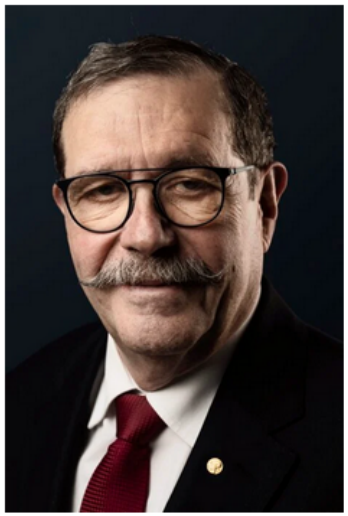
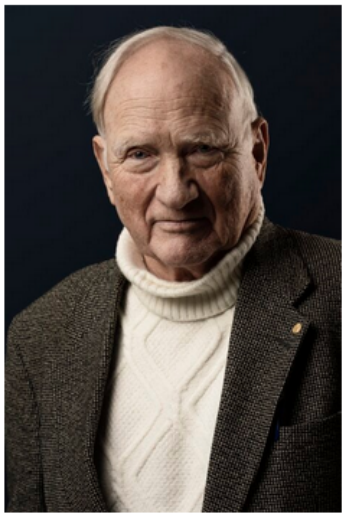
# Nobel Prize 2022

Scientific Background on the Nobel Prize in Physics 2022

"FOR EXPERIMENTS WITH ENTANGLED PHOTONS, ESTABLISHING THE VIOLATION OF BELL INEQUALITIES AND PIONEERING QUANTUM INFORMATION SCIENCE"

The Nobel Committee for Physics


# Now It Starts to Get Weird - Realism 2

If a tree falls in the woods, does it make a sound?

# Now It Starts to Get Weird - Realism 3

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"The objects of sense exist only when they are perceived; the trees therefore are in the garden... no longer than while there is somebody by to perceive them." - George Berkeley. *A Treatise Concerning the Principles of Human Knowledge, 1734. section 45.*

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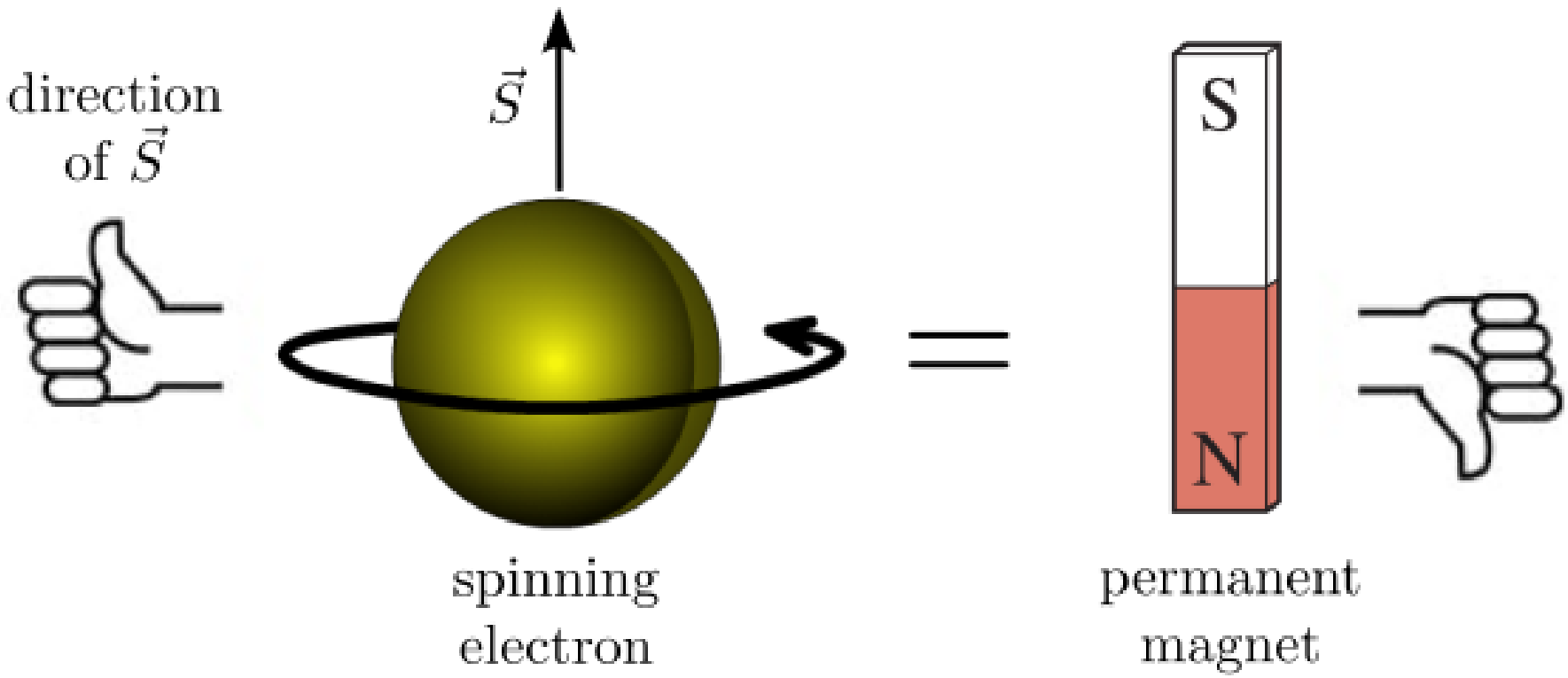
Locality - an object is influenced directly only by its immediate surroundings

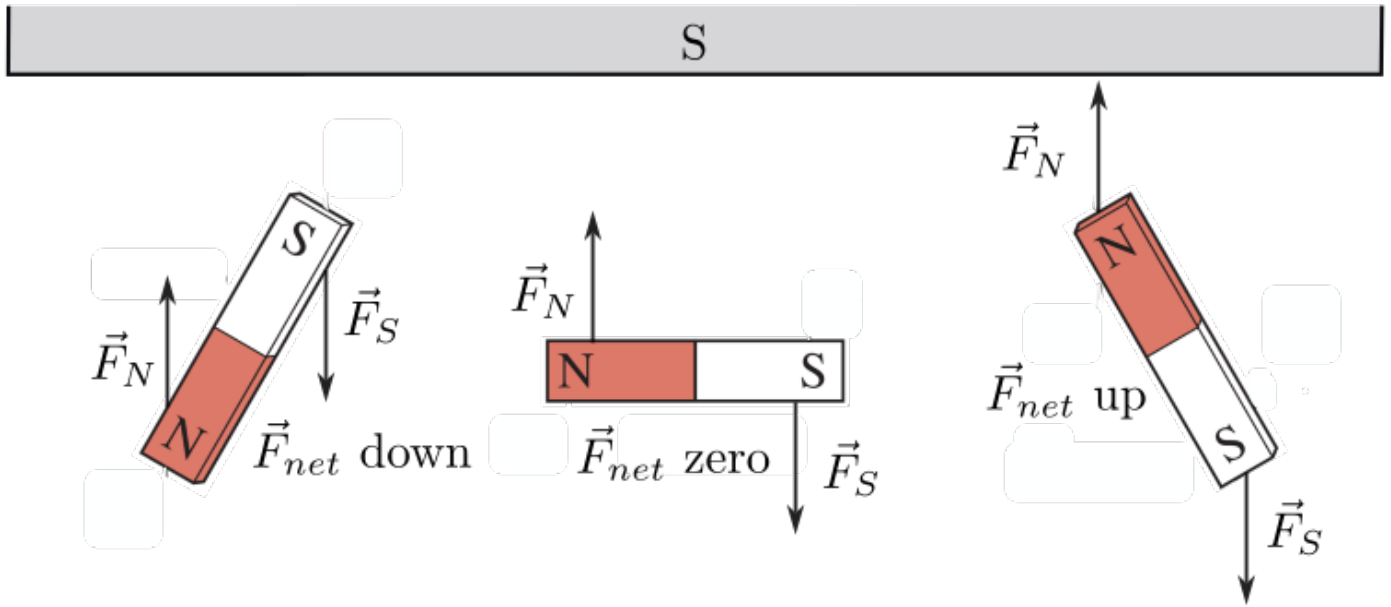
# Spinning charge $\rightarrow \vec{B}$ (Stern-Gerlach) 8



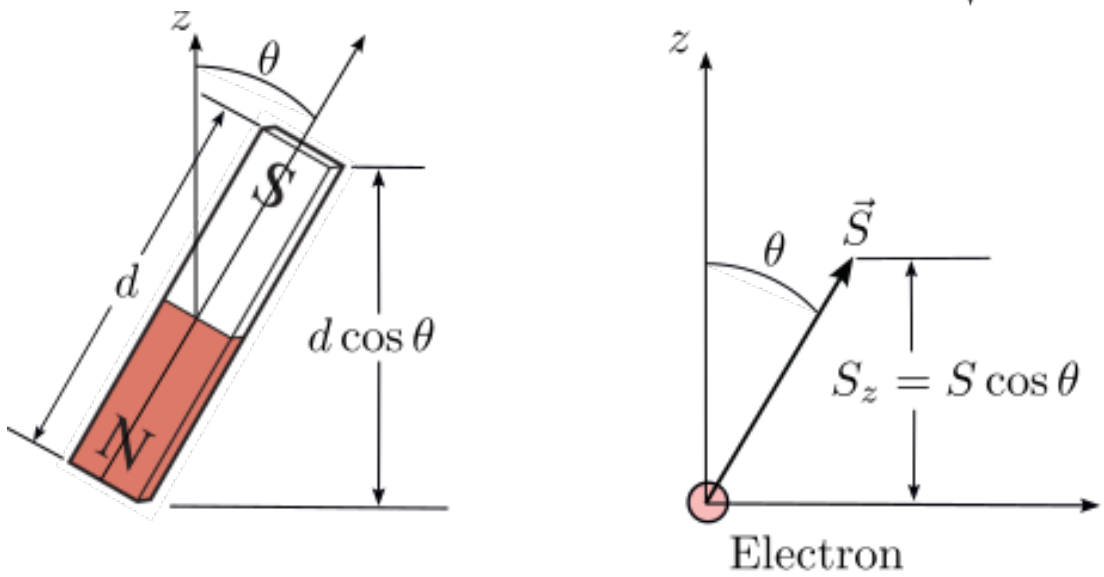

- The spin vector $\vec{S}$ points up by the right-hand rule.
- Charge is spread uniformly on the surface of the sphere.
- Electrons act like little bar magnets.

# Forces on Bar Magnets in a $\vec{B}$ Field 9

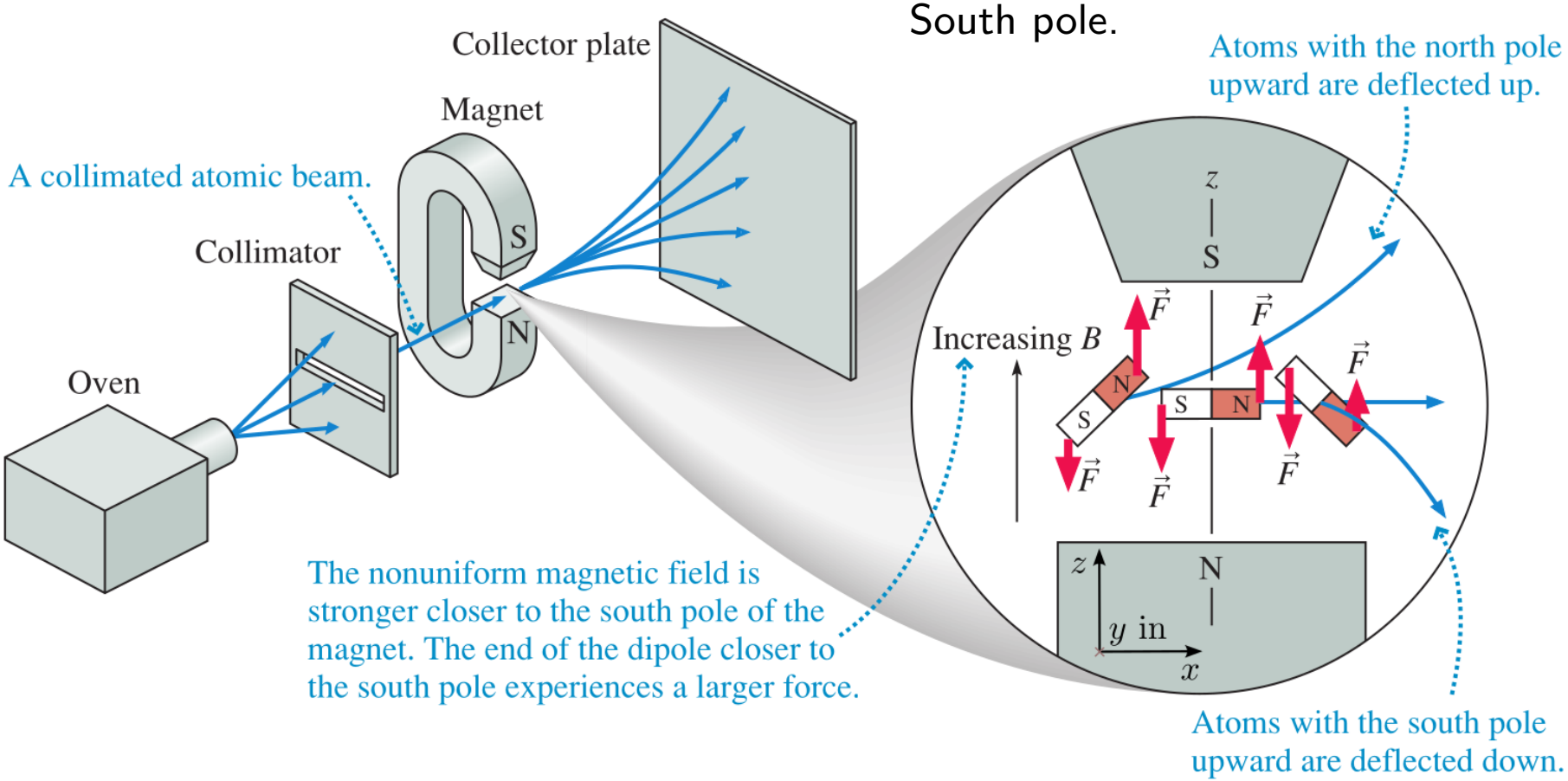
Forces on magnets at different angles to the $\vec{B}$ field. Field is non-uniform and drops off rapidly with distance from the South pole.




The net force on the electron depends on the vertical position of the South pole and the distance from the external magnet. Torque is out of the plane of the paper.



The $\vec{B}$ field is stronger near the South pole.



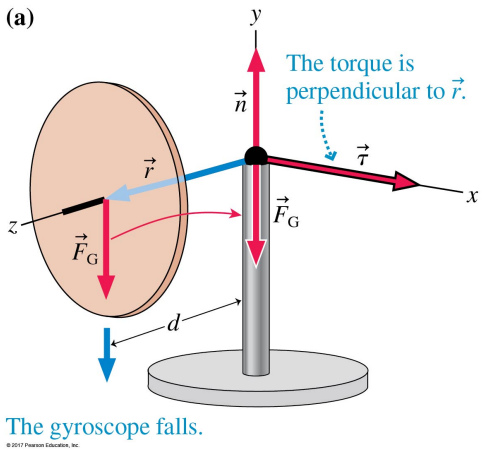
| Linear Quantity | Connection | Rotational Quantity |
|---|---|---|
| $s$ | $s = r\theta$ | $\theta = \frac{s}{r}$ |
| $v_T$ | $v = r\omega$ | $\omega = \frac{v}{r} = \frac{d\theta}{dt}$ |
| $a$ | $a = r\alpha$ | $\alpha = \frac{a}{r} = \frac{d\omega}{dt}$ |
| $\vec{F} = m\vec{a} = \frac{d\vec{p}}{dt}$ | $\vec{\tau} = \vec{r} \times \vec{F}$ | $\vec{\tau} = I\vec{\alpha} = \frac{d\vec{L}}{dt}$ |
| $KE = \frac{1}{2}mv^2$ | | $KE_R = \frac{1}{2}I\omega^2$ |
| $\vec{p} = m\vec{v}$ | $\vec{L} = \vec{r} \times \vec{p}$ | $\vec{L} = I\vec{\omega}$ |

$$\vec{r}_{cm} = \frac{\sum m_i \vec{r}_i}{\sum m_i} \qquad I = \sum m_i r_i^2$$

Spin ($\vec{S}$) is angular momentum.

# Spinning Top in a Gravitational Field 12

1. What is the direction of the torque $\vec{\tau}$ due to gravity?
2. What is the initial angular momentum $\vec{L}$ and how does $\vec{\tau}$ change it?

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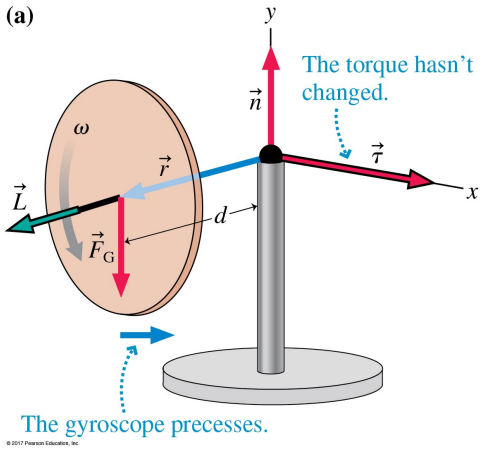
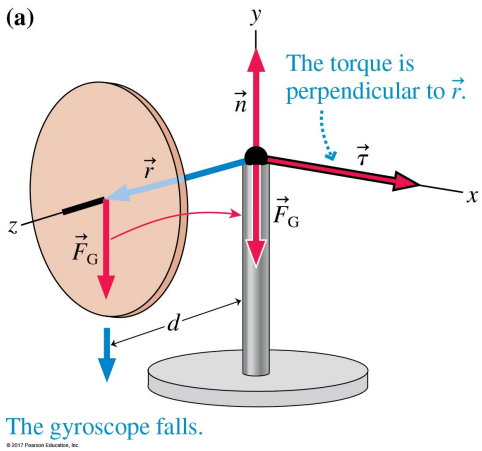


# Spinning Top in a Gravitational Field 13

1. What is the direction of the torque $\vec{\tau}$ due to gravity? $x$ direction
2. What is the initial angular momentum $\vec{L}$ and how does $\vec{\tau}$ change it?

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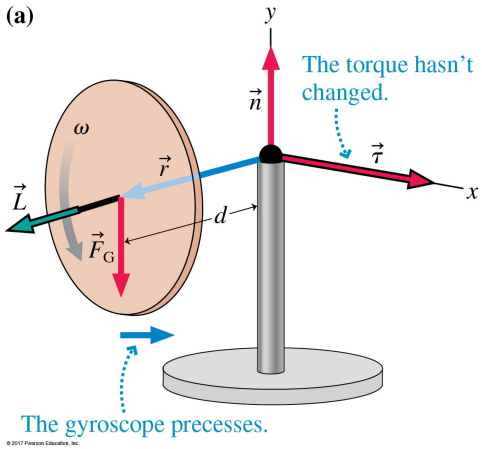

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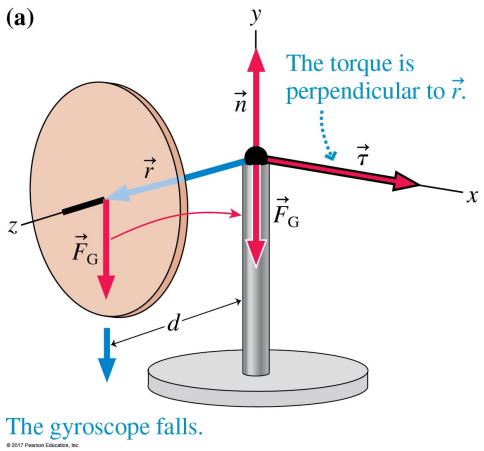


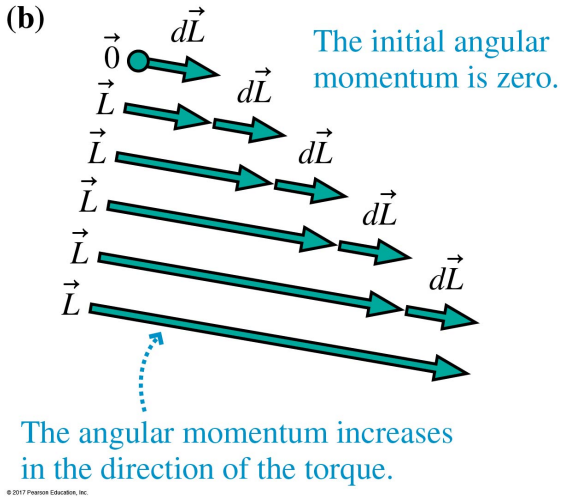


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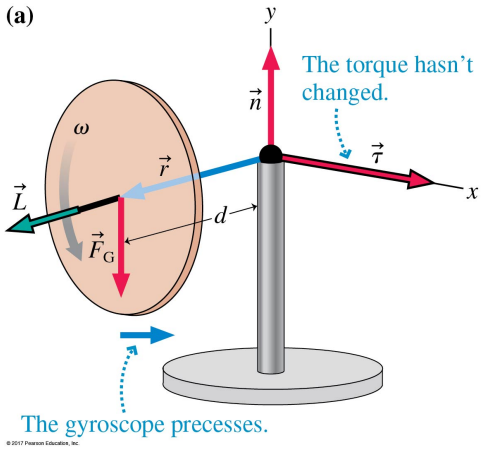

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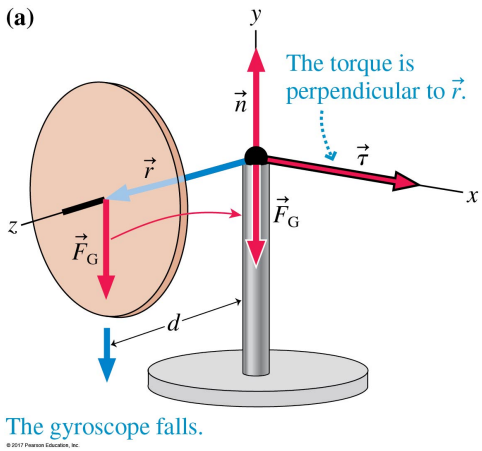
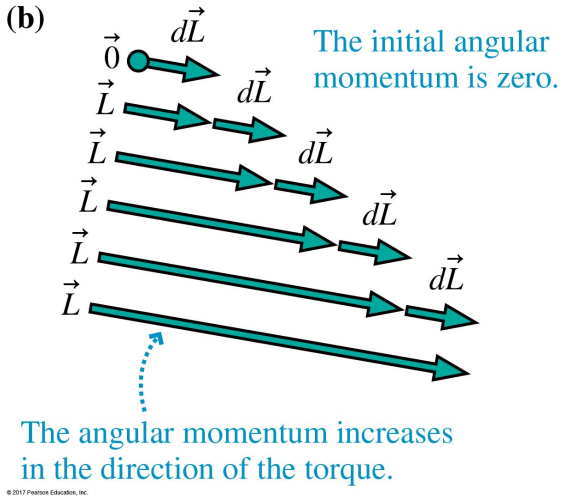
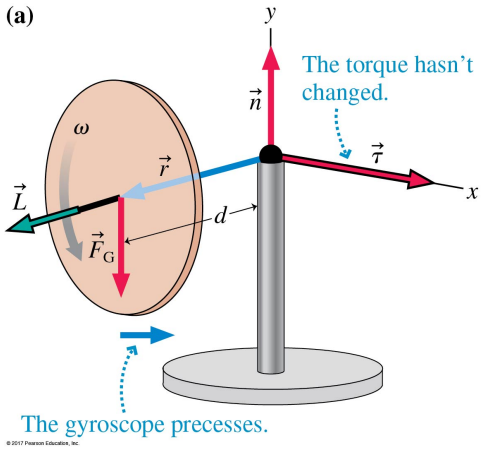



1. What is the direction of the torque $\vec{\tau}$ due to gravity? The same.
2. What is the initial angular momentum $\vec{L}$ and how does $\vec{\tau}$ change it?



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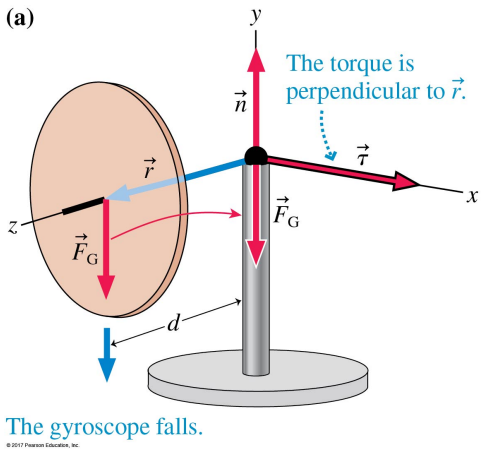


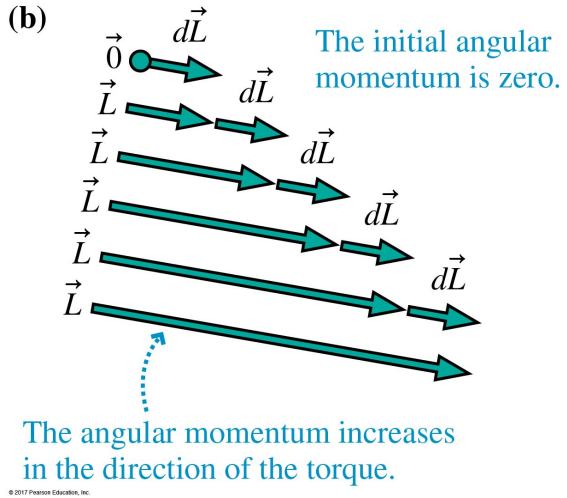


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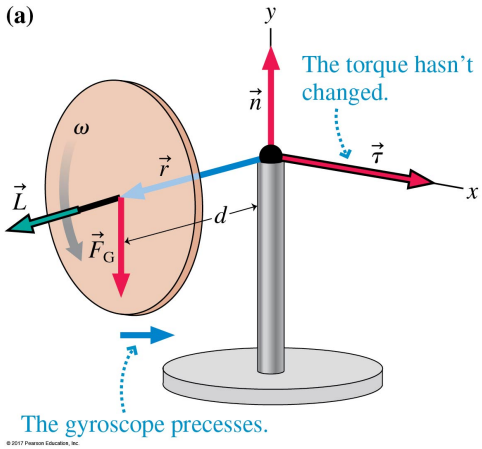
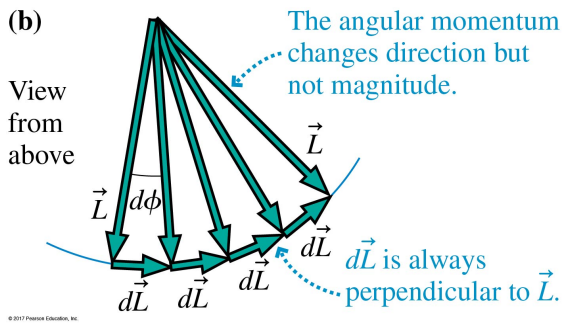
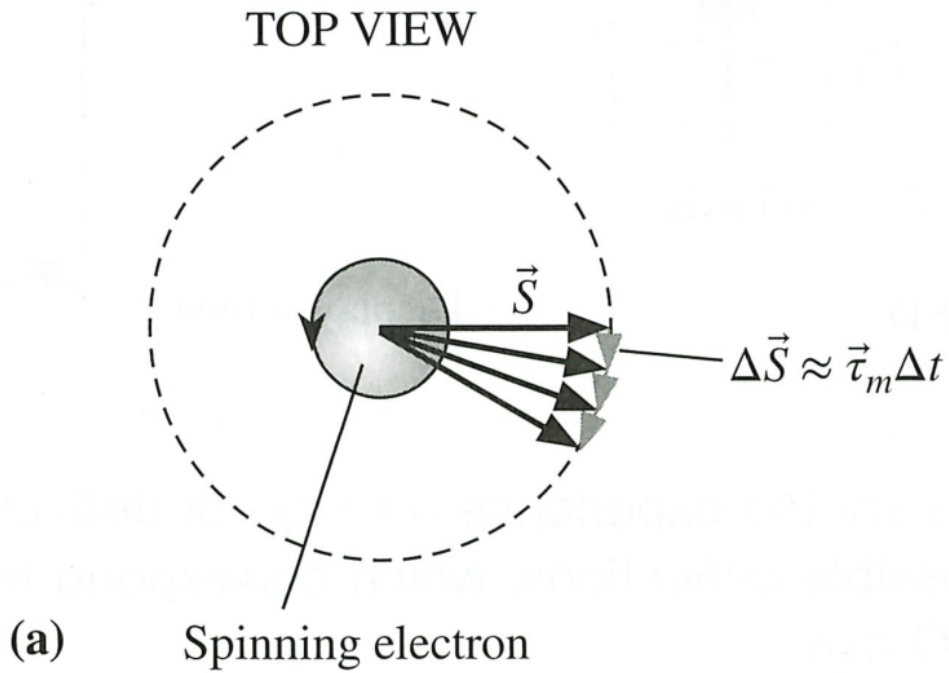
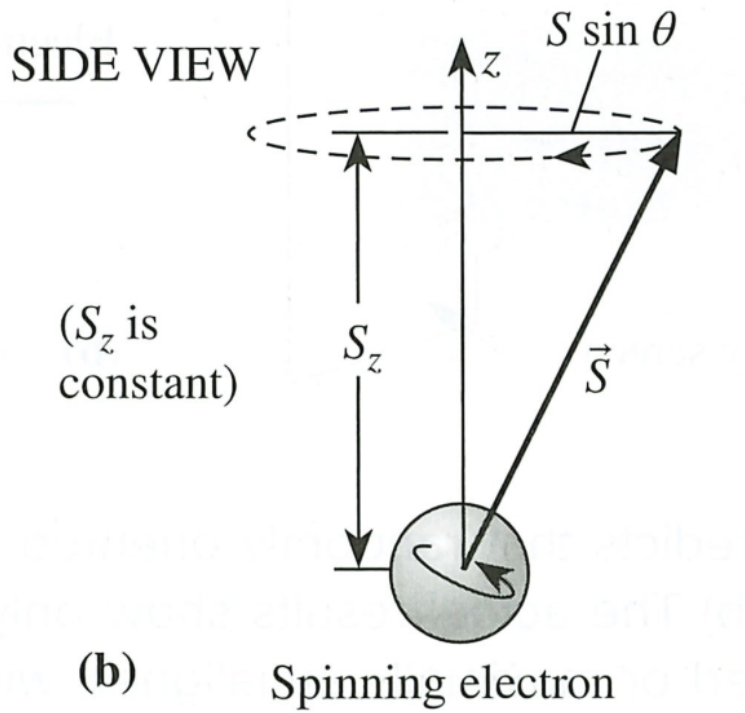
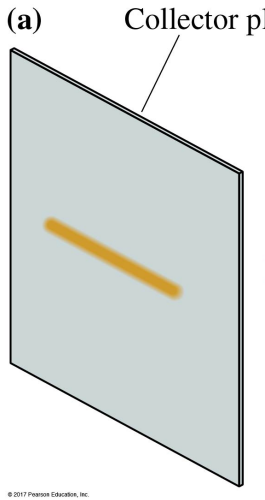



TOP VIEW
$\vec{S}$
$\Delta\vec{S} \approx \vec{\tau}_m \Delta t$
(a)
Spinning electron


SIDE VIEW
$S \sin\theta$
$z$
($S_z$ is constant)
$S_z$
$\vec{S}$
(b)
Spinning electron

# Stern-Gerlach Expected/Observed Results 18




Magnet off: No deflection,
all atoms land at the center.

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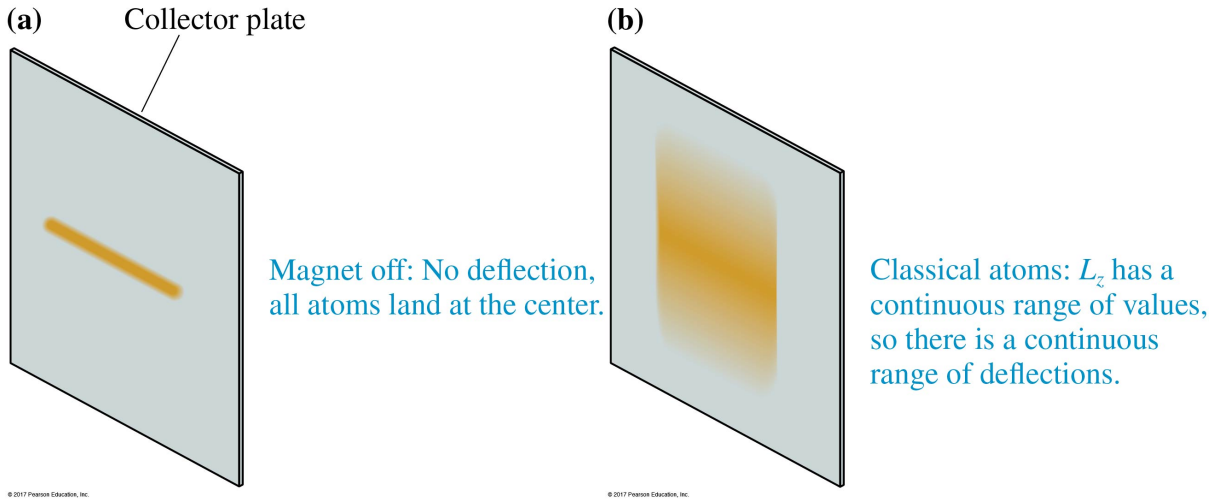
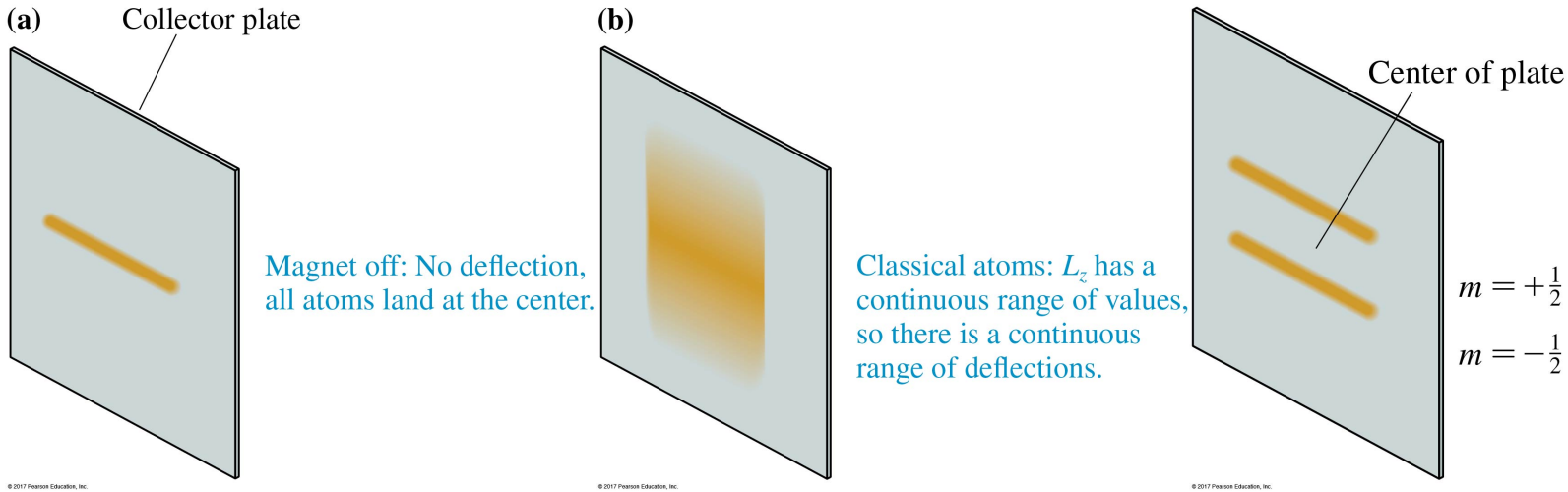
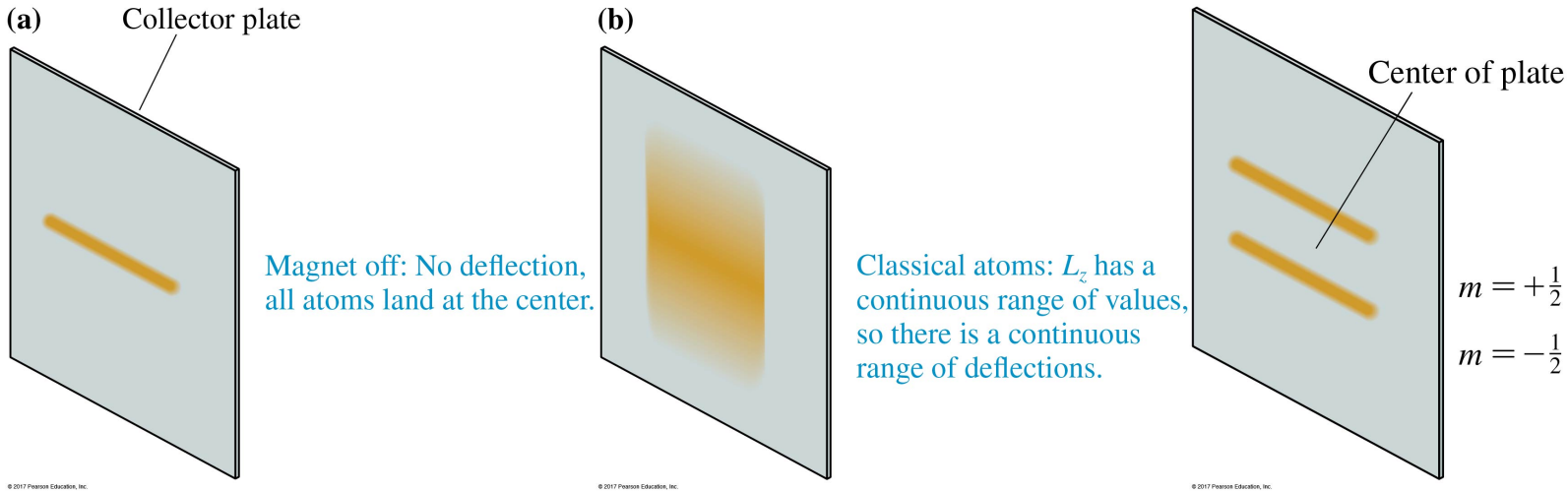
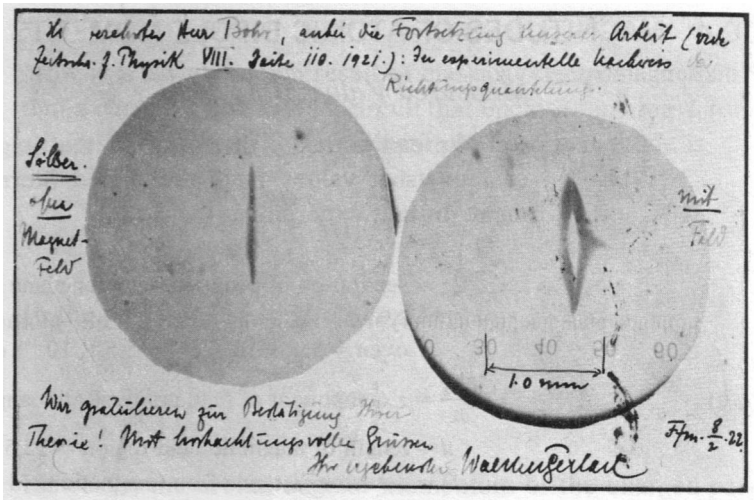


# Stern-Gerlach Expected/Observed Results 20

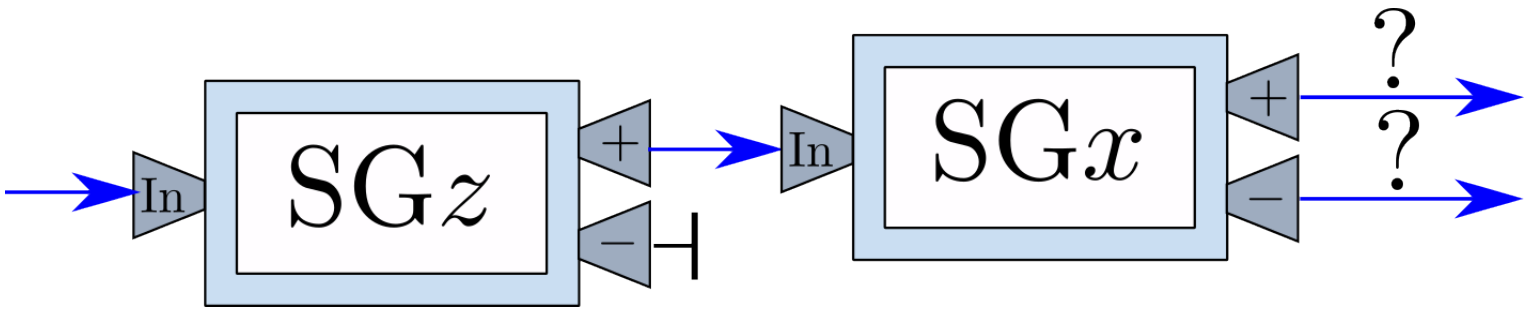


# Stern-Gerlach Expected/Observed Results 21

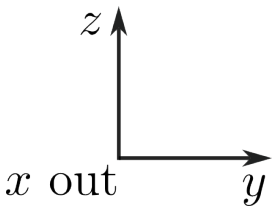


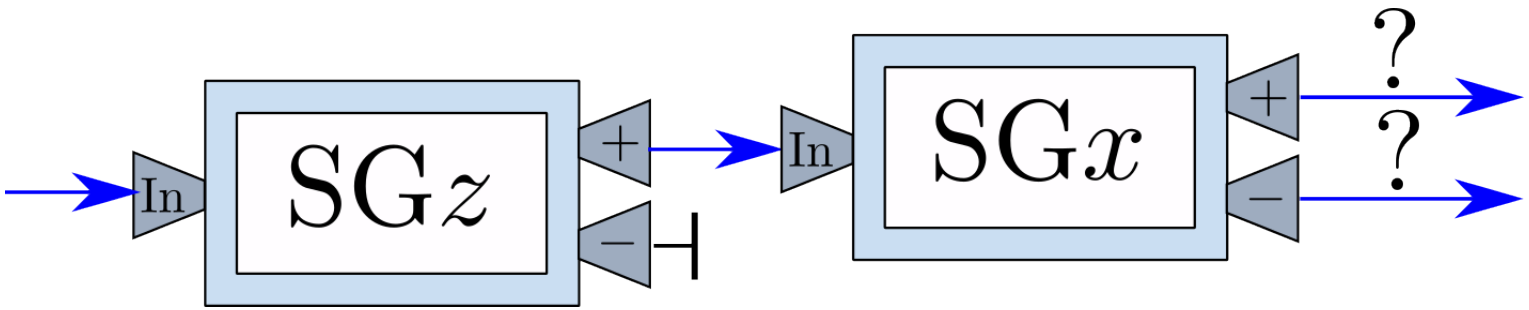




$$S_z = \pm\hbar/2$$




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



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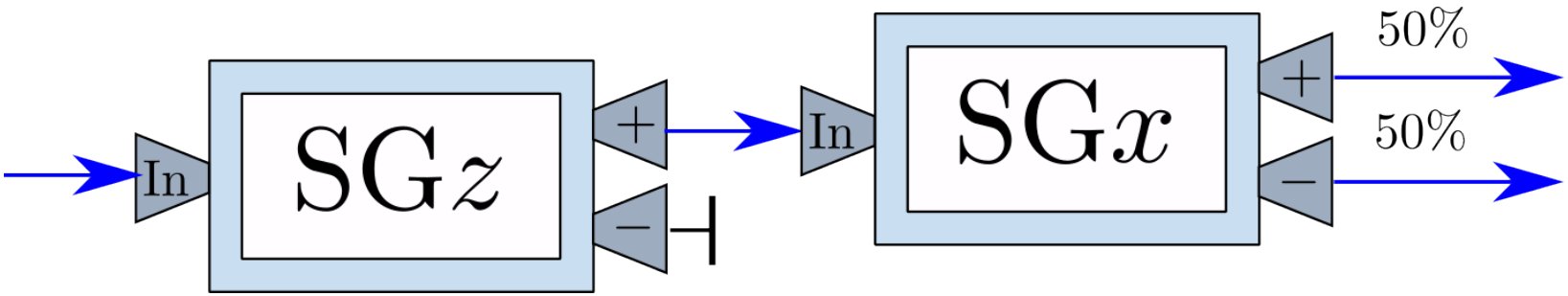
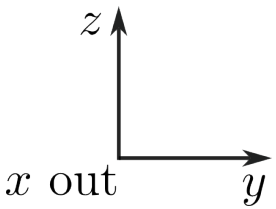
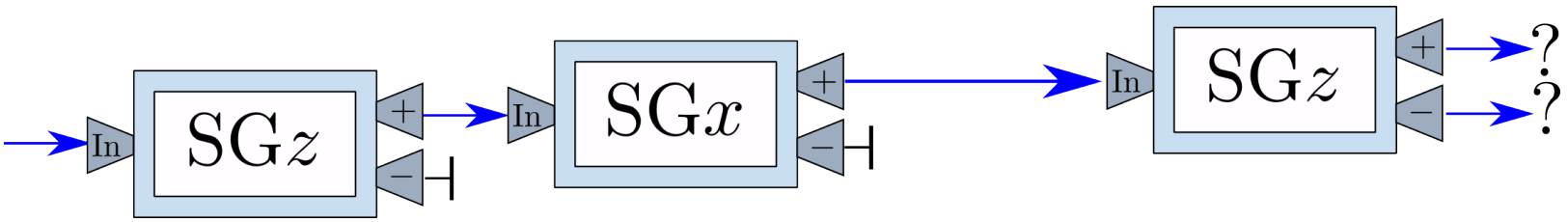
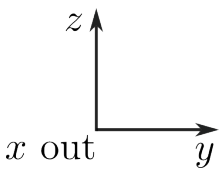



The final outputs are randomly distributed between the $\pm$ outputs.



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



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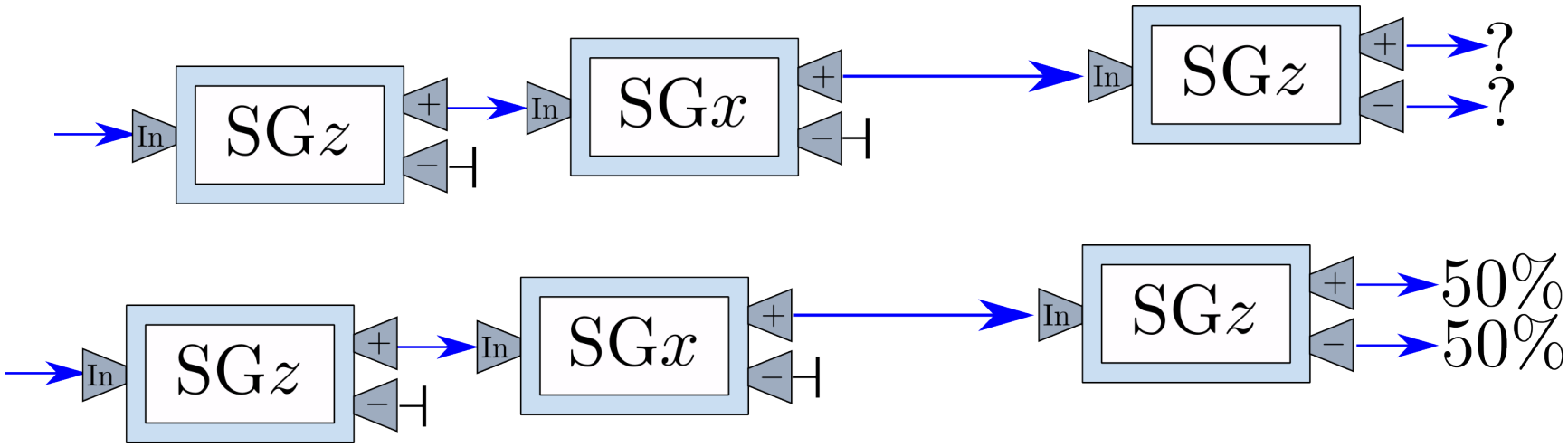
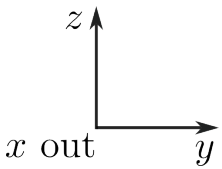
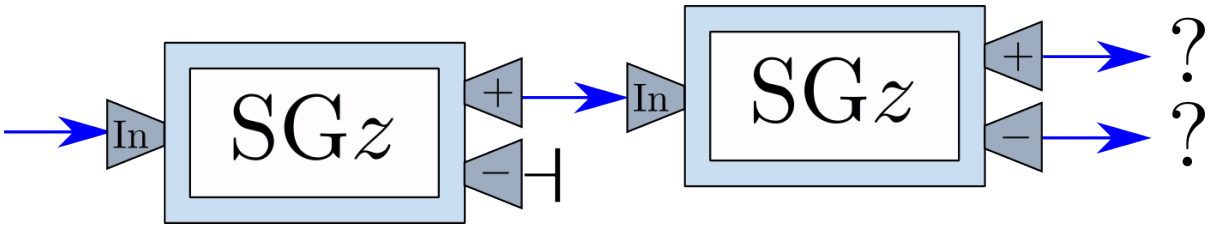


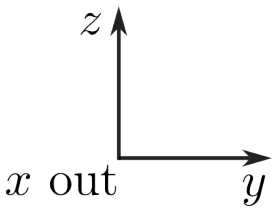

The final outputs are randomly distributed between the $\pm$ outputs. The output of the first SGz device is a beam of pure $S_z = +\hbar/2$. The SGx alters the composition of the electrons to purely $S_x = +\hbar/2$. This last measurement then is perfectly split between $S_z = \pm\hbar/2$. The SGx device altered the composition of the beam.



What are the probabilities here?




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



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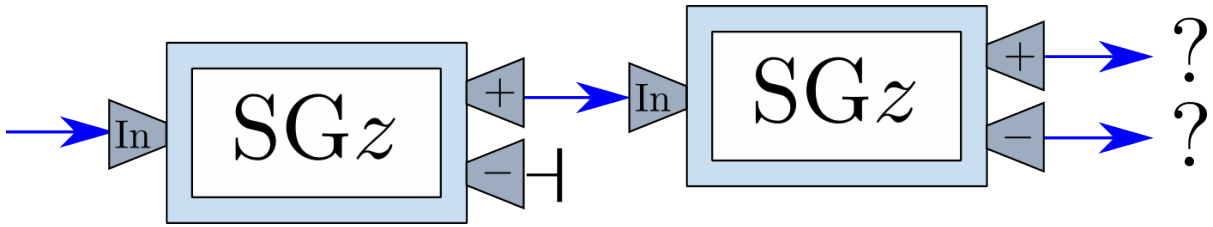


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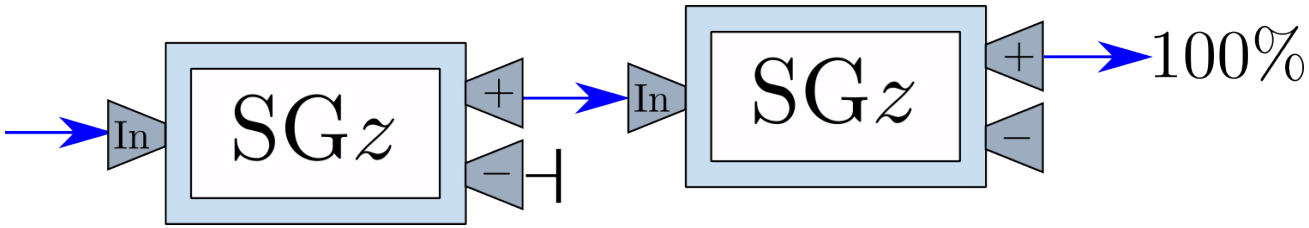
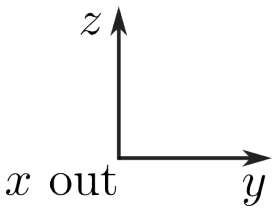



OK, that makes sense.



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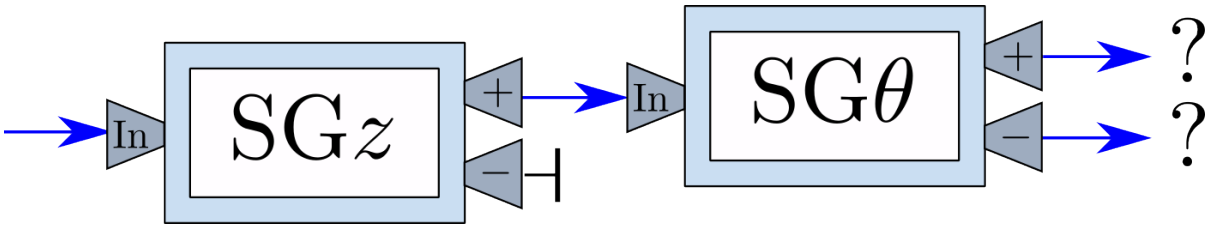
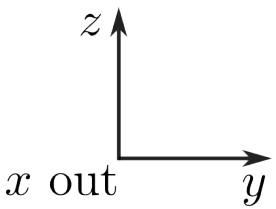
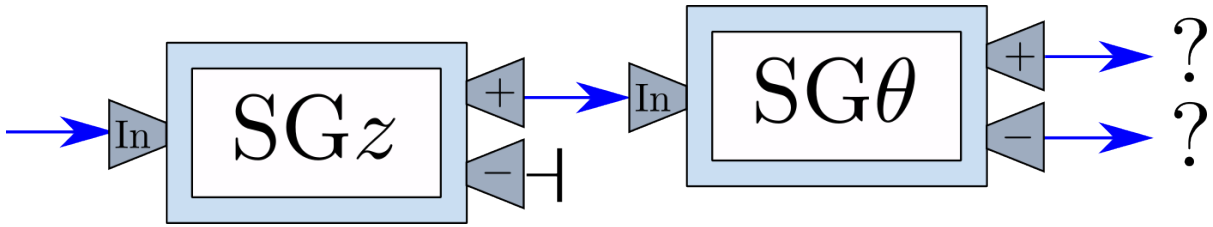



What fraction of the input beam comes out of each output? The angle $\theta$ is the angle between the $z$-axis and the axis of the SG device lying in the $x - z$ plane.



What are the probabilities here?

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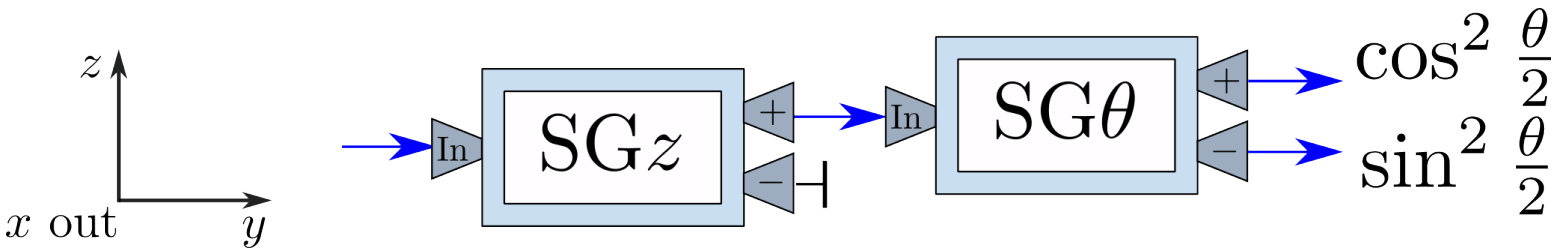
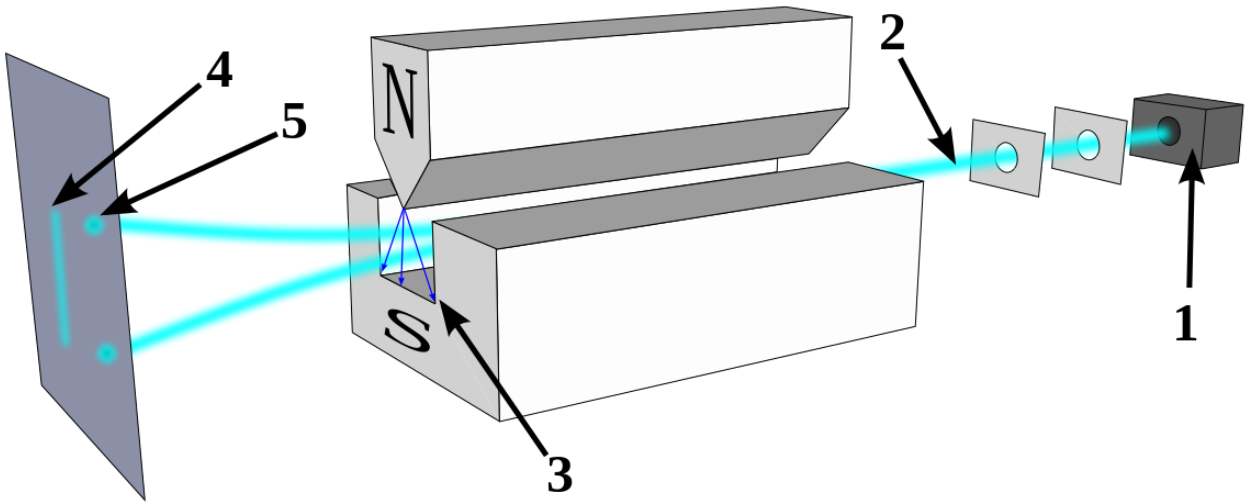



Note that previous cases had $\theta = 0°$ (SG Devices 3) and $\theta = 90°$ (SG Devices 1) and the result here agrees with those.

The Stern-Gerlach experiment showed that particle spin was quantized. Silver atoms traveling through an inhomogeneous magnetic field, and being deflected up or down depending on their spin; (1) furnace, (2) beam of silver atoms, (3) inhomogeneous magnetic field, (4) classically expected result, (5) observed result.




Video introduction is here.