can be considered a qubit and can be modeled as a superposition of the two linearly independent states

$$|q\rangle = a|0\rangle + b|1\rangle, \qquad a = |a|e^{i\alpha}, \qquad b = |b|e^{i\beta}$$

Examples include photon polarization, electron spin, and ground/excited states of atoms

The infinte number of possible states in this system can all be described by the linear superposition $|q\rangle$

Dirac, or bra-ket, notation is used to describe quantum systems. The ket ($|x\rangle$) and bra ($\langle x|$) are used to represent a vector and its conjugate transpose respectively

A complex vector space V is generated by a set of vectors, S, if every $|v\rangle \in V$ can be written as a complex linear superposition of the vectors in the set

$$|v\rangle = a_1|s_1\rangle + a_2|s_2\rangle + \cdots + a_n|s_n\rangle, \quad |s_i\rangle \in S, \quad a_i = |a_i|e^{i\varphi_i}$$

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

$$\langle v|v\rangle = Re\{\langle v|v\rangle\} > 0$$

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

$$\langle v|v\rangle = Re\{\langle v|v\rangle\} > 0$$
$$\langle v_2|v_1\rangle = \overline{\langle v_1|v_2\rangle}$$

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

$$\langle v|v\rangle = Re\{\langle v|v\rangle\} > 0$$

$$\langle v_2|v_1\rangle = \overline{\langle v_1|v_2\rangle}$$

$$(a\langle v_2| + b\langle v_3|)|v_1\rangle = a\langle v_2|v_1\rangle + b\langle v_3|v_1\rangle$$

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

$$\langle v|v\rangle = Re\{\langle v|v\rangle\} > 0$$

$$\langle v_2|v_1\rangle = \overline{\langle v_1|v_2\rangle}$$

$$(a\langle v_2| + b\langle v_3|)|v_1\rangle = a\langle v_2|v_1\rangle + b\langle v_3|v_1\rangle$$

A basis set $B = \{|\beta_1\rangle, |\beta_2\rangle, \ldots |\beta_n\rangle\}$ is said to be orthonormal if

Dirac notation (cont.)

The span of S is the subspace of all linear combinations of vectors in S

A basis, B, is a set of vectors for which every element of V can be written as a unique linear combination of vectors $|b\rangle \in B$

In a two-dimensional space such as a qubit, any two vectors which are not multiples of each other and are orthonormal form a basis

For polarized photons, $\{|\uparrow\rangle, |\rightarrow\rangle\}$, $\{|\nearrow\rangle, |\nwarrow\rangle\}$, and $\{|\circlearrowright\rangle, |\circlearrowleft\rangle\}$ are all valid basis sets

Operations on the vector space V include the inner (scalar, dot) product $\langle v_2|v_1\rangle$ with properties

$$\langle v|v\rangle = Re\{\langle v|v\rangle\} > 0$$
$$\langle v_2|v_1\rangle = \overline{\langle v_1|v_2\rangle}$$
$$(a\langle v_2| + b\langle v_3|)|v_1\rangle = a\langle v_2|v_1\rangle + b\langle v_3|v_1\rangle$$

A basis set $B = \{|\beta_1\rangle, |\beta_2\rangle, \ldots |\beta_n\rangle\}$ is said to be orthonormal if

$$\langle \beta_i|\beta_j\rangle = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases}$$

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

In quantum information processing, the $\{|0\rangle, |1\rangle\}$ basis has a direct correspondence to the classical 0 and 1 bits

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

In quantum information processing, the $\{|0\rangle, |1\rangle\}$ basis has a direct correspondence to the classical 0 and 1 bits

The most important difference is that qubits can take on an infinite number of superpositions of $|0\rangle$ and $|1\rangle$

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

In quantum information processing, the $\{|0\rangle, |1\rangle\}$ basis has a direct correspondence to the classical 0 and 1 bits

The most important difference is that qubits can take on an infinite number of superpositions of $|0\rangle$ and $|1\rangle$

For a basis $\{|\beta_1\rangle, |\beta_2\rangle\}$, an arbitrary ket $|v\rangle$ can be written as a vector in the language of linear algebra

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

In quantum information processing, the $\{|0\rangle, |1\rangle\}$ basis has a direct correspondence to the classical 0 and 1 bits

The most important difference is that qubits can take on an infinite number of superpositions of $|0\rangle$ and $|1\rangle$

For a basis $\{|\beta_1\rangle, |\beta_2\rangle\}$, an arbitrary ket $|v\rangle$ can be written as a vector in the language of linear algebra

$$|v\rangle = a|\beta_1\rangle + b|\beta_2\rangle$$

Vector representation of a qubit

In order to represent a qubit, it is necessary to select a standard basis set, $\{|0\rangle, |1\rangle\}$, of two orthonormal vectors

The specific physical states used for this standard basis is not important but must remain fixed

In quantum information processing, the $\{|0\rangle, |1\rangle\}$ basis has a direct correspondence to the classical 0 and 1 bits

The most important difference is that qubits can take on an infinite number of superpositions of $|0\rangle$ and $|1\rangle$

For a basis $\{|\beta_1\rangle, |\beta_2\rangle\}$, an arbitrary ket $|v\rangle$ can be written as a vector in the language of linear algebra

$$|v\rangle = a|\beta_1\rangle + b|\beta_2\rangle \quad \longrightarrow \quad v = \begin{pmatrix} a \\ b \end{pmatrix}$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix},$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix},$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \;\cdots\; \overline{a_n})$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = \begin{pmatrix} \overline{a_1} & \cdots & \overline{a_n} \end{pmatrix}$$

The inner product of two vectors is

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = \begin{pmatrix} \overline{a_1} & \cdots & \overline{a_n} \end{pmatrix}$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = \begin{pmatrix} \overline{a_1} & \cdots & \overline{a_n} \end{pmatrix} \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix}$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \ \cdots \ \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \ \cdots \ \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \ \cdots \ \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \ \cdots \ \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \ \cdots \ \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \ \cdots \ \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

$$G|\alpha\rangle = \begin{pmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & & \vdots \\ g_{n1} & \cdots & g_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \ \cdots \ \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \ \cdots \ \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

$$G|\alpha\rangle = \begin{pmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & & \vdots \\ g_{n1} & \cdots & g_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

In the standard basis, $\{|0\rangle, |1\rangle\}$,

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \ \cdots \ \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \ \cdots \ \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

$$G|\alpha\rangle = \begin{pmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & & \vdots \\ g_{n1} & \cdots & g_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

In the standard basis, $\{|0\rangle, |1\rangle\}$,

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix},$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = (\overline{a_1} \; \cdots \; \overline{a_n})$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = (\overline{a_1} \; \cdots \; \overline{a_n}) \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

$$G|\alpha\rangle = \begin{pmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & & \vdots \\ g_{n1} & \cdots & g_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

In the standard basis, $\{|0\rangle, |1\rangle\}$, the vector $|v\rangle = a|0\rangle + b|1\rangle$ is

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix},$$

Similarity to linear algebra

The ket, $|\alpha\rangle$, corresponds to a column vector, α, in linear algebra while a bra $\langle\alpha|$ is its conjugate transpose, $\alpha^\dagger$, a row vector

$$|\alpha\rangle = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}, \quad \langle\alpha| = \begin{pmatrix} \overline{a_1} & \cdots & \overline{a_n} \end{pmatrix}$$

The inner product of two vectors is

$$\langle\alpha|\beta\rangle = \begin{pmatrix} \overline{a_1} & \cdots & \overline{a_n} \end{pmatrix} \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \sum_{i=1}^{n} \overline{a_i} b_i$$

Gates are just operators that act on vectors as linear transformations.

$$G|\alpha\rangle = \begin{pmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & & \vdots \\ g_{n1} & \cdots & g_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix}$$

In the standard basis, $\{|0\rangle, |1\rangle\}$, the vector $|v\rangle = a|0\rangle + b|1\rangle$ is

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \quad |v\rangle = \begin{pmatrix} a \\ b \end{pmatrix}$$

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

$$|\gamma\rangle = a|\uparrow\rangle + b|\rightarrow\rangle$$

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

$$|\gamma\rangle = a|\uparrow\rangle + b|\rightarrow\rangle$$

A measurement by the vertical polarization detector will give

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

$$|\gamma\rangle = a|\uparrow\rangle + b|\rightarrow\rangle$$

A measurement by the vertical polarization detector will give

Photon present with probability $|a|^2$

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

$$|\gamma\rangle = a|\uparrow\rangle + b|\rightarrow\rangle$$

A measurement by the vertical polarization detector will give

Photon present with probability $|a|^2$

No photon present with probability $|b|^2$

Postulates of quantum mechanics

Quantum computing requires an understanding of the postulates of quantum mechanics, specifically how measurements are performed

Given a 2-state system, quantum mechanics states that there can only be two results from a measurement, the eigenvalues of the system in the basis that is being used for measurement

The probability of obtaining a specific result is determined by the square of the magnitude of the amplitude of that result in the superposition state of the system

consider the measurement of a photon by a vertical polarization detector, the basis is

$$\{|\uparrow\rangle, |\rightarrow\rangle\}$$

The state of the photon can be expressed as

$$|\gamma\rangle = a|\uparrow\rangle + b|\rightarrow\rangle$$

A measurement by the vertical polarization detector will give

Photon present with probability $|a|^2$

No photon present with probability $|b|^2$

After the measurement any photon that passed through the polarizer is now in the $|\uparrow\rangle$ state

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle = |+\rangle, \qquad \{|+\rangle, |-\rangle\} \equiv \left\{ \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle, \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle \right\}$$

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle = |+\rangle, \qquad \{|+\rangle, |-\rangle\} \equiv \left\{\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle, \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle\right\}$$

A superposition is not just a probabilistic mixture of two states, it is a definite state which consists of both its constitutent states

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle = |+\rangle, \qquad \{|+\rangle, |-\rangle\} \equiv \left\{\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle, \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle\right\}$$

A superposition is not just a probabilistic mixture of two states, it is a definite state which consists of both its constitutent states

Qubits can exist in an infinite number of superposition states yet do not contain more information than classical bits since a single measurement produces only one of two answers depending on the basis

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle = |+\rangle, \qquad \{|+\rangle, |-\rangle\} \equiv \left\{\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle, \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle\right\}$$

A superposition is not just a probabilistic mixture of two states, it is a definite state which consists of both its constitutent states

Qubits can exist in an infinite number of superposition states yet do not contain more information than classical bits since a single measurement produces only one of two answers depending on the basis

There is much more to quantum theory but this is sufficient to develop a theory of quantum computing

More quantum principles

A quantum state may be a superposition in the standard basis but not in another basis

$$|\alpha\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle = |+\rangle, \qquad \{|+\rangle, |-\rangle\} \equiv \left\{\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle, \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle\right\}$$

A superposition is not just a probabilistic mixture of two states, it is a definite state which consists of both its constitutent states

Qubits can exist in an infinite number of superposition states yet do not contain more information than classical bits since a single measurement produces only one of two answers depending on the basis

There is much more to quantum theory but this is sufficient to develop a theory of quantum computing

Realizing an actual quantum computer requires a deep knowledge of quantum mechanics and experimental quantum systems