# Electron spin as a quantum information unit

Our classical information is usually recorded and handled as bits → a binary value.
Every bit is assigned a value 0 or 1.
Thus, for hardware one needs to find a system with two distinct states
Popular choice → magnetized domains aligned in two distinct orientations
These a very small classical objects (magnets) that can be
- initialized (i.e. set to a desired state)
- manipulated (i.e. change direction)
- repeatedly read-out (useful!)

Electron or other quantum particle have magnetic moment (so they are tiny magnets) ↳ $\vec{\mu}_e = g \cdot \mu_B \vec{S}$ electron spin

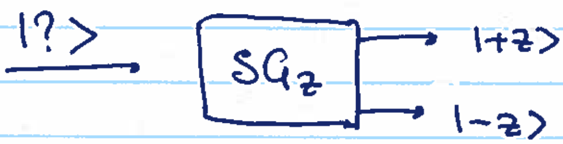
$g \simeq 2$ for electron
$\mu_B = e\hbar/2m_e c$ – Bohr magneton, universal constant

How can we measure a ~~tiny~~ tiny magnetic moment?

Potential energy $U = -\vec{\mu} \cdot \vec{B} = -\mu_z \cdot B_z$
If $B_z$ is inhomogeneous, there will be a force

$$F_z = -\frac{dU}{dz} = \mu_z \cdot \frac{dB_z}{dz} \qquad F_z \propto \mu_z$$

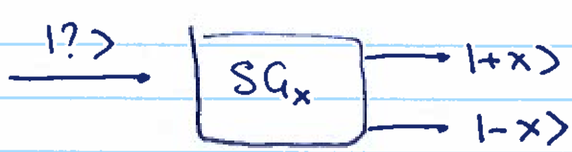
This is an example of a measurement affecting the output state




$S_z = \frac{\hbar}{2}$ $|\uparrow\rangle$

$S_z = -\frac{\hbar}{2}$ $|\downarrow\rangle$

same initial state
different measurement

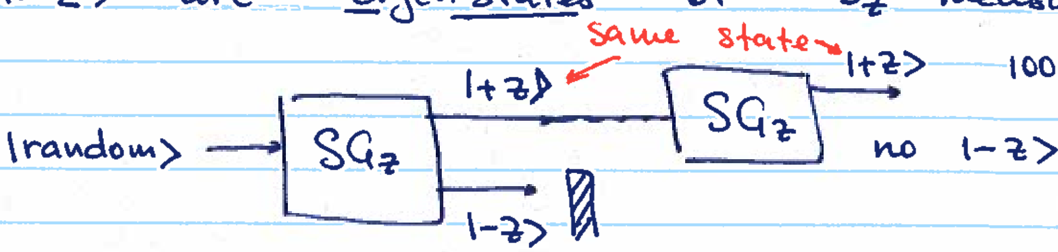



$S_x = \frac{\hbar}{2}$

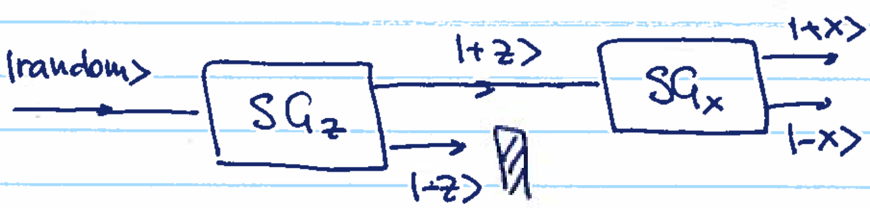
$S_z = -\frac{\hbar}{2}$

A spin component measurement for a spin-1/2 particle has only two possible outcomes $\pm\hbar/2$ for any spin orientation.

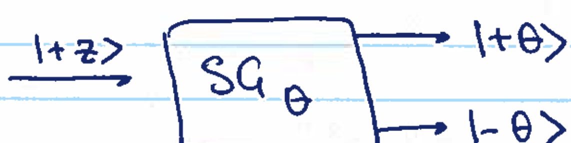
$|\pm z\rangle$ are <u>eigen states</u> of $S_z$ measurements




However, measurement of $S_x$ changes $|\pm z\rangle$ state




In general




$|+\theta\rangle$ $\cos^2\theta/2$

$|-\theta\rangle$ $1-\cos^2\theta/2$

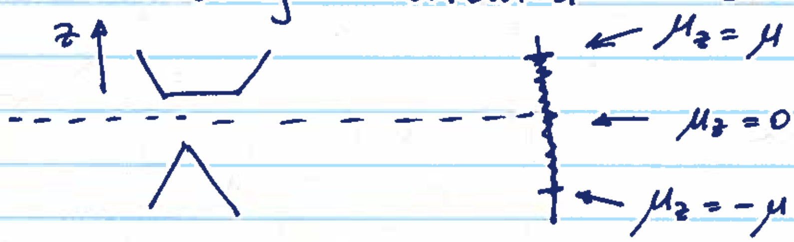
SG rotated by angle …

Stern – Gerlach apparatus

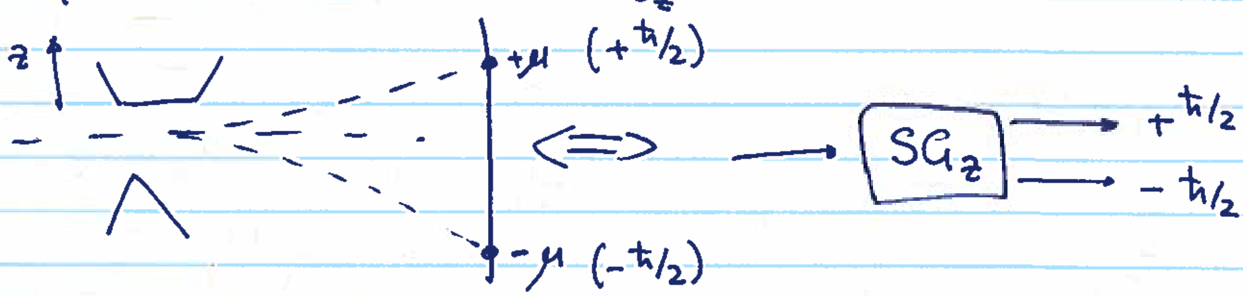

strong magnetic field gradient b/w two magnets

If $|\vec{\mu}|$ is constant, and the B gradient is only in z-direction, then particles will be deflected depending on their $\mu_z$ (or $S_z$)

Randomly oriented classical magnets $\vec{\mu}$

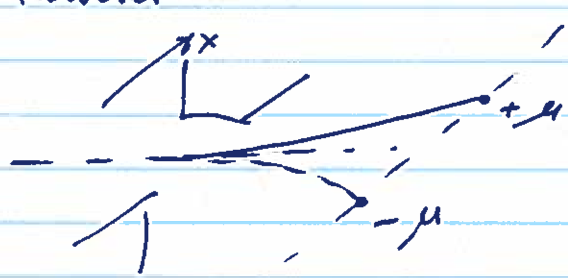



Quantum behavior $S_z$



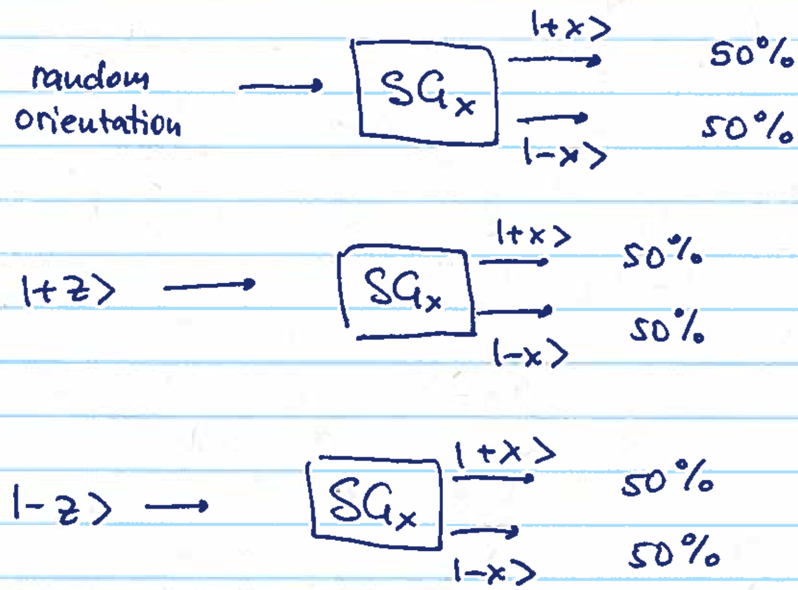

Classical conclusions atoms are only oriented along +z or −z only.

However




atoms appear to be oriented along +x or −x only

A big question to think about




How do we know the difference?