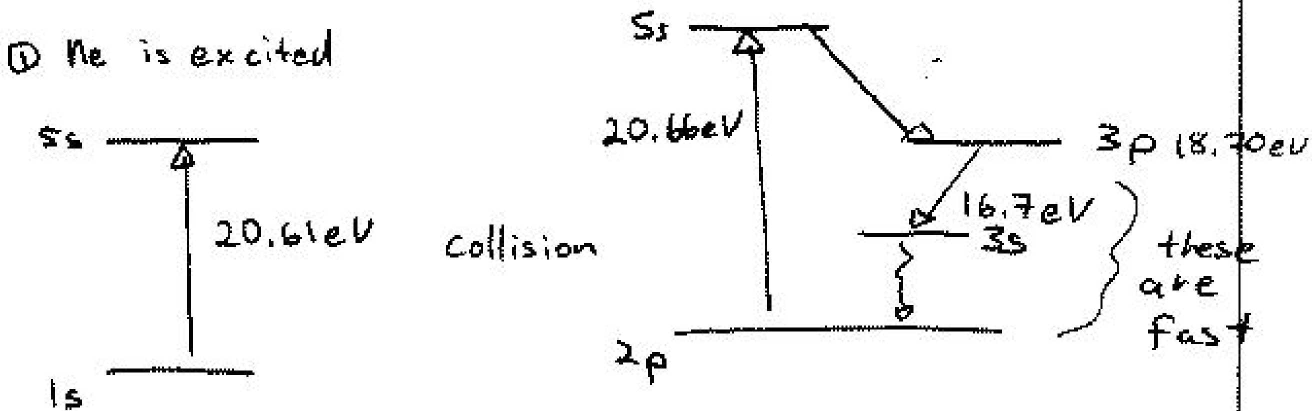
how a HeNe laser works.

① Ne is excited by electrical discharge

② Transfers this energy to He via a collision

③ He emits photons via stimulated emission & we control the direction with mirrors

④ He returns to the ground state



So what's with all this s, p stuff & why are there always s-p, p-s like transitions when photons are emitted

Not only in He, but other atoms too.

Turns out we need to modify our Bohr Picture. In quantum mechanics, angular momentum is pretty wierd stuff. We tend to think of it as stuff that rotates, in QM this is true, but it is also a question of symmetry. We've seen that the uncertainty principle tends to smear stuff out. Consider a pebble at the bottom of a bowl. This is the pebbles lowest energy state.

Now think about a super tiny pebble that gets kicked around by the uncertainty principle.

- This smeared out, spherically symmetric fuzz is hydrogen's lowest energy state

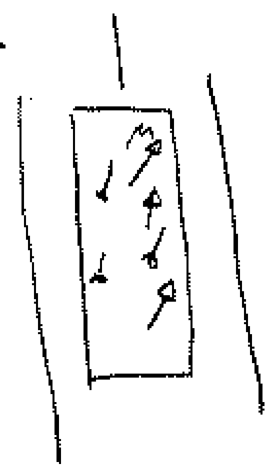
- Now suppose we give the pebble a horizontal kick, it starts to orbit, this is angular momentum, and a higher energy state
- Or suppose we give the tiny pebble some more energy, the fuzz will tend to spread out, this is also a higher energy

OK, so when we describe an atom's energy, we're going to need ways to describe states with and without angular momentum.

1) Is this real? Is it really angular momentum or just all fuzz?

Consider 2 experiments

1) Einstein - de Hass

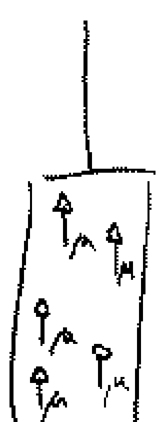


piece of iron in a magnetic field

all the little dipoles in iron are all over the place

turn on B

all μ's align

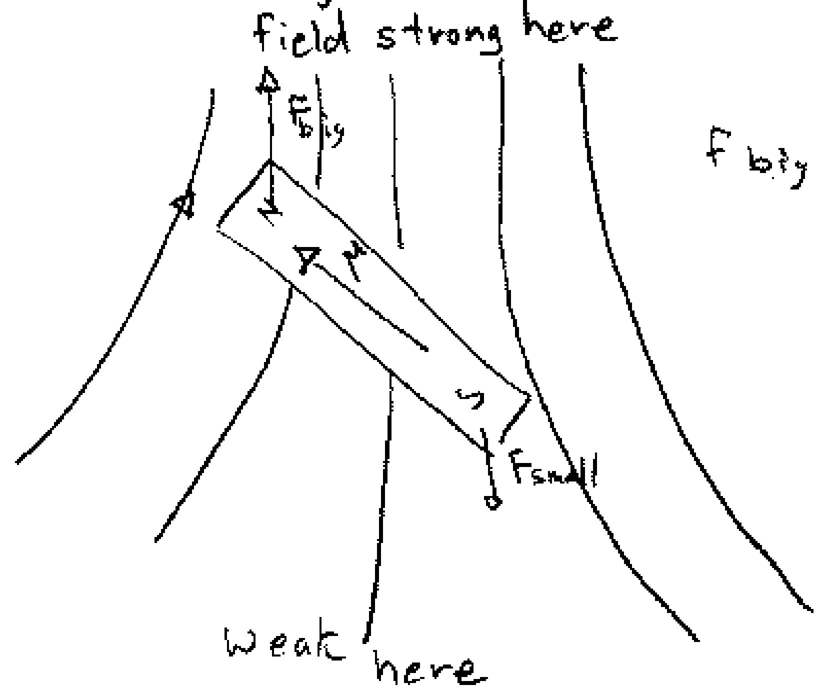


$\longrightarrow$ means all $\vec{L}$ in "same" direction $=$ iron rotates

So this is really angular momentum

2) Put a beam of atoms in a non-uniform magnetic field (why non uniform)

think of a magnet

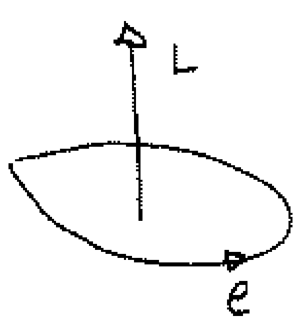


so what?

Quantum mechanics is really wierd, turns out angular momentum <u>is</u> really quantized

Here's one reason why.

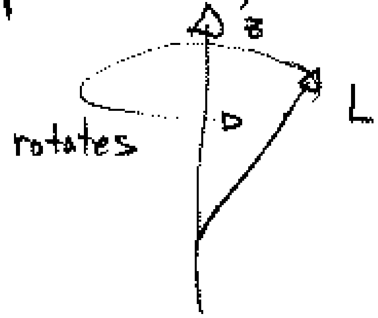
Consider an electron moving in an orbit



If we knew exactly where L pointed, we'd know $p_z = 0$ <u>and</u> $z = 0$ which can't be

$$\Delta z \Delta p_z \geq \frac{h}{4\pi}$$

so instead, we think about the L vector processing around the z axis



so that we satisfy the uncertainty principle

& the projections are quantized in units of $\left(\frac{h}{2\pi}\right)$ for an orbiting electron

now since L can rotate about $\pm z$ or $z=0$ (an x or y axis)

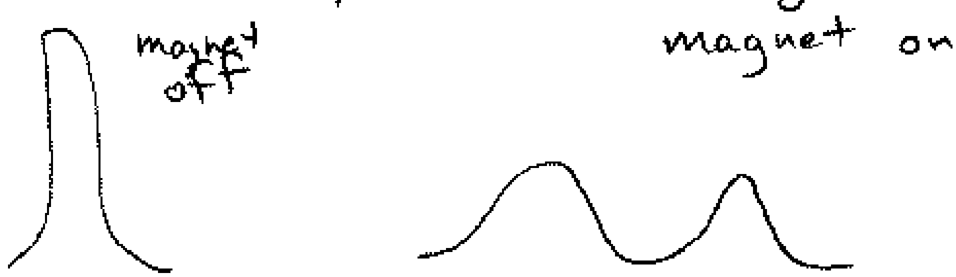
we say that the lowest L state actually has 3 possibilities

$$L_z = +\frac{h}{2\pi},\ 0,\ -\frac{h}{2\pi}$$

So, if we run a beam of atoms through a magnetic field, we can determine which L_z is present, if this is truly what's happening.

This was done, and the results were surprizing

① a split was seen, but it was too good



where is $L_z = 0$?

Since silver was used, it was suggested to try this with something simpler, Hydrogen.

They found the same pattern.

Turns out that the electron carrys an intrinsic angular momenta and it was screwing up all the nice theory.

$$S_z = \pm\frac{1}{2}\left(\frac{h}{2\pi}\right) \text{ for an electron } \underline{\text{only}}$$

& this has no $S_z = 0$ projection.

This is called spin

- really don't think there is a spinning electron
- but it __is__ angular momentum all the same.

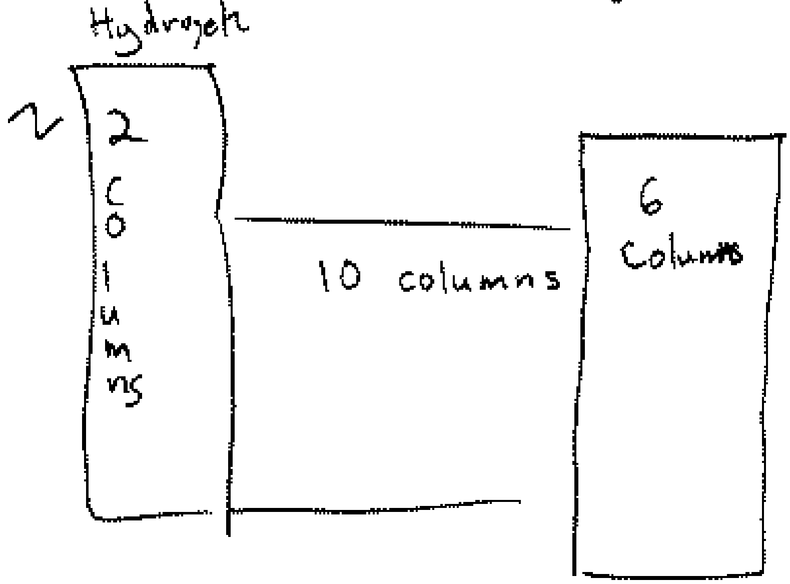
Now, it turns out that the most favorable transition are those where $\Delta L = 1$

- This implies the photon has spin 1!

When $\Delta L = 0$ you have to flip the spin of an electron to get a transition, & this is rarer.

- Still doesn't quite explain how the periodic table, ~~~~
- lets look at it a second

notice how its arranges



as we go through the periodic table

- element get heavier
- elements get more electrons
- elements are neutral (need more mass than proton)
- some elements have similar chemical properties

- we said lowest energy is a spherically symmetric fuzzy state H

- next higher energy state (for a single electron) is to get some angular momentum

- but we don't have a bunch of electrons piling up in one giant fuzzy state.

Pauli exclusion principle

- no 2 particles with $\frac{1}{2} \frac{h}{2\pi}$ spin can share the same state!

For 2 electrons
- so, lowest energy fuzzy state is $S_z = +\frac{1}{2}$, $S_z = -\frac{1}{2}$ $L = 0$ (2 states)

- when $L_z = \frac{h}{2\pi}, 0, -\frac{h}{2\pi}$

each one of these can hold 2 electrons (6 columns)

(He is where it is due to its chemical properties)

$$L_z = 2\frac{h}{2\pi}, \frac{h}{2\pi}, 0, -\frac{h}{2\pi}, -2\frac{h}{2\pi}$$

(10 columns)

or $L_z = m_\ell \frac{h}{2\pi}$ $m_\ell = -2, -1, 0, 1, 2$
$= -2\ell, \ell, 0, \ell, 2\ell$

and

$\ell = n - 1$

orbital quantum number (ℓ)

our old principle quantum number (n)

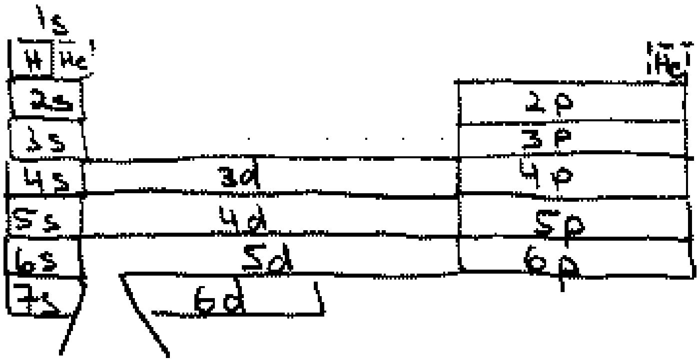
(electrons tend to fill the orbitals unpaired 1st) so, for $n=2$ energy state can have $\ell = 0$, $\ell = 1$ with $L_z = 1, 0, -1$

$n=3$ $\ell = 2$ $L_z = 2, 1, 0, -1, -2$, $\ell = 1$ $L_z = 1, 0, -1$, $\ell = 0$

So, how would we completely fill the $n=3$ shell.

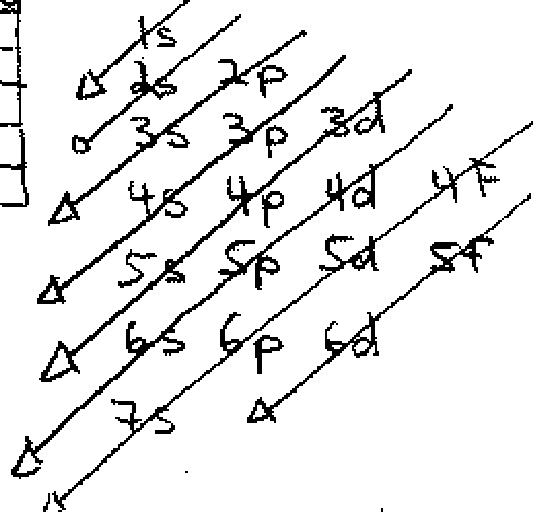
1) going to have to fill up the 4s (fuzzy) shell too

The layout of the periodic table will let you remember the order of filling



Funny stuff in here
start filling in f states

so filling order



s	p	d	f
$\ell=0$	$\ell=1$	$\ell=2$	$\ell=3$

ℓ is allowed as high as $(n-1)$

L_z goes $\pm\ell$ in integer steps

each L_z can have 2 electrons

So, to completely fill $n=3$, fill 1s, 2s, 2p, 3s, 3p, 4s, 3d

	ℓ	L_z	S_z
1s	0	0	$+\frac{1}{2}, -\frac{1}{2}$
2s	0	0	$+\frac{1}{2}, -\frac{1}{2}$
2p	1	-1	$+\frac{1}{2}, -\frac{1}{2}$
		0	$+\frac{1}{2}, -\frac{1}{2}$
		1	$+\frac{1}{2}, -\frac{1}{2}$
3s	0	0	$+\frac{1}{2}, -\frac{1}{2}$
3p	1	-1	$+\frac{1}{2}, -\frac{1}{2}$
		0	$+\frac{1}{2}, -\frac{1}{2}$
		1	$+\frac{1}{2}, -\frac{1}{2}$
4s	0	0	$+\frac{1}{2}, -\frac{1}{2}$

	ℓ	L_z	S_z
3d	2	-2	$+\frac{1}{2}, -\frac{1}{2}$
		-1	$+\frac{1}{2}, -\frac{1}{2}$
		0	$+\frac{1}{2}, -\frac{1}{2}$
		1	$+\frac{1}{2}, -\frac{1}{2}$
		2	$+\frac{1}{2}, -\frac{1}{2}$

A total of 30 electrons, this element is Zinc

How bout a partially fill 3d, how do we arrange the electrons?

Consider Iron, has $Z = 26$ (26 electrons)

has 1s, 2s, 2p, 3s, 3p, 4s filled & part of 3d filled, where do we put the e's?

↑ indicates spin direction

3d

$\boxed{\uparrow\downarrow}\ \boxed{\uparrow}\ \boxed{\uparrow}\ \boxed{\uparrow}\ \boxed{\uparrow}$

or

$\boxed{\uparrow\downarrow}\ \boxed{\downarrow}\ \boxed{\downarrow}\ \boxed{\downarrow}\ \boxed{\downarrow}$

book describes Hund's Rule (Fill electrons unpaired)

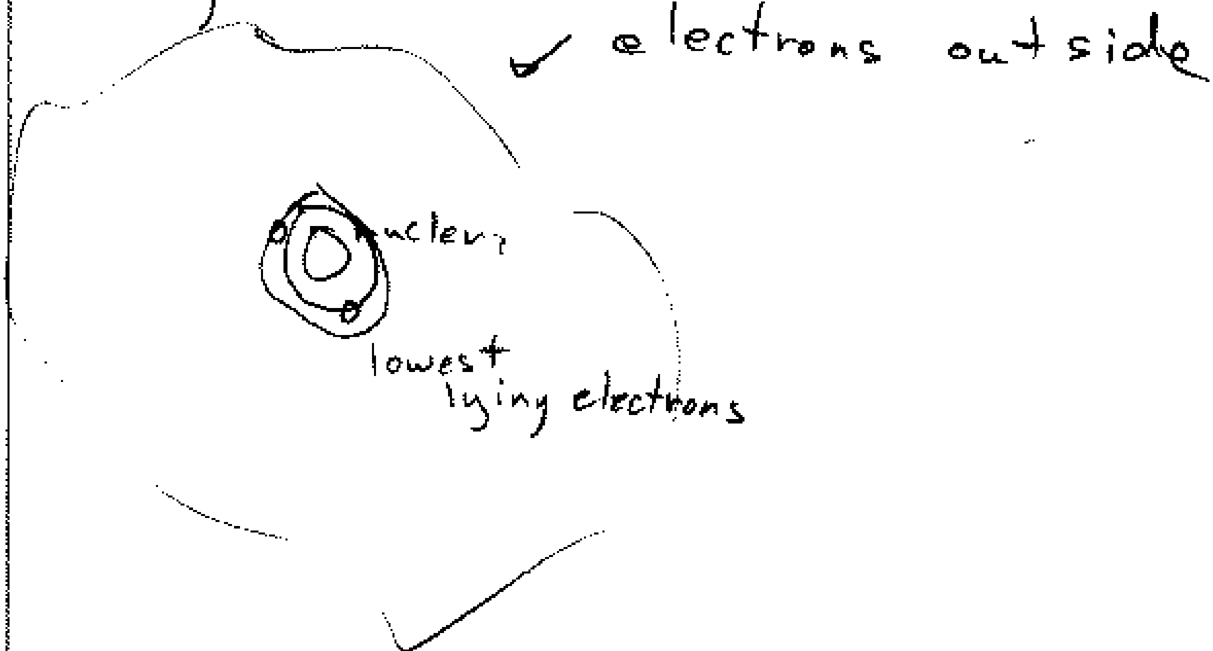
both ok

Book has this progressions

Z		1s	2s		3p	
3	Li	↑↓	↑			
4	Be	↑↓	↑↓			
5	B	↑↓	↑↓	↑		
6	C	↑↓	↑↓	↑	↑	
7	N	↑↓	↑↓	↑	↑	↑
8	O	↑↓	↑↓	↑↓	↑	↑
9	F	↑↓	↑↓	↑↓	↑↓	↑
10	Ne	↑↓	↑↓	↑↓	↑↓	↑↓

Hard to believe? consider more evidence.

Suppose we have an atom with many electrons



recall from gauss's Law, those inner electrons don't feel the effect of the outside electrons much so they're really attracted to the nucleas

recall for Hydrogen $E_{tot} = -\frac{k q_e q_p}{2r}$ $\frac{1}{r} = \frac{m_e (2\pi)^2}{n^2 h^2} k q_e q_p$

$E_{tot} \propto q_p^2$ wow

so that innermost electron is realy held in there since there's another electron there though, there will be some repulson so

$$E_0 \sim (\underbrace{\overset{\text{charge of nucleus}}{Z} - 1}_{Z\text{effective}})^2 \; -13.6\,eV$$

& you can use this principle to determine other Energy states

$$E_n = (\underset{n \text{ big more electrons inside}}{Z_{eff}})^2 \; \frac{-13.6\,eV}{n^2}$$

now, consider what happens if we

Knock out one of these inner electrons,

there is a hole that can be filled up

by an electron making a jump from a higher energy level to the lower one

$$E_{higher} = \Big(Z - \underset{\text{don't forget one that's gone already!}}{\left\{\begin{matrix}\#\text{ of electrons}\\ \text{in lower } n\text{'s}\end{matrix}\right\}}\Big)^2 \; \frac{-13.6\,eV}{n^2}$$

and you see $E_{photon} = E_{higher} - E_0$

These are characteristic of a material