H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

H

Hadamard Gate

H

Rotates about the
(x+z)-axis by 180°

H

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

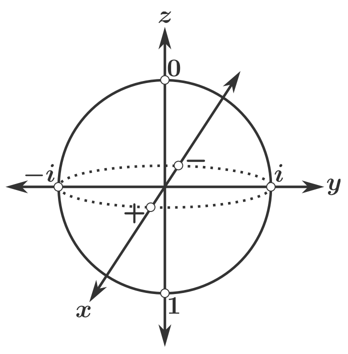
S

Phase Gate

S

Rotates about the
z-axis by 90°

S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−i
i
y
+
x
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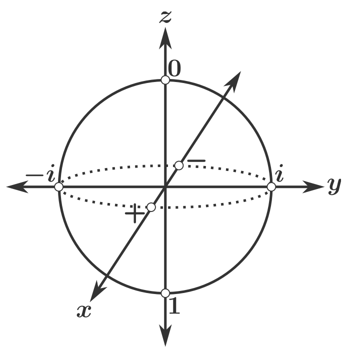
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+
x
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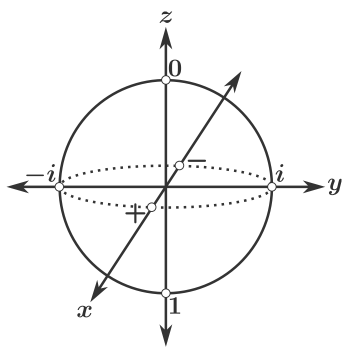
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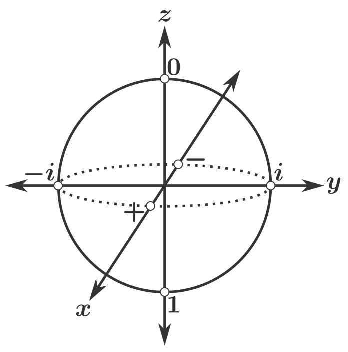
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y
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x
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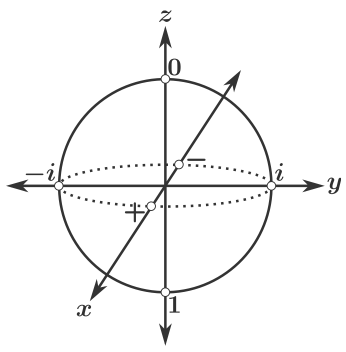
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y
+
x
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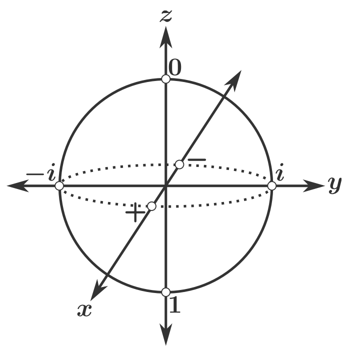
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x
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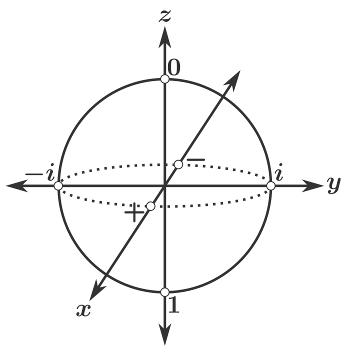
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y
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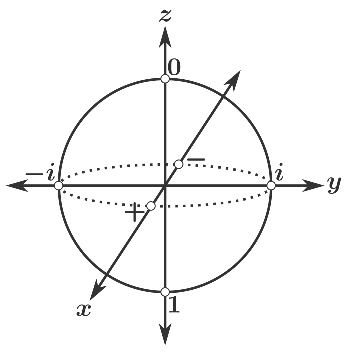
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−
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y
+
x
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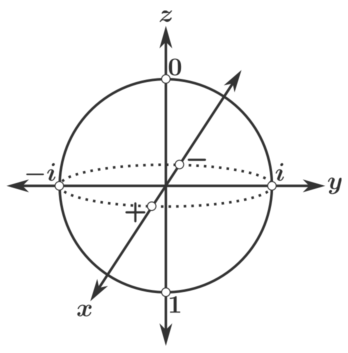

z
0
−
−i
i
y
+
x
1

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

S

Phase Gate

S

Rotates about the
z-axis by 90°

S

X

Pauli X Gate

X

Rotates about the
x-axis by 180°

X

X

Pauli X Gate

X

Rotates about the
x-axis by 180°

X

X

Pauli X Gate

X

Rotates about the
x-axis by 180°

X

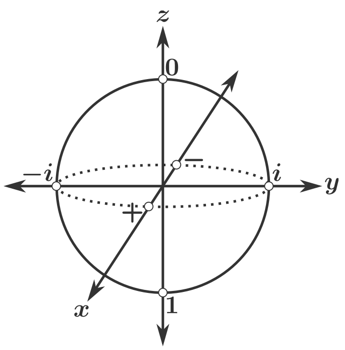
X

Pauli X Gate

X

Rotates about the
x-axis by 180°

X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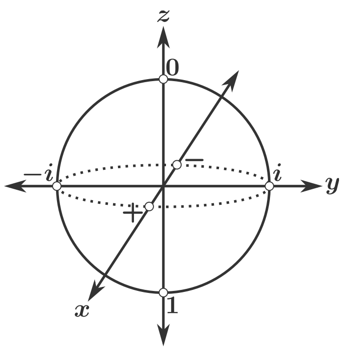
i
y
+
x
1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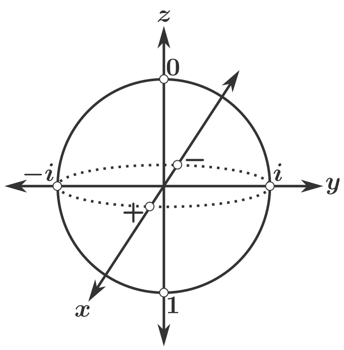
y
+
x
1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y
+
x
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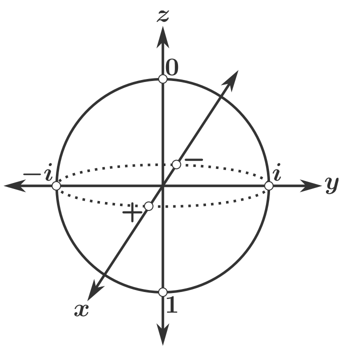
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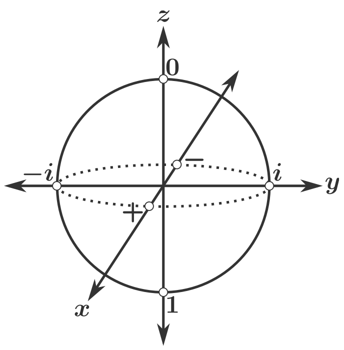
y
+
x
1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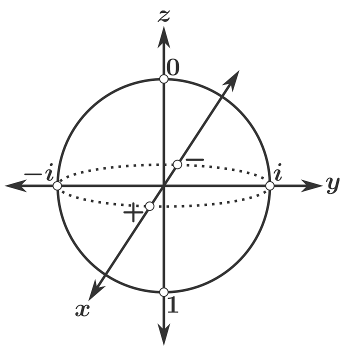
−
−i
i
y
+
x
1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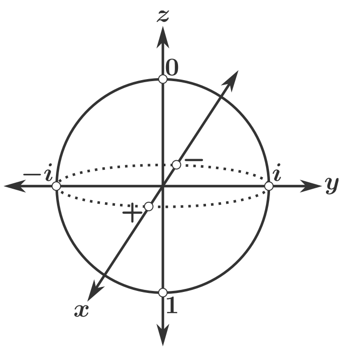
−
−i
i
y
+
x
1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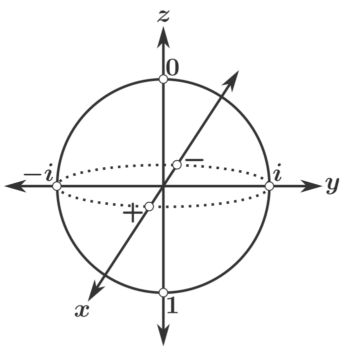
−
−i
i
y
+
x
1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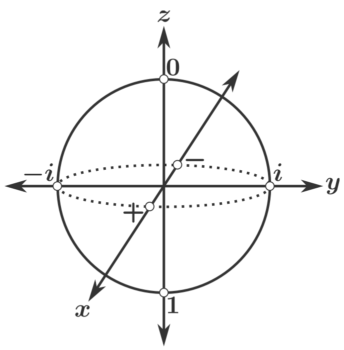
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

Y

Pauli Y Gate

Y

Rotates about the
y-axis by 180°

⅄

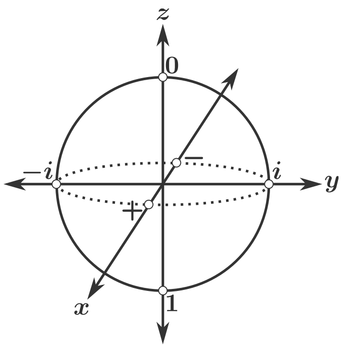
Y

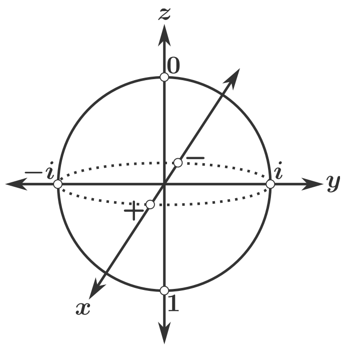
Pauli Y Gate

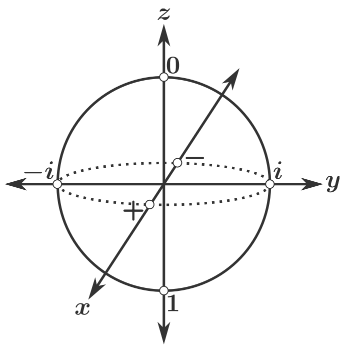
Y

Rotates about the
y-axis by 180°

⅄


z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1


z
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−
−i
i
y
+
x
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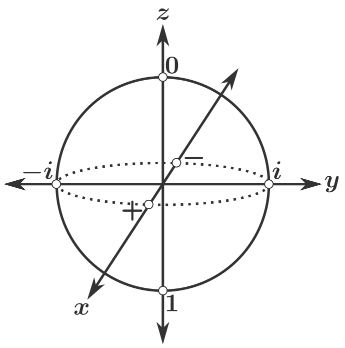
z
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−
−i
i
y
+
x
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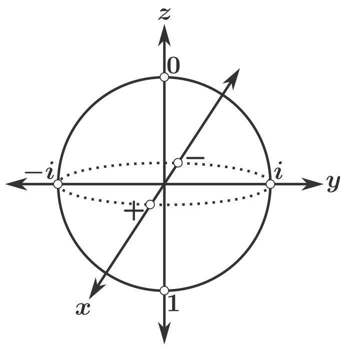
z
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y
+
x
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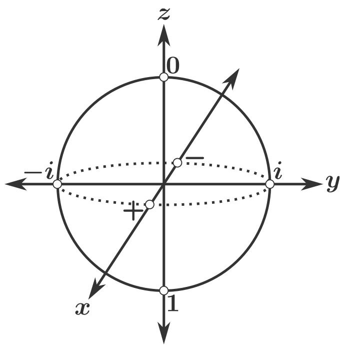
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−i
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y
+
x
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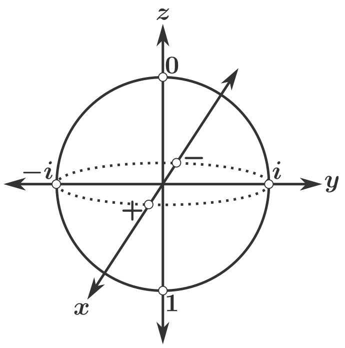
z
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−i
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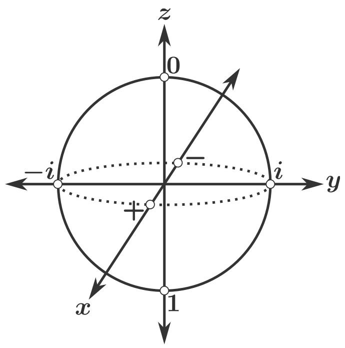
y
+
x
1


z
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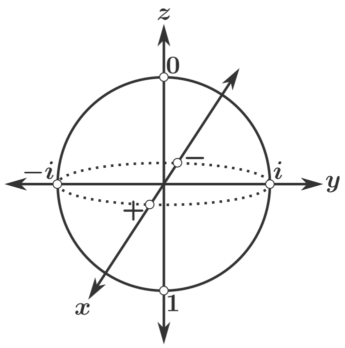
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

Z

Pauli Z Gate

Z

Rotates about the
z-axis by 180°

Z

I

Identity Gate

I

Does nothing

I

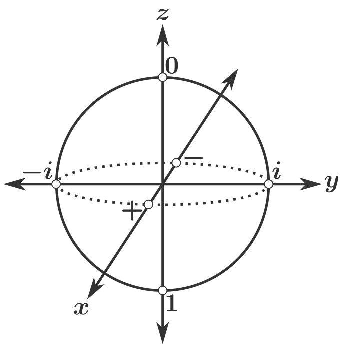
I

Identity Gate

I

Does nothing

I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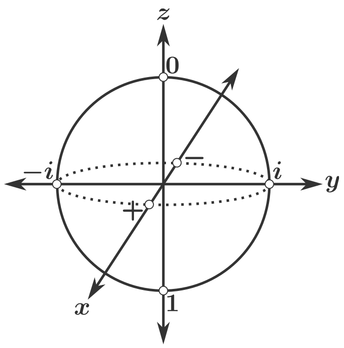
−
−i
i
y
+
x
1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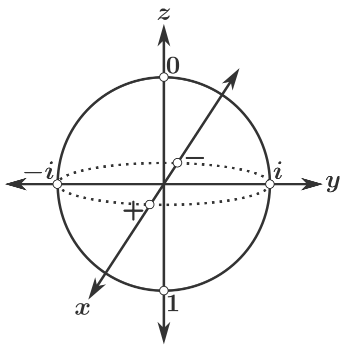
0
−
−i
i
y
+
x
1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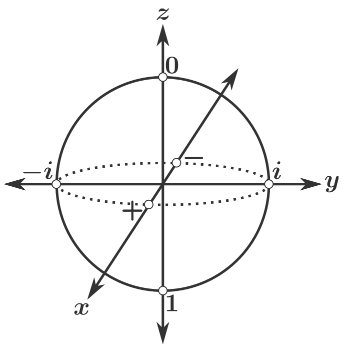
−
−i
i
y
+
x
1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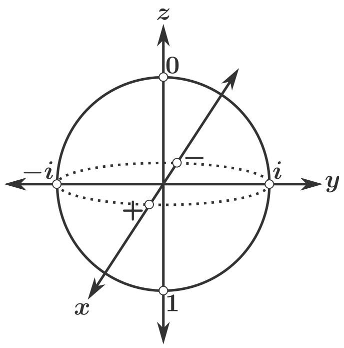
−
−i
i
y
+
x
1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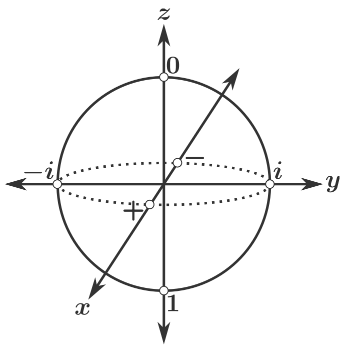
−
−i
i
y
+
x
1


z
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−
−i
i
y
+
x
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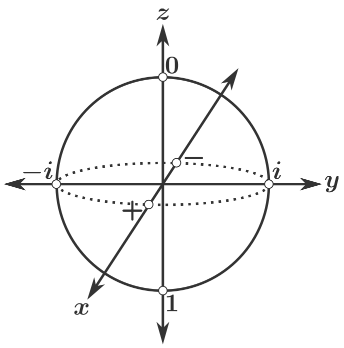
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−i
i
y
+
x
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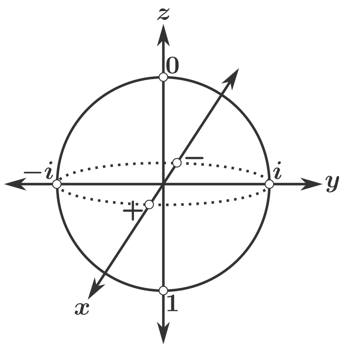
z
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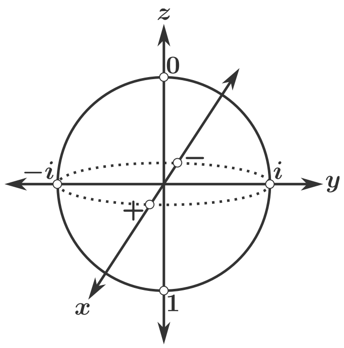
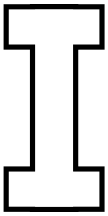
−
−i
i
y
+
x
1

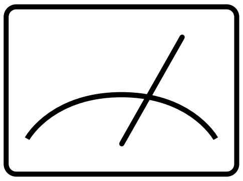

z
0
−
−i
i
y
+
x
1

Identity Gate



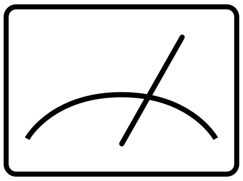
Does nothing

Measurement



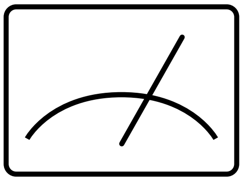
If the token is at 0 or 1, do nothing
Otherwise, roll the die and move

Measurement



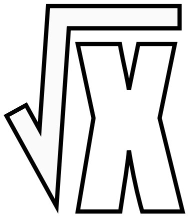
If the token is at 0 or 1, do nothing
Otherwise, roll the die and move

Measurement



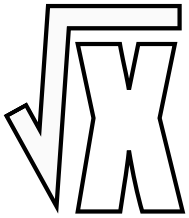
If the token is at 0 or 1, do nothing
Otherwise, roll the die and move

Square Root of X Gate



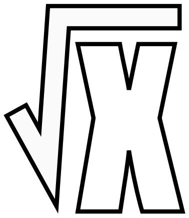
Rotates about the
x-axis by 90°

Square Root of X Gate



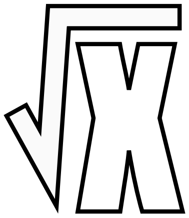
Rotates about the
x-axis by 90°

Square Root of X Gate



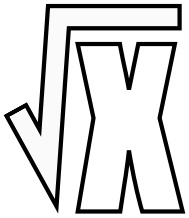
Rotates about the
x-axis by 90°

Square Root of X Gate

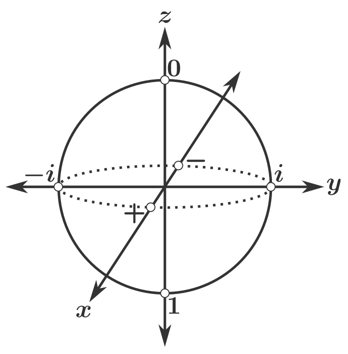


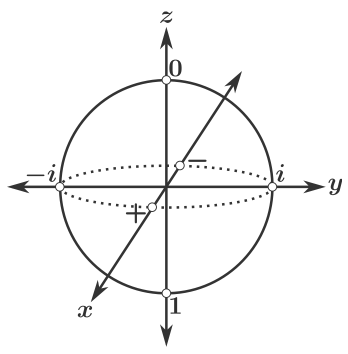
Rotates about the
x-axis by 90°

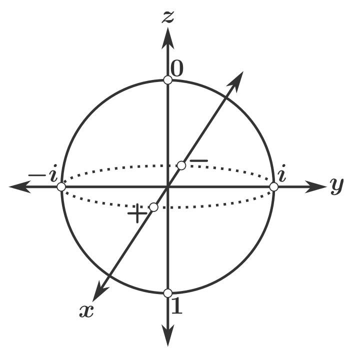
Square Root of X Gate

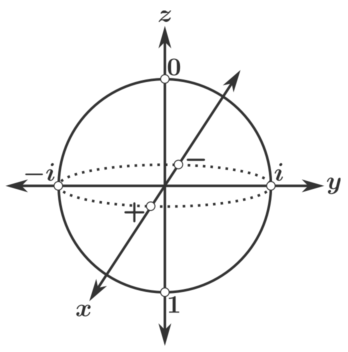


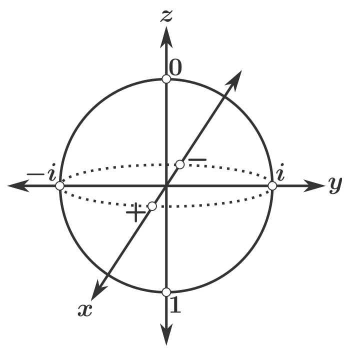
Rotates about the
x-axis by 90°

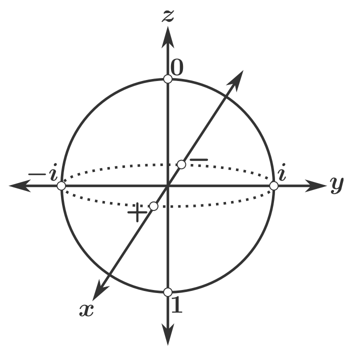

z
0
−
−i
i
y
+
x
1

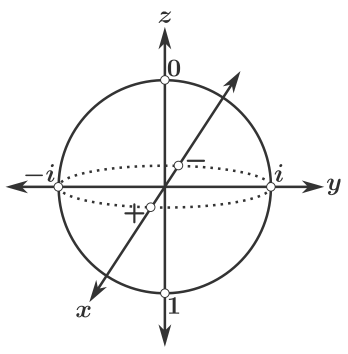

z
0
−
−i
i
y
+
x
1

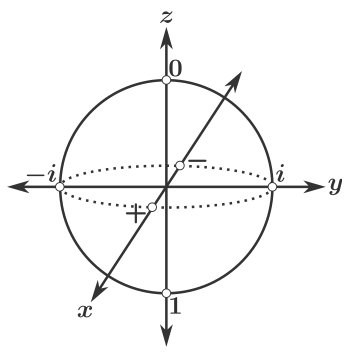

z
0
−
−i
i
y
+
x
1

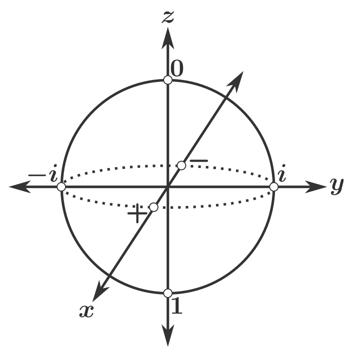

z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1


z
0
−
−i
i
y
+
x
1

$\sqrt{X}$

Square Root
of X Gate

$$\sqrt{X}$$

Rotates about the
x-axis by 90°

$\sqrt{X}$

Square Root
of X Gate

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How to Play

Two players compete to score the most touchdowns in their opponent's end zone.

Place the game board between the two players, with an end zone facing each player. Shuffle the 52 action cards and give each player 4 cards. Place the remaining 44 action cards facedown in a draw pile. Designate a location for a discard pile.

One player “kicks off” by rolling the binary die and placing the football token on the game board at 0 or 1, accordingly.

The other player does the following 3 steps:

1. Discard an action card from their hand. For gate cards, move the token according to the white lines drawn on the board. (The green lines can be ignored—they are for teaching.) If a transition for a gate is not shown, the token stays put.

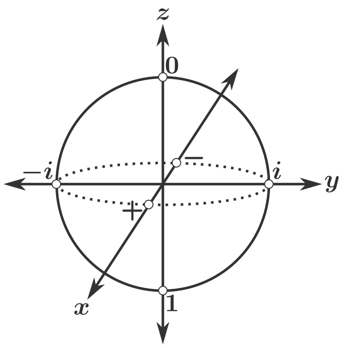
The Physics of Qubit Touchdown

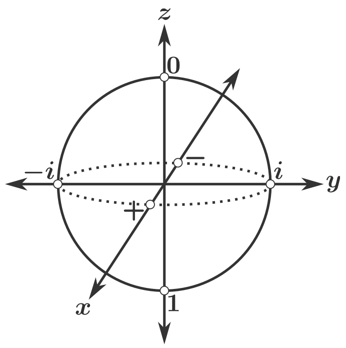
The back of every action card has a drawing of a *Bloch sphere*. Its North and South poles are 0 and 1, which are the two possible states of a classical computer bit.

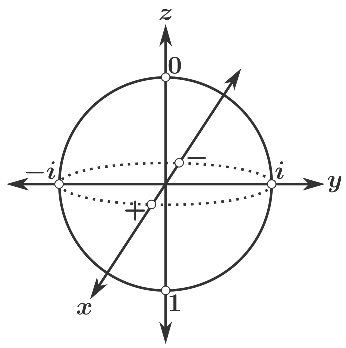
A quantum bit, or *qubit*, however, can be any point on the Bloch sphere, so it has an infinite number of possible states. Qubit Touchdown uses just six states, and they are drawn on the Bloch sphere and labeled 0, 1, +, –, i, and –i.

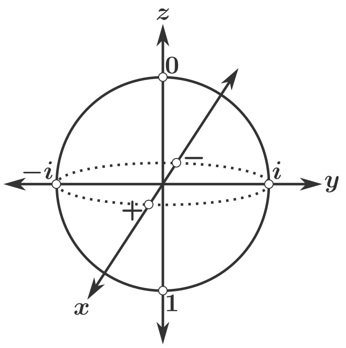
The positions on the game board correspond to these six states, and the football token is a qubit moving between these states.

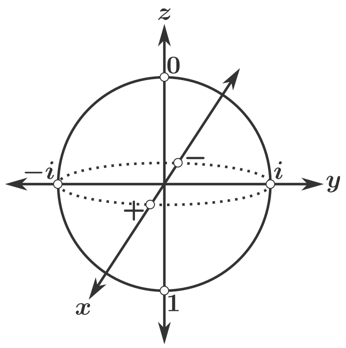
Quantum gates, which correspond to the gate action cards, change a qubit's state. For example, the $\sqrt{X}$ gate rotates the qubit's state about the x-axis by 90°. So $\sqrt{X}$ turns 0 into i, i into 1, 1 into –i, and –i into 0. It also leaves

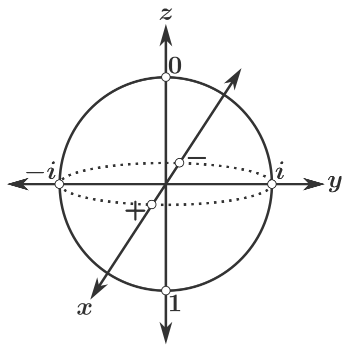












+ and – unchanged. Each gate action card contains a description of its rotation.

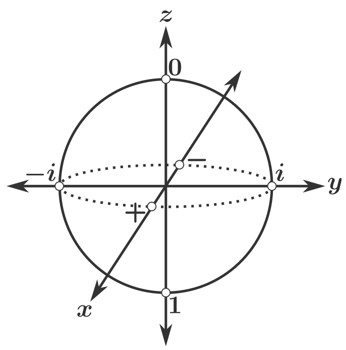
Although a qubit can be any point on the Bloch sphere, *measuring* its value yields 0 or 1, each with some probability. Since +, –, i, and –i lie on the equator, they are *superpositions*, or combinations, of half 0 and half 1. Then measuring them yields 0 or 1, each with a 50% probability. Furthermore, measuring 0 yields 0 with certainty, and measuring 1 yields 1 with certainty. Kicking off after a touchdown, or playing the measurement action card, corresponds to a quantum measurement.

To start a quantum computation, the qubits are *initialized* to 0 or 1. Kicking off at the beginning of the game corresponds to this.

Example: At position 0, H moves the token to position +; X to –i; X and Y to 1; and Z, I, and S keep the token at position 0.

For measurement cards, do nothing if the token is at 0 or 1. Otherwise, kick off.

2. Take an action card from the draw pile, if one is available.
3. If the football token is in an end zone (the + or – positions), score a touchdown for the appropriate player. It is possible to score a touchdown for one's opponent by moving the token into one's own end zone. Roll the binary die to kick off, and place the football token at 0 or 1, accordingly.

Play transfers to the other player, who completes the above three steps. Continue taking turns until all 52 action cards have been played. The player who scored the most touchdowns wins.