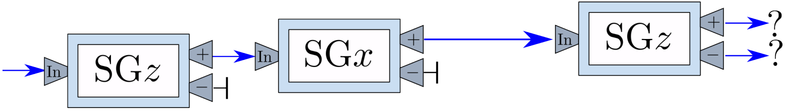
What fraction of the input beam comes out of each, final output?



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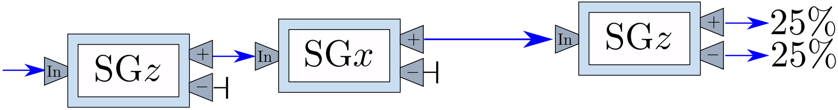


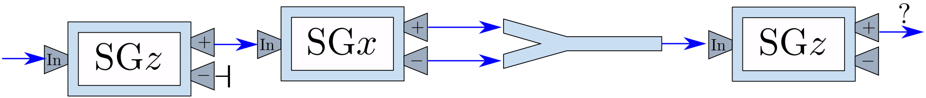
What fraction of the input beam comes out of each output?

$$A_+ = \langle +z|+x\rangle\langle +x|+z\rangle = \left[(1\ 0)\begin{pmatrix}\sqrt{1/2}\\ \sqrt{1/2}\end{pmatrix}\right]\left[(\sqrt{1/2}\ \sqrt{1/2})\begin{pmatrix}1\\ 0\end{pmatrix}\right] = \frac{1}{2}$$

$$A_- = \langle -z|+x\rangle\langle +x|+z\rangle = \left[(0\ 1)\begin{pmatrix}\sqrt{1/2}\\ \sqrt{1/2}\end{pmatrix}\right]\left[(\sqrt{1/2}\ \sqrt{1/2})\begin{pmatrix}1\\ 0\end{pmatrix}\right] = \frac{1}{2}$$

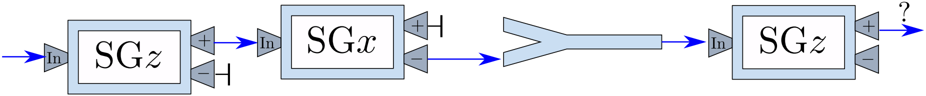
$$P_+ = |A_+|^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4} \qquad P_- = |A_-|^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

What is the probability for the electron to have the final $+z$ state?



Observable	S_z	S_x	S_θ
$+\frac{1}{2}\hbar$	$\lvert +z\rangle = \begin{bmatrix}1\\0\end{bmatrix}$	$\lvert +x\rangle = \begin{bmatrix}\sqrt{1/2}\\\sqrt{1/2}\end{bmatrix}$	$\lvert +\theta\rangle = \begin{bmatrix}\cos\frac{\theta}{2}\\\sin\frac{\theta}{2}\end{bmatrix}$
$-\frac{1}{2}\hbar$	$\lvert -z\rangle = \begin{bmatrix}0\\1\end{bmatrix}$	$\lvert -x\rangle = \begin{bmatrix}\sqrt{1/2}\\-\sqrt{1/2}\end{bmatrix}$	$\lvert -\theta\rangle = \begin{bmatrix}-\sin\frac{\theta}{2}\\\cos\frac{\theta}{2}\end{bmatrix}$

What is the probability for the electron to have the final $+z$ state now?



Observable	S_z	S_x	S_θ
$+\frac{1}{2}\hbar$	$\vert+z\rangle = \begin{bmatrix}1\\0\end{bmatrix}$	$\vert+x\rangle = \begin{bmatrix}\sqrt{1/2}\\\sqrt{1/2}\end{bmatrix}$	$\vert+\theta\rangle = \begin{bmatrix}\cos\frac{\theta}{2}\\\sin\frac{\theta}{2}\end{bmatrix}$
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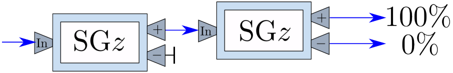
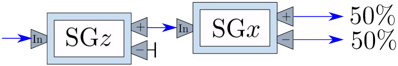
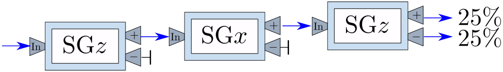
Summary of Spin Measurements 5



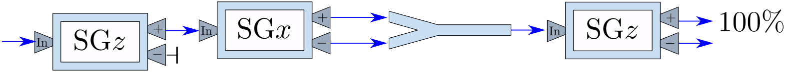
Not a surprise.



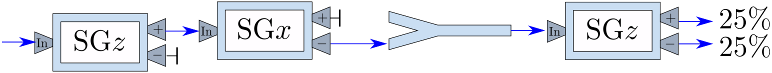
Electrons with a definite S_z value have an equal chance for either S_x eigenvalue.



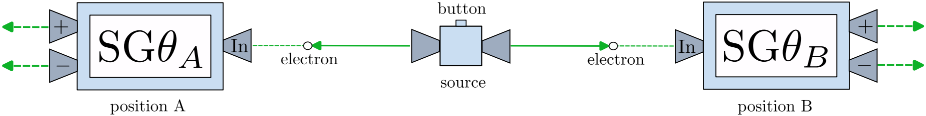
Measurement alters the properties/components of the spin.

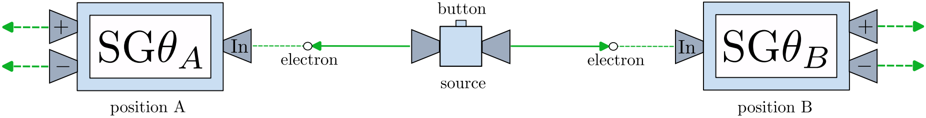


Removing information 'removes' a measurement (see second measurement).

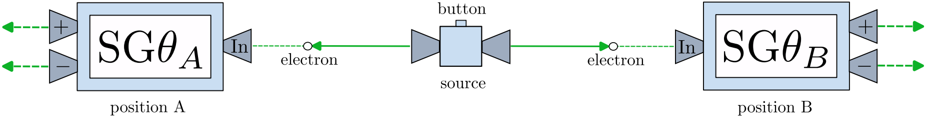


Blocking a channel destroys the 'interference' pattern.


button
SGθA
In
electron
source
electron
In
SGθB
position A
position B
+
−
+
−



1. Fire two electrons in a joint quantum state where the electrons have opposite momentum and zero total spin angular momentum.



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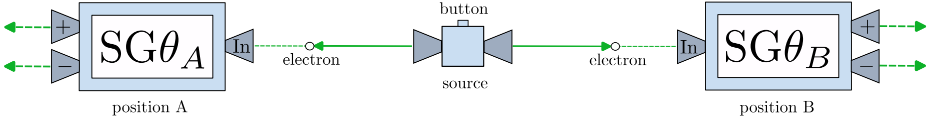
2. The detectors are at A and B equidistant from the source.

The Einstein, Podolsky, Rosen (EPR) Paradox



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2. The detectors are at A and B equidistant from the source.
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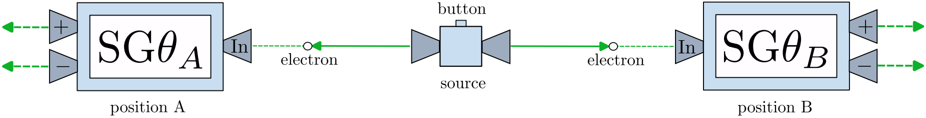

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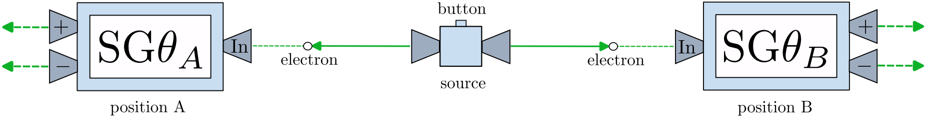

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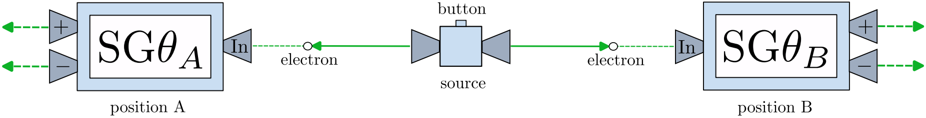

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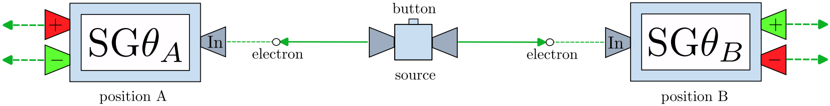
6. Quantum mechanics is incomplete. There must be hidden variables.

1. Consider firing two electrons in a joint quantum state. The electrons have opposite momentum and zero total spin angular momentum.



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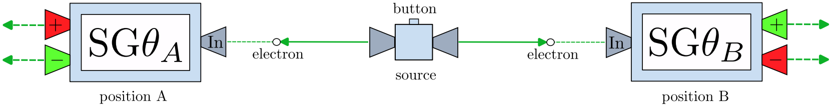

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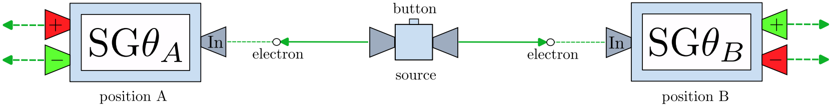

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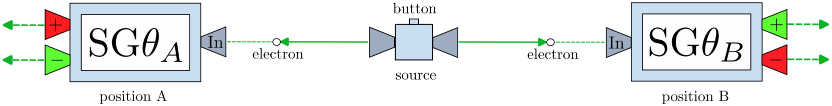

2. The red and green colors flash when an electron is detected.
3. If the two $\mathrm{SG}\theta$ devices have the same orientation, they flash the same color when each detects an electron - the color links opposite spins in the two detectors.
4. Let $\theta_A = 0°$, $\theta_B = 120°$, and A flashes red. (a) What is the state of the other electron? (b) For the B device to flash red, what state must it be in? (c) What is the probability of the lights both flashing red?

Observable	S_z	S_x	S_θ
$+\frac{1}{2}\hbar$	$\vert +z\rangle = \begin{bmatrix}1\\0\end{bmatrix}$	$\vert +x\rangle = \begin{bmatrix}\sqrt{1/2}\\\sqrt{1/2}\end{bmatrix}$	$\vert +\theta\rangle = \begin{bmatrix}\cos\frac{\theta}{2}\\\sin\frac{\theta}{2}\end{bmatrix}$
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Do a series of runs where you press the EPR button, select θ_A and θ_B in flight, at random, and independently. Set the orientations of each SG devices to one of the values $\theta_1 = 0^\circ$, $\theta_2 = 120^\circ$, and $\theta_3 = -120^\circ$.

1. When the orientations are the same what fraction have the same color?
2. When the orientations are different what fraction have the same color?
3. Ignoring the orientations what is the fraction of events with the same color?

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31RG	23RG	23RG	23GR	22GG	33GG	22GG
23RR	31GR	12GR	33RR	33GG	32RG	11RR
13GR	22GG	23GR	13RG	33RR	21GR	21RG
32RG	12RR	11RR	33GG	13GR	12GG	23RR
13GR	13RG	33GG	32GG	33GG	23GR	21GR
23RR	33GG	23GG	31RG	13RR	21RG	12RG
22RR	21RG	31GR	11RR	11GG	32RG	13RR
31RG	11GG	33GG	11GG	23GR	31GR	23GR

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2. When the orientations are different what fraction have the same color?
3. Ignoring the orientations what is the fraction of events with the same color?

Consider a classical model for the electron that includes hidden variables consistent with locality and reality. Add this 'observable' to the electron that will identify the color for for different orientations or values of θ for the SG devices. Call it the electron 'gizmo'.

Assign the colors:

1. $0^\circ \rightarrow \text{red.}$
2. $120^\circ \rightarrow \text{green.}$
3. $-120^\circ \rightarrow \text{red.}$

gizmo $= RGR$.

What are all the different combinations for the gizmos?

What are all the different combinations for orientations of the SG devices?

Consider the classical model where electrons carry additional information (hidden variables that tell which colors to flash for the different orientations). In the table below the columns represent all the combinations of orientations. The rows represent the 'hidden variable'. The 'Pr' is the probability of getting the same color. 'S' means the orientations are the same and 'D' means they are different.

	11	12	13	21	22	23	31	32	33	Pr
RRR										
RRG										
RGR	S	D	S	D	S	D	S	D	S	
RGG										
GRR										
GRG										
GGR										
GGG										

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	11	12	13	21	22	23	31	32	33	Pr
RRR	S	S	S	S	S	S	S	S	S	1
RRG	S	S	D	S	S	D	D	D	S	5/9
RGR	S	D	S	D	S	D	S	D	S	5/9
RGG	S	D	D	S	S	S	D	S	S	5/9
GRR	S	D	D	D	S	S	D	S	S	5/9
GRG	S	D	S	D	S	D	S	D	S	5/9
GGR	S	S	D	S	S	D	D	D	S	5/9
GGG	S	S	S	S	S	S	S	S	S	1

Bell's Theorem - 3 22

Consider the classical model where electrons carry additional information (hidden variables that tell which colors to flash for the different orientations). In the table below the columns represent all the combinations of orientations. The rows represent the 'hidden variable'. The 'Pr' is the probability of getting the same color. 'S' means the orientations are the same and 'D' means they are different.

	11	12	13	21	22	23	31	32	33	Pr
RRR	S	S	S	S	S	S	S	S	S	1
RRG	S	S	D	S	S	D	D	D	S	5/9
RGR	S	D	S	D	S	D	S	D	S	5/9
RGG	S	D	D	S	S	S	D	S	S	5/9
GRR	S	D	D	D	S	S	D	S	S	5/9
GRG	S	D	S	D	S	D	S	D	S	5/9
GGR	S	S	D	S	S	D	D	D	S	5/9
GGG	S	S	S	S	S	S	S	S	S	1

What is the average probability $\langle Pr \rangle$ for getting the same color from the EPR apparatus?

1. EPR argument - for joint, entangled states there is no apparent delay when one partner/electron/photon is measured and the wave function collapse is instantaneous violating relativity.
2. Bell's Theorem (1) - Using standard quantum mechanical methods we found the EPR apparatus would detect events with the same color lights a fraction $f = 0.50$ of the time.
3. Bell's Theorem (2) - A 'hidden variable' model predicts the fraction f of events with the same color lights is the following.

$$f > 5/9 \quad \text{and} \quad \langle Pr \rangle = \frac{2}{3}$$

WHO WINS? WHY?

1. We found that in the quantum case 50% of the SG events should flash the same color.
2. How does that fraction compare with the classical model?

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Quantum wins.
Nature is non-local and unreal.

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Experimental Tests of Realistic Local Theories via Bell's Theorem

Alain Aspect, Philippe Grangier, and Gérard Roger
Institut d'Optique Théorique et Appliquée, Université Paris-Sud, F-91406 Orsay, France
(Received 30 March 1981)

We have measured the linear polarization correlation of the photons emitted in a radiative atomic cascade of calcium. A high-efficiency source provided an improved statistical accuracy and an ability to perform new tests. Our results, in excellent agreement with the quantum mechanical predictions, strongly violate the generalized Bell's inequalities, and rule out the whole class of realistic local theories. No significant change in results was observed with source-polarizer separations of up to 6.5 m.

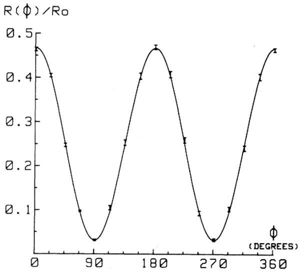


FIG. 4. Normalized coincidence rate as a function of the relative polarizer orientation. Indicated errors are ± 1 standard deviation. The solid curve is not a fit to the data but the prediction of quantum mechanics.

The z component of the muon magnetic moment is

$$(\mu_s)_z = -g_s \mu_B m_s$$

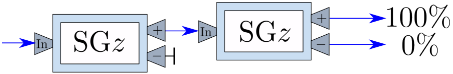
where $m_s = 1/2$ is the spin quantum number, $\mu_B = e\hbar/2m_e$ is the Bohr magneton, and the spin g-factor is

$$g_\mu = -2.00\ 233\ 184\ 131(82)\ \mathrm{(exp)}$$

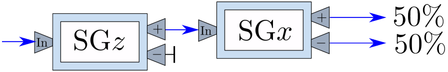
$$g_\mu = -2.00\ 233\ 183\ 620(86)\ \mathrm{(th)}$$

where the relative standard uncertainty for both values is about 4×10^{-10}. This difference may be due to physics Beyond the Standard Model (BSM).

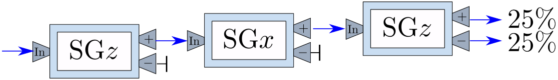
Some Properties of Spin Measurements



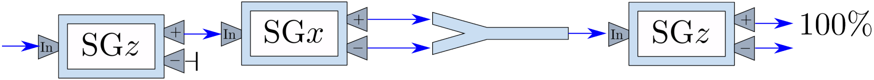
Not a surprise.



Electrons with a definite value of S_z have an equal chance for either eigenvalue of S_x.



Measurement alters the properties/components of the spin.



Removing information 'removes' a measurement (see second measurement.