

Quantum in Pictures Lecture Series

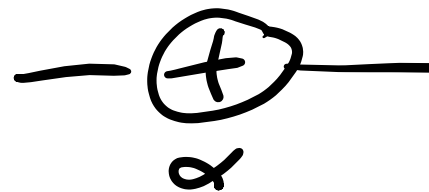
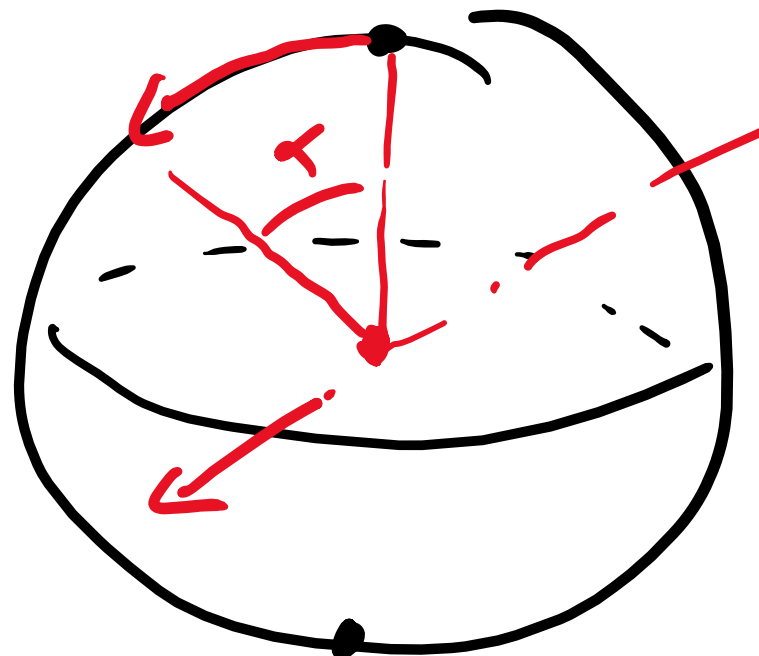
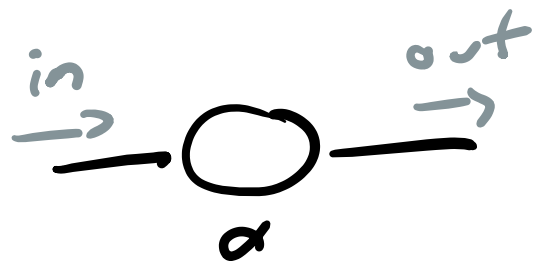
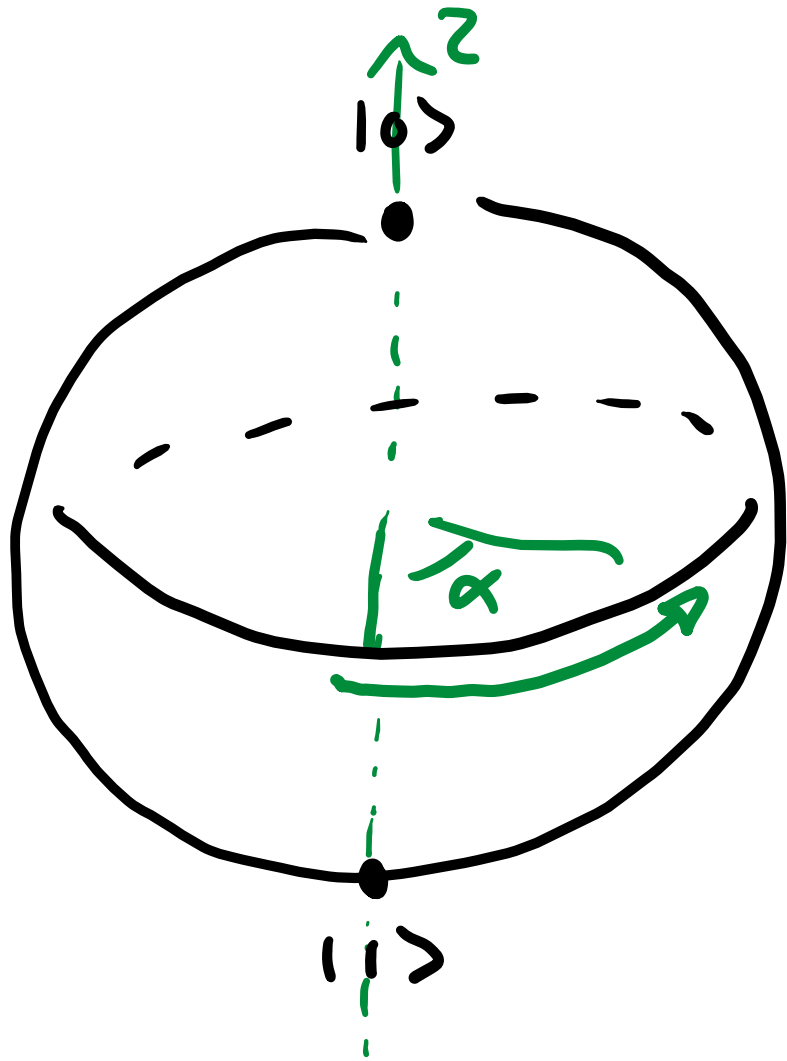
Lecturer: Stefano Gogioso

Tue 27 June 2023 – Morning Lecture

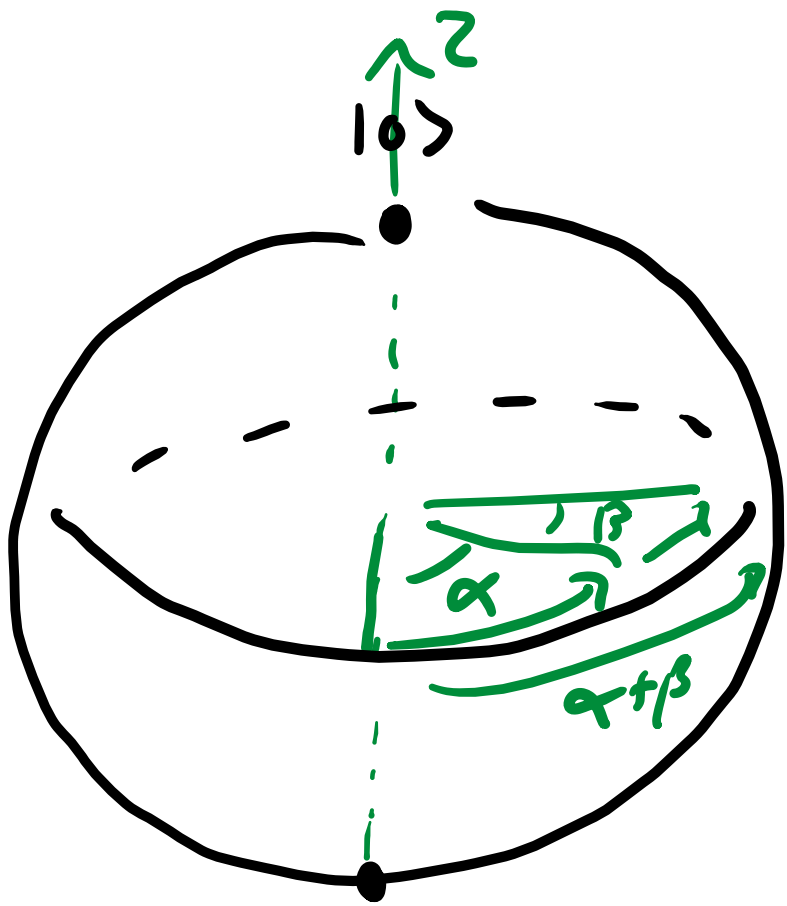


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$\rightarrow t$

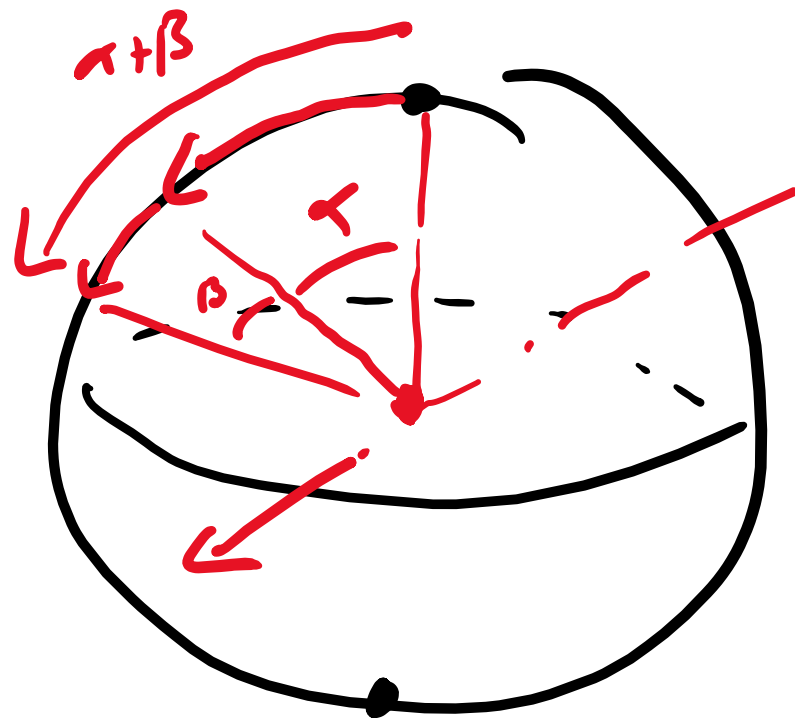


→ t



Z rot

$|1\rangle$



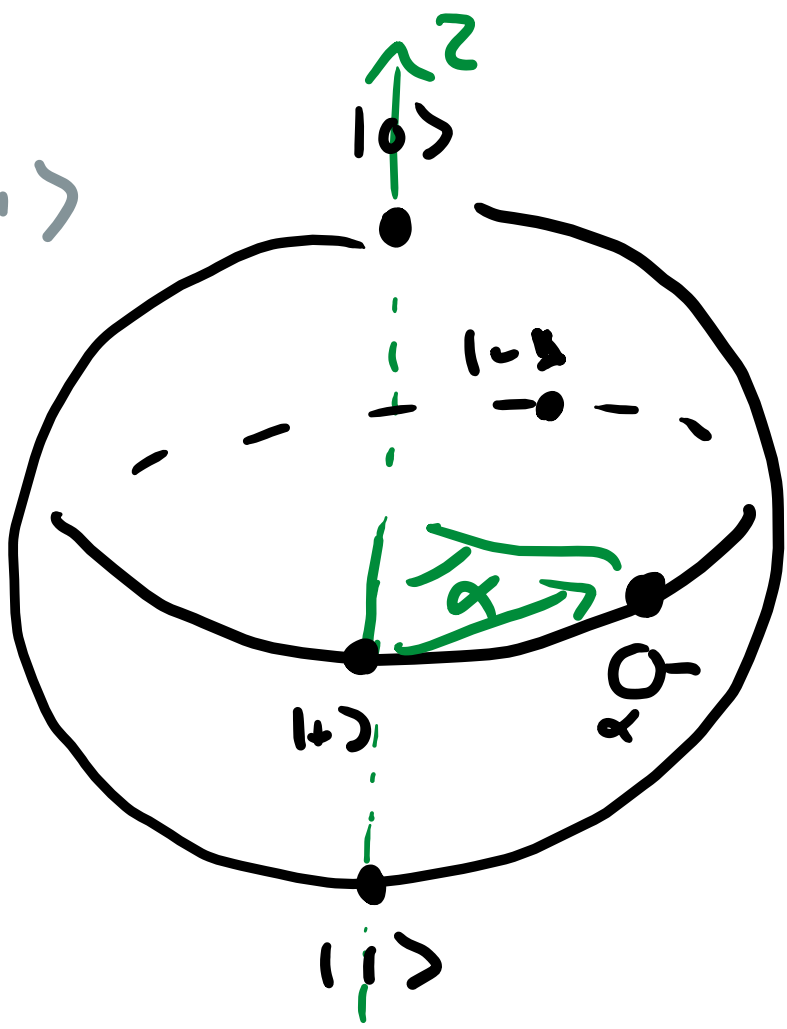
X ref

$$\begin{array}{c} \text{---} \end{array} \text{---} \bigcirc_{\alpha} \text{---} \bigcirc_{\beta} \text{---} \stackrel{\text{fuse}}{=} \text{---} \bigcirc_{\alpha+\beta} \text{---}$$

$$\begin{array}{c} \text{---} \end{array} \text{---} \bigoplus_{\alpha} \text{---} \bigoplus_{\beta} \text{---} \stackrel{\text{fuse}}{=} \text{---} \bigoplus_{\alpha+\beta} \text{---}$$

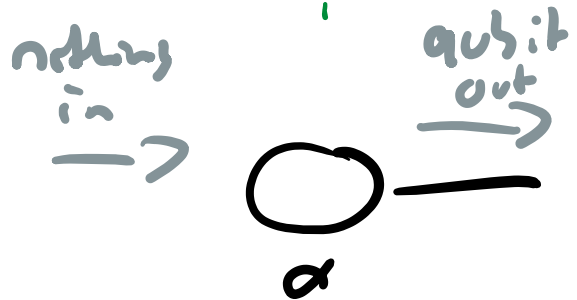
$\rightarrow t$

$|0\rangle + e^{i\alpha} |1\rangle$

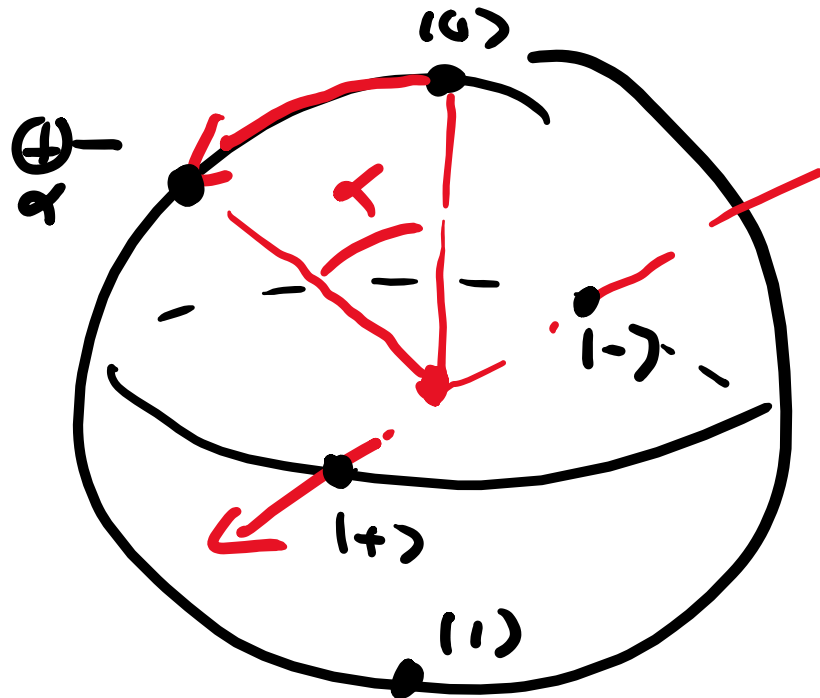


$|+\rangle = \bigoplus$

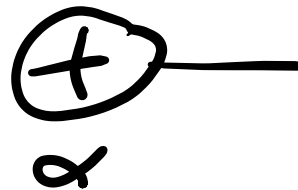
$|-\rangle = \bigoplus^-$



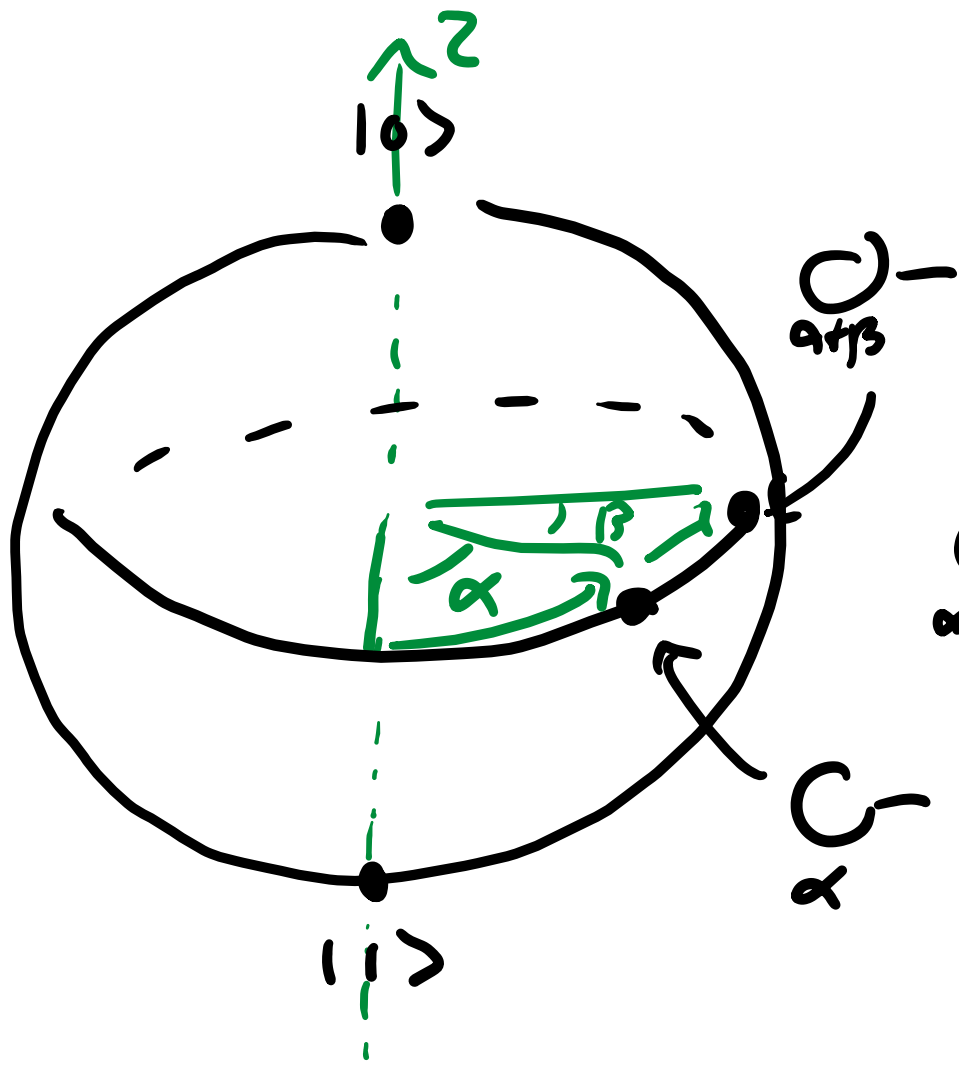
$|+\rangle + e^{i\alpha} |-\rangle$



$|0\rangle = \bigoplus^+$
 $|1\rangle = \bigoplus^-$



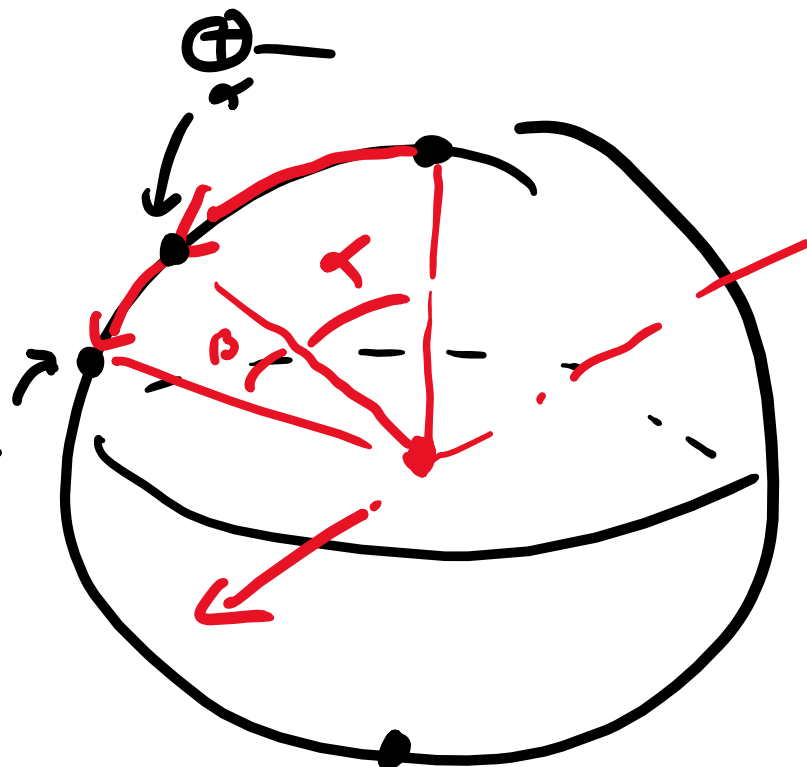
$\rightarrow t$



Z rot

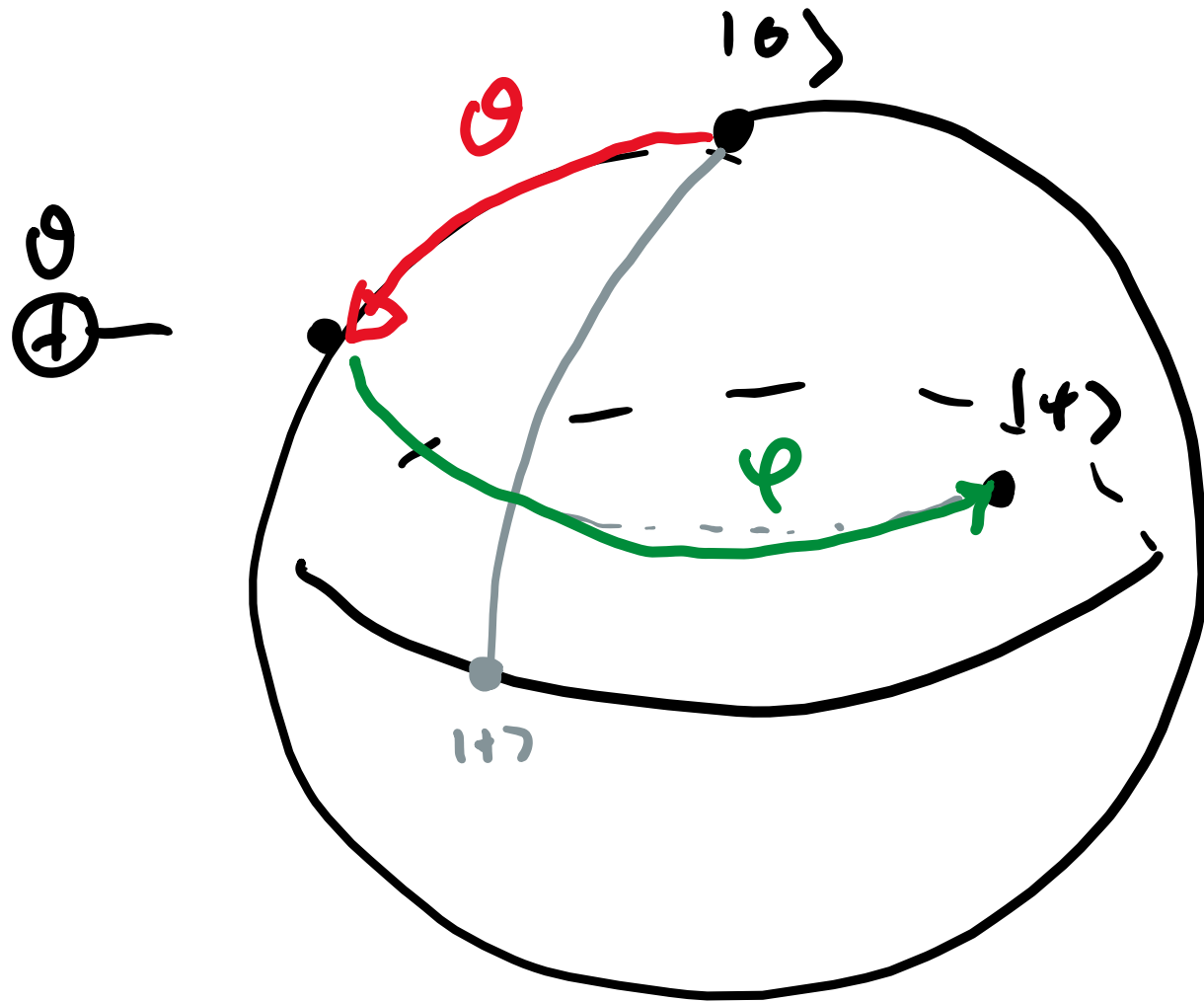
$|1\rangle$

$$\alpha \cup \beta \xrightarrow{f_{use}} \alpha + \beta$$



X ref

$$\alpha \oplus \beta \xrightarrow{f_{use}} \alpha + \beta$$



$$\oplus - \overset{g}{\oplus} - \overset{\varphi}{\circ} - = \oplus - \overset{\varphi}{\circ} -$$

$$\oplus - \text{---} = |0\rangle$$

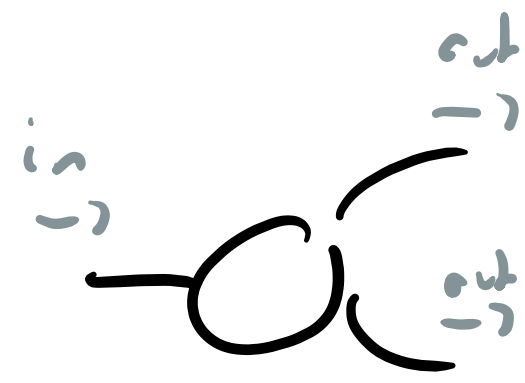
$$\oplus - \text{---} = |1\rangle$$

$$\oplus - \bigcirc =$$

$$= \begin{array}{|c|} \hline \\ \hline \end{array} = 1$$

$$\oplus - \bigcirc =$$

$$= \begin{array}{|c|} \hline \\ \hline \end{array} = 1$$



$$|0\rangle \oplus - \bigcirc =$$

$$|00\rangle \oplus - \text{---}$$

$$|1\rangle \oplus - \bigcirc =$$

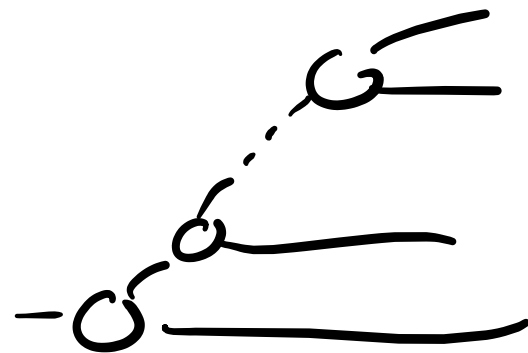
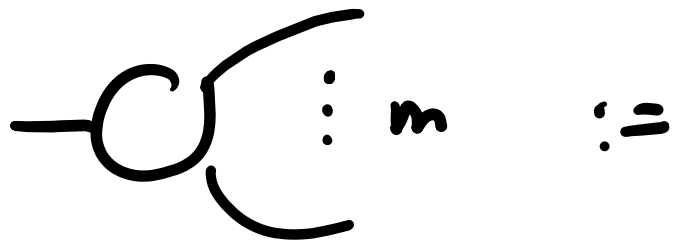
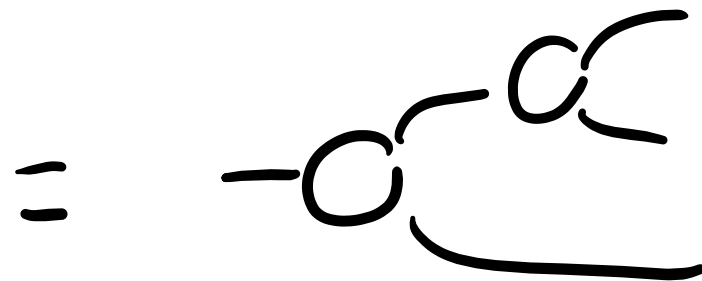
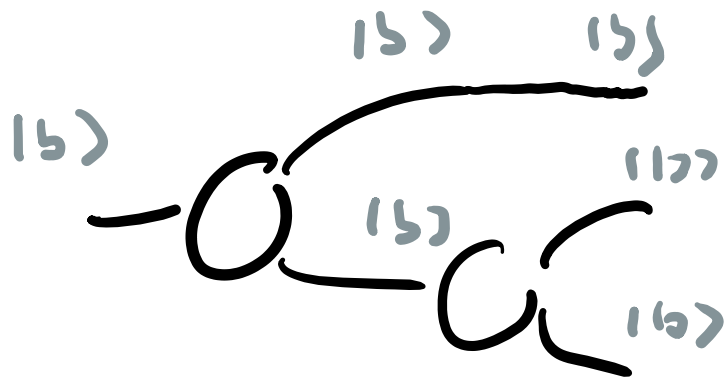
$$|11\rangle \oplus - \text{---}$$

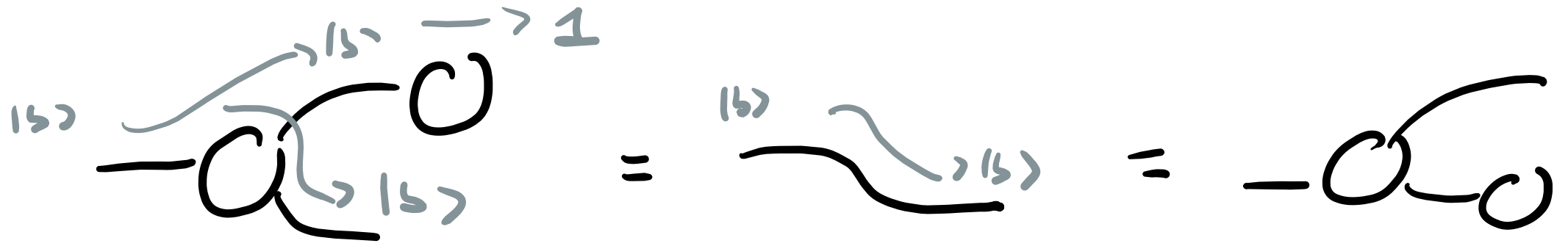
$-O-$
 α
2 rotation

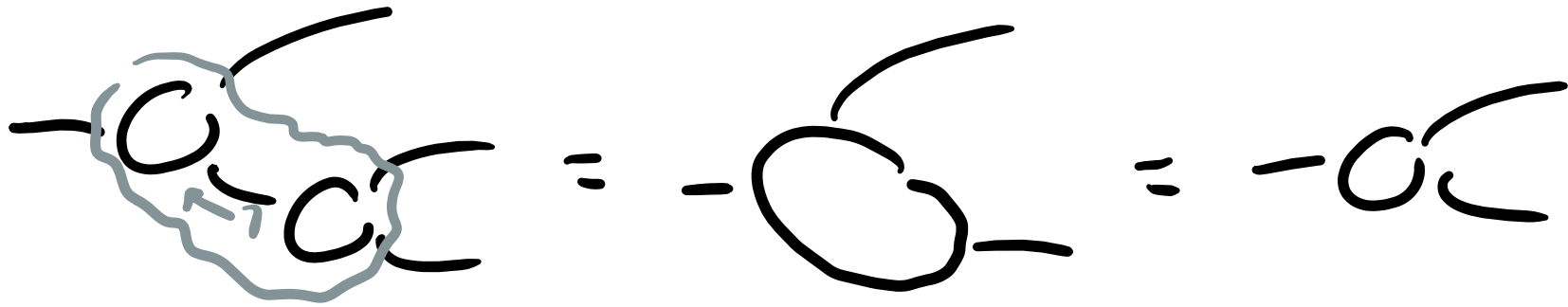
$O-$
 α
2 eq. strk

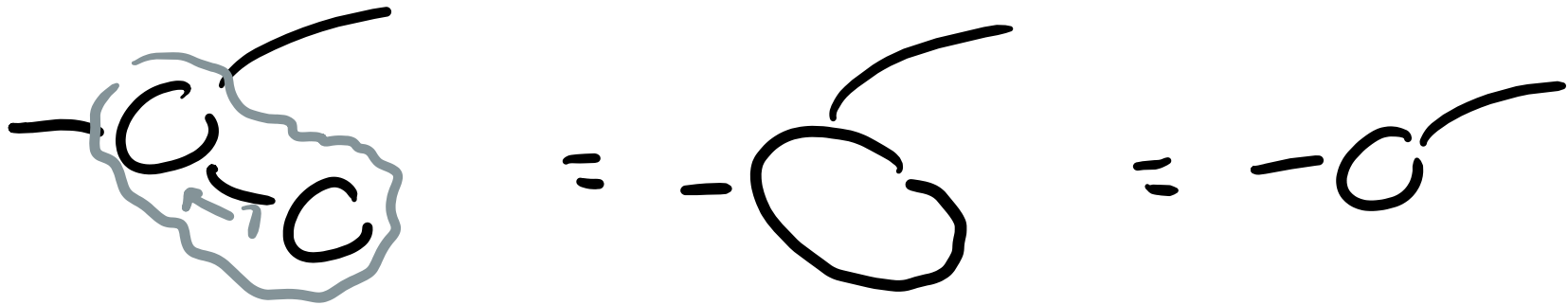
$-O$
2 copy

$-O$
2 delete



$15\rangle$ 

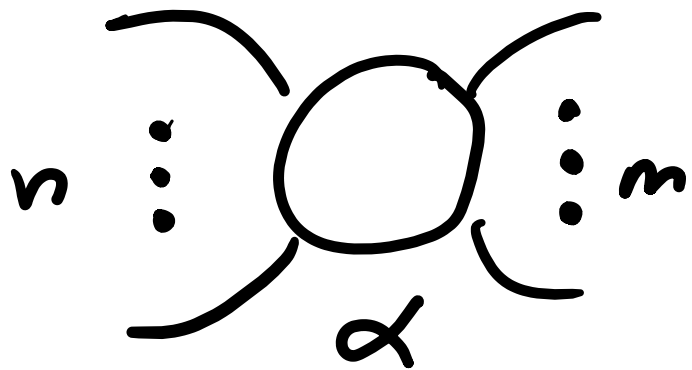




$$- \text{O} = \begin{matrix} |0\rangle \mapsto |00\rangle \\ |1\rangle \mapsto |11\rangle \end{matrix} = \sum_{b \in \{0,1\}} |bb\rangle \langle b|$$

$$- \text{O} = \begin{matrix} |0\rangle \mapsto | \\ |1\rangle \mapsto | \end{matrix} = (11) = \sqrt{2} \underbrace{\langle + |}_{\left(\frac{1}{\sqrt{2}} \quad \frac{1}{\sqrt{2}}\right)}$$

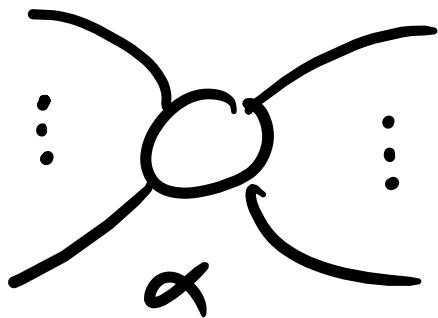
Z Spider



$$= \sum_{b \in \{0,1\}} |b \dots b\rangle e^{i b \alpha} \langle b \dots b|$$

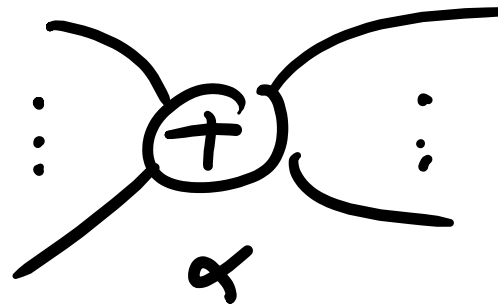
$$= |0 \dots 0\rangle \langle 0 \dots 0| + e^{i \alpha} |1 \dots 1\rangle \langle 1 \dots 1|$$

2 basis



sum colours
 $\leftarrow \rightarrow$

X Spider



$$|0\dots 0\rangle\langle 0\dots 0| + e^{i\alpha} |1\dots 1\rangle\langle 1\dots 1|$$

$$|+\dots+\rangle\langle +\dots+| + e^{i\alpha} |-\dots-\rangle\langle -\dots-|$$

$$\text{Circle } \alpha \text{ --- Circle } \beta = \text{Circle } \alpha+\beta$$

$$\text{Circle } \alpha \text{ with } + \text{ --- Circle } \beta \text{ with } + = \text{Circle } \alpha+\beta \text{ with } +$$

below)

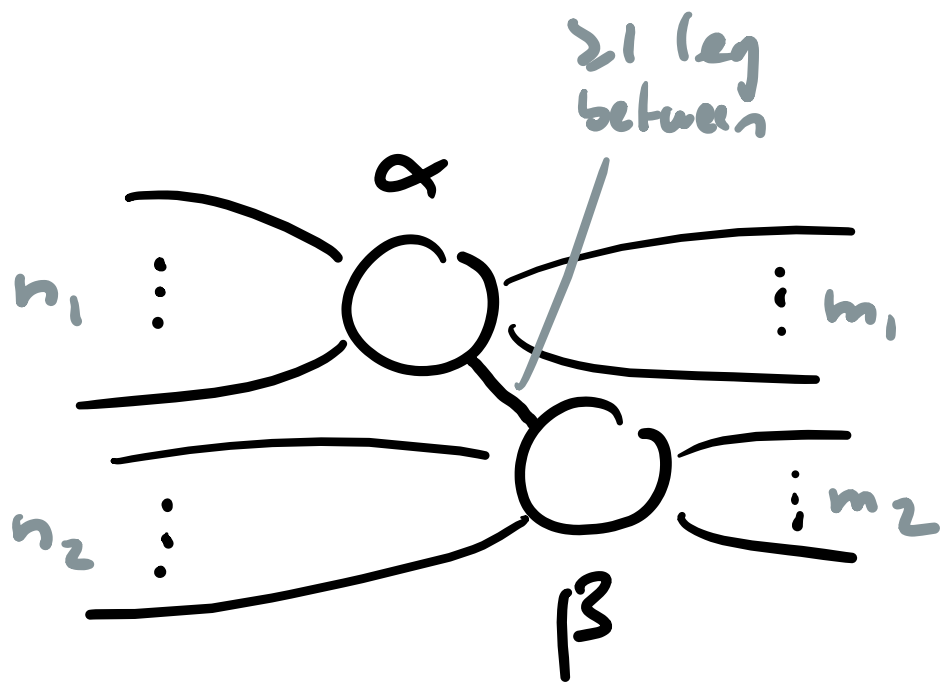
$$\text{Circle } \alpha \text{ with } + \text{ --- Arc } = \text{Arc } \alpha \text{ with } +$$

$$\text{Circle } \alpha \text{ --- Circle } \beta \text{ with } + = \text{Arc } \alpha \text{ with } +$$

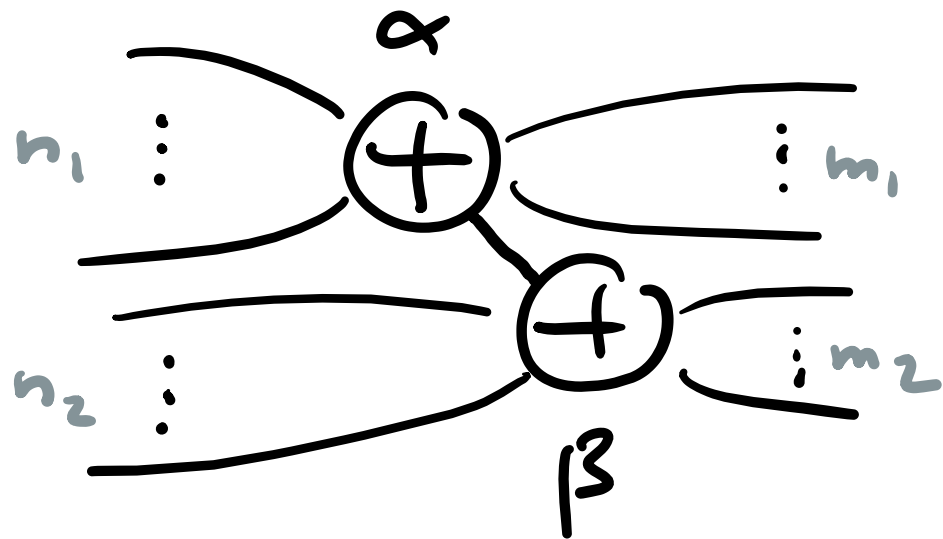
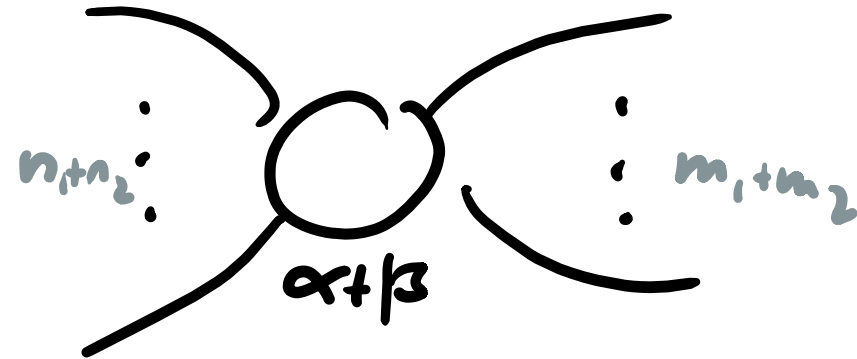
$$\text{Circle } \alpha \text{ with } + \text{ --- Circle } = \text{Dashed box}$$

$$\text{Circle } \alpha \text{ --- Circle } \alpha \text{ with } + = \text{Dashed box}$$

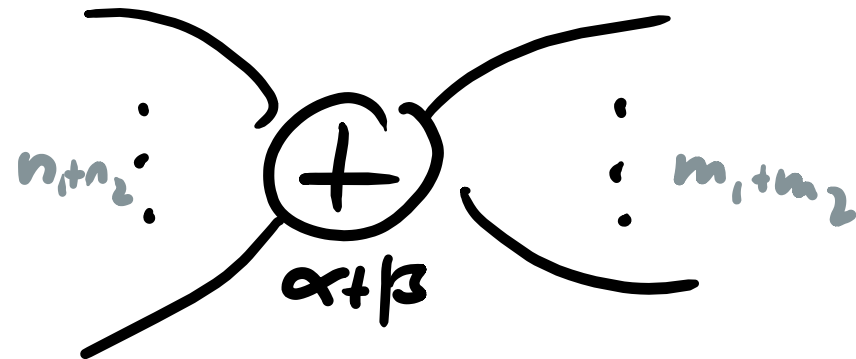
Spider fusion



fuse
=



fuse
=



$$\begin{array}{c}
 a\pi \leftarrow |a\rangle \\
 \oplus \\
 \oplus \\
 b\pi \\
 \leftarrow |b\rangle
 \end{array}
 \oplus \text{---} = \oplus \text{---} = \oplus \text{---}$$

$a\pi + b\pi$
 $(a \oplus b)\pi$

$a, b \in \{0, 1\}$

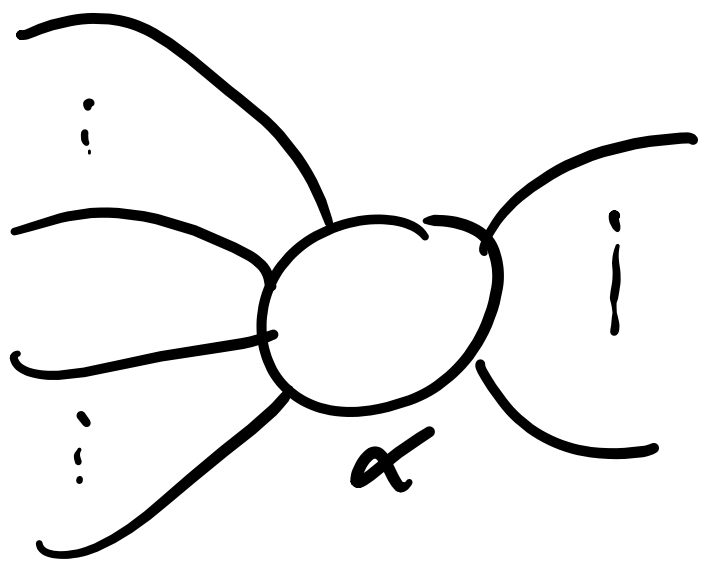
$$\oplus \text{---} = \times \mathbb{C} \mathbb{R}$$

$$\oplus \text{---} = |0\rangle$$

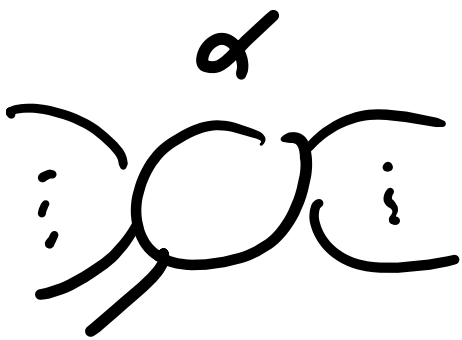
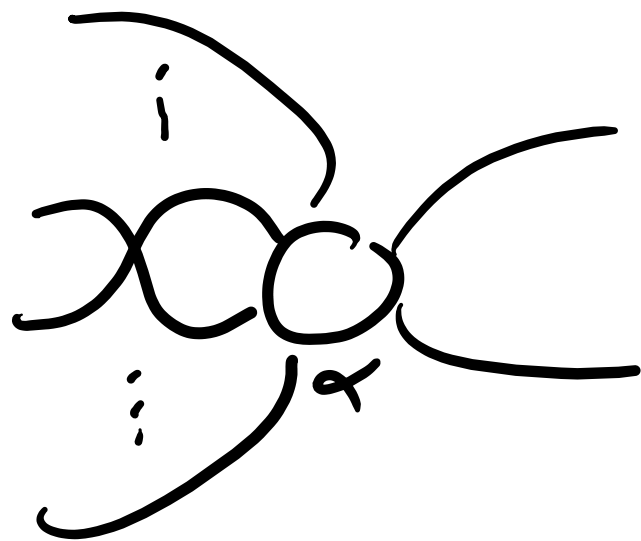
$$\text{⊕} \text{---} \text{⊕} \text{---} = \text{---} = \text{⊕} \text{---}$$

$$\text{⊕} \text{---} \text{⊕} \text{---} = \text{⊕} \text{---} = \text{⊕} \text{---}$$

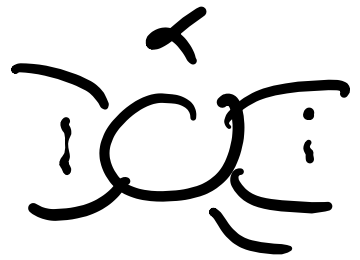
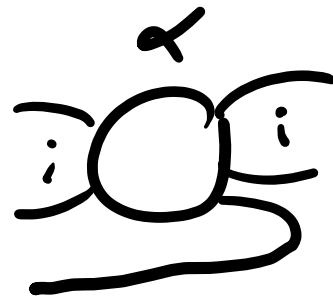
$$\text{⊕} \text{---} = \text{⊕} \text{---}$$



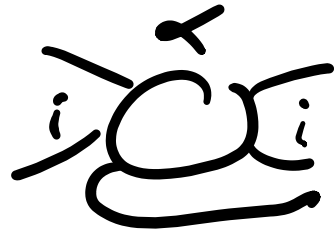
"



"



"



$$-C_1 = - \quad = -\Phi -$$

$$= \quad =$$

$$= \quad =$$

$$=$$

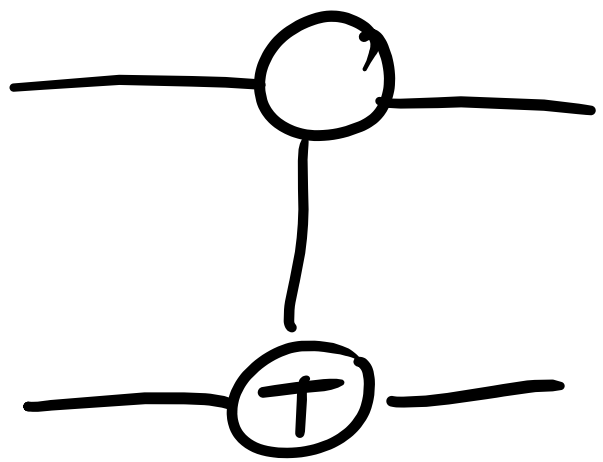
$$\alpha$$

same
=

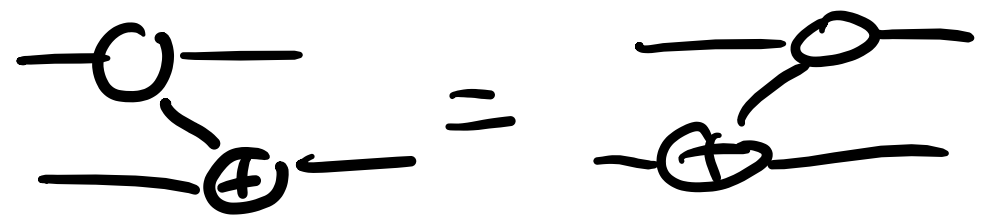
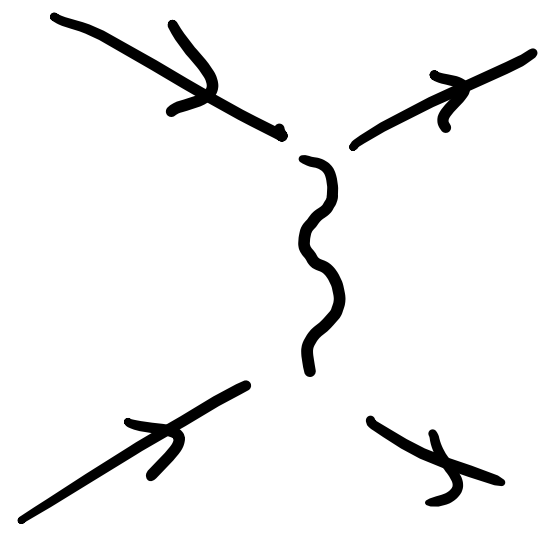
$$\alpha$$

rule
=

$$\alpha$$

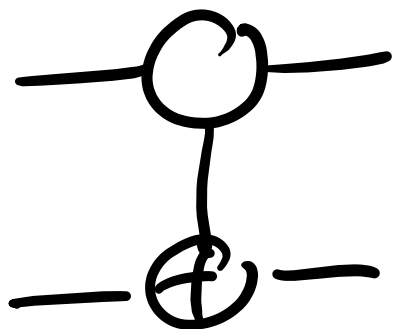


\approx



(for qubits)

$$\overset{1,2}{\text{---}} \bigcirc \overset{1,2}{\text{---}} = \text{---} = \overset{1,2}{\text{---}} \oplus \overset{1,2}{\text{---}}$$

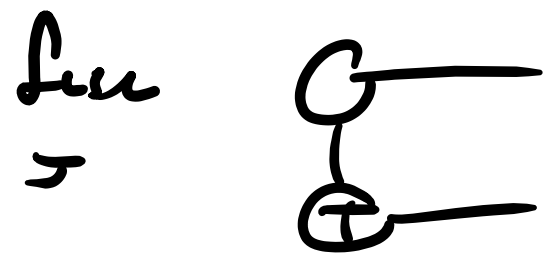
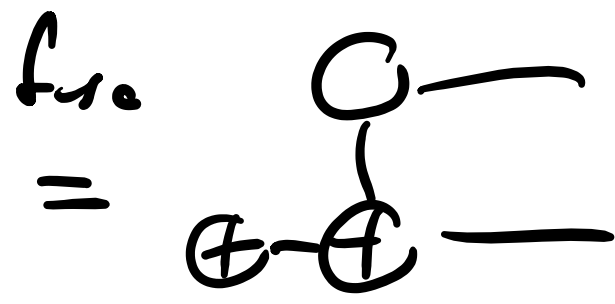
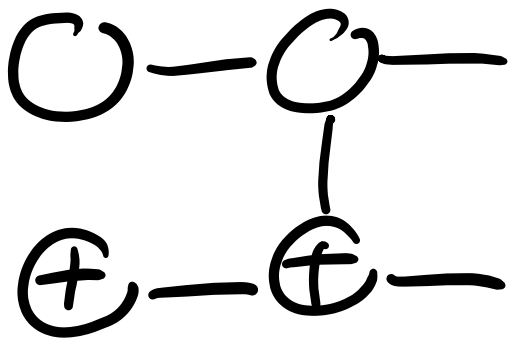


CNOT

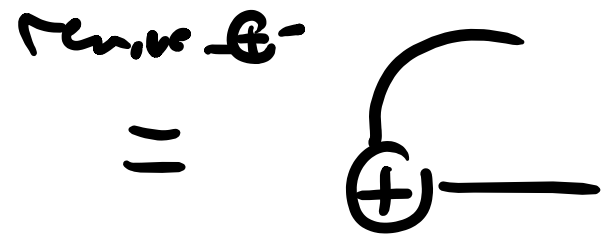
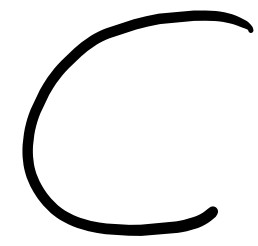
$$\begin{array}{c} a\bar{a} \oplus \\ b\bar{b} \oplus \end{array} \begin{array}{c} \oplus \\ \oplus \end{array} \begin{array}{c} \text{---} \\ \text{---} \end{array} \begin{array}{c} \oplus \\ \oplus \end{array} \begin{array}{c} \text{---} \\ \text{---} \end{array} = \begin{array}{c} a\bar{a} \oplus \\ b\bar{b} \oplus \end{array} \begin{array}{c} \oplus \\ \oplus \end{array} \begin{array}{c} \text{---} \\ \text{---} \end{array}$$

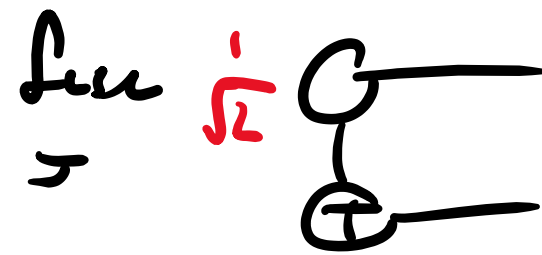
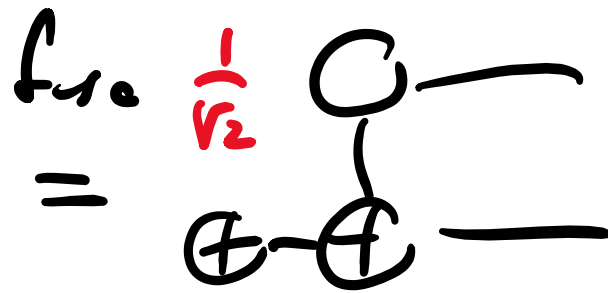
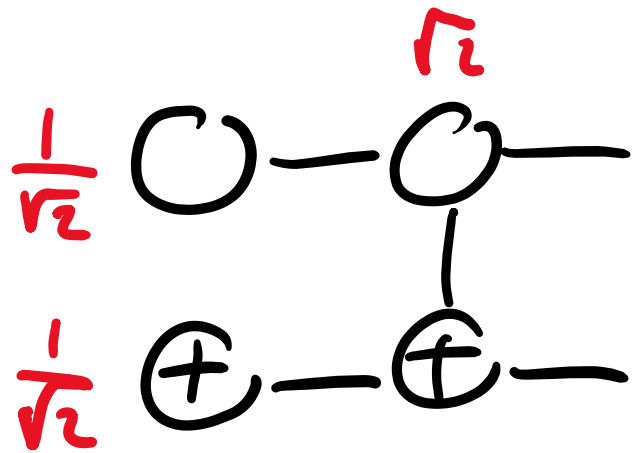
$$\begin{array}{c} a\bar{a} \oplus \\ (a \oplus b) \bar{b} \end{array} \begin{array}{c} \oplus \\ \oplus \end{array} \begin{array}{c} \text{---} \\ \text{---} \end{array} = \begin{array}{c} a\bar{a} \oplus \\ a\bar{a} \oplus \\ (a \oplus b) \bar{b} \oplus \\ b\bar{b} \oplus \end{array} \begin{array}{c} \oplus \\ \oplus \\ \oplus \\ \oplus \end{array} \begin{array}{c} \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array}$$

|| copy



|| sense -C-





|| sense — H —

