Looks aren't everything...



(Let's take a spin).

Bohr correctly deduced the energies for the hydrogen atom, but he didn't know about the Schrödinger Eq. and he didn't know about wavefunctions. So his picture of the hydrogen atom was wrong...



Bohr and Einstein in Leiden, 1925.

http://upload.wikimedia.org/wikipedia/commons/thumb/d/d5/Niels_Bohr_Albert_Einstein_by_Ehrenfest.jpg/414px-Niels_Bohr_Albert_Einstein_by_Ehrenfest.jpg





$$E_n = -\frac{hcR}{n^2}$$
 n = 1, 2, 3... hcR = 13.60 eV

$$n,l,m_l,m_s$$

State vectors are labeled with the quantum number n... AND three more: l, m_l, m_s

$$|n,l,m_l,m_s\rangle$$

n is called the principal quantum number.

n = 1, 2, 3....

I is called the orbital angular momentum quantum number.

m_l is called the magnetic quantum number.

$$m_l = I, I-1, ... - I$$
 : a total of $2I + 1$

m_s is called the spin magnetic quantum number.

 $m_s = 1/2, -1/2$ - we'll deal with this one later.

The quantum states of a hydrogen atom:



...the wavefunctions for the hydrogen atom, $\psi(\mathbf{r}, \theta, \phi)$, are three-dimensional. We use spherical polar coordinates to express this wavefunction... A $\mathbf{0}$ $\Psi_{n,l,m_l}(\mathbf{r})$ V X

The three dimensional H atom wavefunction can be defined by the three quantum numbers n, l, and m_l :

$$\Psi_{n,l,m_l}(\mathbf{r}) = R_{n,l}(r)Y_{l,m_l}(\theta,\phi)$$

The three dimensional H atom wavefunction can be defined by the three quantum numbers n, l, and m_l :

$$\Psi_{n,l,m_l}(\mathbf{r}) = R_{n,l}(r) Y_{l,m_l}(\theta,\phi)$$

 $R_{n,l}(\mathbf{r})$ is the radial component of the wavefunction.

 $R_{n,l}$ depends on the two quantum numbers n and l.

The three dimensional H atom wavefunction can be defined by the three quantum numbers n, l, and m_l:

$$\Psi_{n,l,m_l}(\mathbf{r}) = R_{n,l}(r) Y_{l,m_l}(\theta,\phi)$$

 $Y_{I,mI}(\theta, \phi)$ is the angular component of the wavefunction.

 $Y_{I,mI}$ depends on the two quantum numbers I and m_I .

(a) R	adial way	vefunctions, $R_{nl}(r)$	(b) A	ngular wavefu	nctions, $Y_{lm_l}(\boldsymbol{\theta}, \boldsymbol{\phi})$
n	l	$R_{nl}(r)$	l	" <i>m</i> _l "*	$Y_{lm_l}(0, \mathbf{\phi})$
1	0	$2\left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0}$	0	0	$\left(rac{1}{4\pi} ight)^{1/2}$
2	0	$\frac{1}{2\sqrt{2}} \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) e^{-Zr/2a_0}$	1	x	$\left(\frac{3}{4\pi}\right)^{1/2}\sin\theta\cos\phi$
	1	$\frac{1}{2\sqrt{6}} \left(\frac{Z}{a_0}\right)^{3/2} \left(\frac{Zr}{a_0}\right) e^{-Zr/2a_0}$		У	$\left(\frac{3}{4\pi}\right)^{1/2}\sin\theta\sin\phi$
3	0	$\frac{1}{9\sqrt{3}} \left(\frac{Z}{a_0}\right)^{3/2} \left(3 - \frac{2Zr}{a_0} + \frac{2Z^2r^2}{9a_0^2}\right) e^{-Zr/3a_0}$		z	$\left(\frac{3}{4\pi}\right)^{1/2}\cos\theta$
	1	$\frac{2}{27\sqrt{6}} \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{3a_0}\right) e^{-Zr/3a_0}$	2	xy	$\left(rac{15}{16\pi} ight)^{1/2}\sin^2\theta\cos2\phi$
	2	$\frac{4}{81\sqrt{30}} \left(\frac{Z}{a_0}\right)^{3/2} \left(\frac{Zr}{a_0}\right)^2 e^{-Zr/3a_0}$		уz	$\left(rac{15}{4\pi} ight)^{1/2}\cos\theta\sin\theta\sin\phi$
				ZX	$\left(rac{15}{4\pi} ight)^{1/2}\cos\theta\sin\theta\cos\phi$
				$x^2 - y^2$	$\left(rac{15}{16\pi} ight)^{1/2}\sin^2\theta\sin2\phi$
				z^2	$\left(\frac{5}{16\pi}\right)^{1/2} (3\cos^2\theta - 1)$

Note: In each case, $a_0 = 4\pi\varepsilon_0^2/m_e^2$, or close to 52.9 pm; for hydrogen itself, Z = 1. *In all cases except $m_l = 0$, the orbitals are sums and differences of orbitals with specific values of m_l .

note: THREE quantum numbers here: n, l, m_l.

150 ...let's look at the first one: $n=1, l=0, m_l=0$. |s = |100> $\psi(r,\theta,\phi) = \left(\frac{1}{4\pi}\right)^{1/2} 2\left(\frac{Z}{a_0}\right)^{3/2} exp\left(\frac{-Zr}{a_0}\right)$ (c) (a) **(b)** three dimensional probability densities

...let's look at the first one: $n=1, l=0, m_l=0$. |s = ||00> $\psi(r,\theta,\phi) = \left(\frac{1}{4\pi}\right)^{1/2} 2\left(\frac{Z}{a_0}\right)^{3/2} exp\left(\frac{-Zr}{a_0}\right)$ (c) (a) (b) ...electron density does not depend on θ, ϕ . orbital is spherically symmetric. We call it an **"s-orbital"**.

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2s = |200>
$$\psi(r,\theta,\phi) = \left(\frac{1}{4\pi}\right)^{1/2} \left(\frac{1}{2\sqrt{2}}\right) \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) exp\left(\frac{-Zr}{2a_0}\right)$$

 $\psi(r,\theta,\phi) = \left(\frac{1}{4\pi}\right)^{1/2} \left(\frac{1}{2\sqrt{2}}\right) \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) exp\left(\frac{-Zr}{2a_0}\right)$
 $\psi(r,\theta,\phi) = \left(\frac{1}{4\pi}\right)^{1/2} \left(\frac{1}{2\sqrt{2}}\right) \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) exp\left(\frac{-Zr}{2a_0}\right)$
All of the s orbitals are spherically symmetric.



For I=I, we have three m_I values: -1, 0, 1



Note: In each case, $a_0 = 4\pi\varepsilon_0^2/m_e^2$, or close to 52.9 pm; for hydrogen itself, Z = 1. *In all cases except $m_l = 0$, the orbitals are sums and differences of orbitals with specific values of m_l .

we take linear combinations the m_1 wavefunctions -1, 0, 1 to get these p wavefunctions

p orbital probability density plots



For I=2, we have five m_1 values: -2, -1, 0, 1, 2



we take linear combinations of the m_1 wavefunctions -2, -1, 0, 1, 2 to get these d wavefunctions

d orbital probability density plots



we take linear combinations of the m_1 wavefunctions -2, -1, 0, 1, 2 to get these d wavefunctions

Looks aren't everything...



(Let's take a spin).

$$|n,l,m_l,m_s\rangle$$

n is called the principal quantum number.

n = 1, 2, 3....

I is called the orbital angular momentum quantum number.

m_l is called the magnetic quantum number.

$$m_l = I, I-1, ... - I : a total of 2I + 1$$

m_s is called the spin magnetic quantum number.

$$n,l,m_l,m_s$$

n is called the principal quantum number.

n = 1, 2, 3....

I is called the orbital angular momentum quantum number.

m_l is called the magnetic quantum number.

$$m_l = I, I-1, ... - I : a total of 2I + 1$$

m_s is called the spin magnetic quantum number.

 $m_s = 1/2$, -1/2 : a total of 2s + 1 implying that s = ?

$$n,l,m_l,m_s$$

n is called the principal quantum number.

n = 1, 2, 3....

I is called the orbital angular momentum quantum number.

m_l is called the magnetic quantum number.

$$m_l = I, I-1, ... - I : a total of 2I + 1$$

m_s is called the spin magnetic quantum number.

 $m_s = 1/2, -1/2$: a total of 2s + 1 implying that s = 1/2

Since s is always 1/2, we don't list it in Ψ .

m_l is called the magnetic quantum number.

m_s is called the spin magnetic quantum number.

What does magnetism have to do with atomic structure?



Pieter Zeeman 1865 - 1943

The Zeeman effect is the splitting of a spectral line into several components in the presence of a static magnetic field.

1902 Nobel Prize in Physics

In 1896, three years after submitting his thesis on the Kerr effect, he disobeyed the direct orders of his supervisor and used laboratory equipment to measure the splitting of spectral lines by a strong magnetic field. He was fired for his efforts, but revenge later on was sweet: he won the 1902 Nobel Prize in Physics for the discovery of the Zeeman effect.



Pieter Zeeman 1865 - 1943

The Zeeman effect is the splitting of a spectral line into several components in the presence of a static magnetic field.





Zeeman's original data on Na atoms

Pieter Zeeman 1865 - 1943

The Zeeman effect can only be explained by the existence of two magnetic dipoles:*

one from the orbital angular momentum of the electron in the atom

one from the intrinsic angular momentum of the electron



spin!!

*Zeeman and Lorentz actually blew the explanation. They got the Nobel Prize anyway.

The Zeeman effect can only be explained by the existence of two magnetic dipoles:

one from the orbital angular momentum of the electron in the atom

one from the intrinsic angular momentum of the electron

 $\vec{\mu}_L = \frac{g_L \mu_B}{\hbar} \vec{L}$ $\vec{\mu}_S = \frac{g_S \mu_B}{\hbar} \vec{S}$

 $\mu_B = \frac{e\hbar}{2m_e}$

Bohr magneton 9.274 x 10⁻²⁴ Joules/Tesla S is spin!!

The Zeeman effect can only be explained by the existence of two magnetic dipoles:

one from the orbital angular momentum of the electron in the atom

one from the intrinsic angular momentum of the electron

$$\vec{\mu}_L = \frac{g_L \mu_B}{\hbar} \vec{L}$$
$$\vec{\mu}_S = \frac{g_S \mu_B}{\hbar} \vec{S}$$

 \mathbf{n}

. . .

electron orbital g-factor $g_L = I$

electron spin g-factor $g_s = 2.002$

S is spin!!

An isolated electron will align itself with an external magnetic field just like a classical bar magnet. But the directions an electron can point are QUANTIZED; there are only two possible directions, "up" (with the field) or "down" (against the field). These two states are represented by the quantum number m_s:



L and S are both angular momentum vectors

The orbital angular momentum quantum number L can vary from 0 to n-1.

The magnetic quantum number m_L represents the different directions that the orbital magnetic dipole moment can take, and varies from -L to +L.



Example:

$$L = 2$$
 (d orbital)

 $m_L = -2, -1, 0, 1, 2$

L and S are both angular momentum vectors

The spin angular momentum quantum number S is ALWAYS 1/2. So we don't mention it in the H atom state.

The spin magnetic quantum number m_s represents the different directions that the spin magnetic dipole can take, and varies from -1/2 to +1/2.



- S = 1/2 (always)
- $m_s = -1/2, +1/2$

Even though the Zeeman effect shows the effects of electron spin, it was not understood correctly until 1925:

1922 - the Stern-Gerlach experiment on Ag atoms in magnetic fields.
 1925 - Sam Goudsmit and George Uhlenbeck propose that the electron has its own, intrinsic, angular momentum...called spin.



Otto Stern,

"After venting to release the vacuum, Gerlach removed the detector flange. But he could see no trace of the silver atom beam and handed the flange to me. With Gerlach looking over my shoulder as I peered closely at the plate, we were surprised to see gradually emerge the trace of the beam.... Finally we realized what [had happened]. I was then the equivalent of an assistant professor. My salary was too low to afford good cigars, so I smoked bad cigars. These had a lot of sulfur in them, so my breath on the plate turned the silver into silver sulfide, which is jet black, so easily visible. It was like developing a photographic film."

ARTICLES

Stern and Gerlach: How a Bad Cigar Helped Reorient Atomic Physics

Bretislav Friedrich and Dudley Herschbach

Physics Today, December 2003, page 53



Reenactment of the Stern-Gerlach cigar episode by Bretislav Friedrich and Dudley Herschbach. Friedrich holds the slide as Herschbach blows sulfurous cigar breath onto a silver-coated glass slide to test his hearing (or Otto Stern's telling) of the story more than 40 years ago. **The silver film turns out to require exposure to cigar smoke (not simply sulfurous breath)** to form any visible contrast between the masked (light) part of the slide--shaped in the form of the magnet pole pieces--and the outer (dark) part of the slide exposed to the smoke.

					,												
1A																	8A
1																	2
H Lal	24											3.4	4.4	5.4	6.4	7.4	He
- 13-	4	1										54	4/4	JA	0A e	/A	15-
Li	Be											B	ĉ	Ń	å	F	Ne
251	$2s^2$											$2s^22n^1$	252202	252203	252204	2.222.05	2,222,06
11	12											13	14	15	16	17	18
Na	Mg	0.000										Al	Si	P	S	CI	Ar
351	$3s^2$	3B	4B	5B	6B	7B		- 8B -		1 B	2B	$3s^23p^1$	$3s^23p^2$	$3s^23p^3$	$3s^23p^4$	3s23p5	$3s^23p^6$
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
451	452	3d ¹ 4s ²	3d ² 4s ²	3d ⁵ 4s ²	3d ⁵ 4s ¹	3d ⁵ 4s ²	$3d^{6}4s^{2}$	3d/4s2	$3d^{8}4s^{2}$	$3d^{10}4s^1$	$3d^{10}4s^2$	$4s^24p^1$	$4s^24p^2$	$4s^24p^3$	$4s^24p^4$	$4s^24p^5$	$4s^24p^6$
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
KD Sel	Sr 5-2	115.2	Lr 120.2	ND 1.4c 1	M0	10	KU Ac 1	Kn	Pa	Ag	Cd	In = 2e 1	Sn 2 2 2	Sb - 2- 3	Te	1	Xe
55	56	4d*58= 57	44-55-	44'55'	40.55	44-55-	40'55"	40.55	4410	4010551	441055=	5s-5p1	5s*5p*	5s25p3	5s25p7	5s25p3	5s25p6
Cs	Ba	*La	Hr	Ta	W	Re	05	Ir	78 Pt	/9 Au	80 Hg	81 TI	82 Ph	83 Ri	84 Po	85	86 Bn
6s ¹	6s ²	$5d^{1}6s^{2}$	$5d^{2}6s^{2}$	$5d^{3}6s^{2}$	$5d^46s^2$	$5d^{5}6s^{2}$	$5d^{6}6s^{2}$	5d76s2	5d96s1	5d106s1	5d106s2	$6s^26p^1$	$6s^26p^2$	6s26p3	$6s^{2}6p^{4}$	6s ² 6p ⁵	6s26p6
87	88	89	104	105	106	107	108	109	110	111	112		114		^{††} 116		^{††} 118
Fr	Ra	†Ac	Rf	Db	Sg	Bh	Hs	Mt				Unknown		Unknown	110	Unknown	110
$7s^{1}$	$7s^2$	$6d^{1}7s^{2}$	$6d^27s^2$	$6d^{3}7s^{2}$	$6d^47s^2$												
				58	50	60	61	62	63	64	65	66	67	69	60	70	71

...but wait a second, why **silver** atoms?

	28	59	60	01	62	0.5	64	65	00	6/	68	69	70	71
	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	$4f^26s^2$	$4f^{3}6s^{2}$	$4f^46s^2$	$4f^{5}6s^{2}$	$4f^{6}6s^{2}$	$4f^{7}6s^{2}$	$4f^{7}5d^{1}6s^{2}$	$4f^{9}6s^{2}$	$4f^{10}6s^2$	$4f^{11}6s^2$	$4f^{12}6s^2$	$4f^{13}6s^2$	$4f^{14}6s^2$	$4f^{14}5d^{1}6s^{2}$
1	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
	$6d^27s^2$	$5f^26d^17s^2$	$5f^{3}6d^{1}7s^{2}$	$5f^46d^17s^2$	$5f^{6}7s^{2}$	$5f^{7}7s^{2}$	$5f^{7}6d^{1}7s^{2}$	$5f^{9}7s^{2}$	$5f^{10}7s^2$	$5f^{11}7s^2$	$5f^{12}7s^2$	$5f^{13}7s^2$	$5f^{14}7s^2$	$5f^{14}6d^{1}7s^{2}$

http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib

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but	it wait a second, why silver atoms?													I			
1A 1 H 1s ¹	2A		V	Ve'll	dea	al w	ith t	:his	in a	bit.		3A	4A	5A	6A	7A	8A 2 He 1s ²
3 Li 2s ¹	4 Be 2s ²											$5 \\ B \\ 2s^2 2p^1$		7 N $2s^22p^3$		$9 \\ F \\ 2s^2 2n^5$	10 Ne 2s ² 2p
11 Na 3s ¹	12 Mg 3s ²	3B	4B	5B	6B	7B		— 8B —		1B	2B	13 Al 3s ² 3p ¹	14 Si 3s ² 3p ²	$15 P = 3s^2 3p^3$	16 S $3s^23p^4$	17 Cl 3s ² 3p ⁵	18 Ar 3s ² 3p
19 K 4s ¹	20 Ca 4s ²	21 Sc 3d ¹ 4s ²	22 Ti 3d ² 4s ²	23 V 3d ³ 4s ²	24 Cr 3d ⁵ 4s ¹	25 Mn 3d ⁵ 4s ²	26 Fe 3d ⁶ 4s ²	27 Co 3d ⁷ 4s ²	28 Ni 3d ⁸ 4s ²	29 Cu 3d ¹⁰ 4s ¹	30 Zn 3d ¹⁰ 4s ²	31 Ga $4s^24p^1$	32 Ge $4s^24p^2$	33 As $4s^24p^3$	34 Se 4s ² 4p ⁴	35 Br $4s^24p^5$	36 Kr 4s ² 4n
37 Rb 5s ¹	38 Sr 5s ²	39 Y 4d ¹ 5s ²	$40 \\ Zr \\ 4d^{2}5s^{2}$	41 Nb 4d ⁴ 5s ¹	42 Mo 4d ⁵ 5s ¹	43 Tc 4d ⁵ 5s ²	44 Ru 4d ⁷ 5s ¹	45 Rh 4d ⁸ 5s ¹	46 Pd 4d ¹⁰	47 Ag 4d ¹⁰ 5s1	48 Cd 4d ¹⁰ 5s ²	49 In 5s ² 5p ¹	50 Sn $5s^{2}5p^{2}$	51 Sb 5s ² 5p ³	52 Te 5s ² 5p ⁴	53 I 5s ² 5p ⁵	54 Xe 5s ² 5p
55 Cs 6s ¹	56 Ba 6s ²	57 *La 5d ¹ 6s ²	$72 \\ Hf \\ 5d^26s^2$	73 Ta 5d ³ 6s ²	74 W 5d ⁴ 6s ²	75 Re 5d ⁵ 6s ²	76 Os 5d ⁶ 6s ²	77 Ir 5d ⁷ 6s ²	78 Pt 5d ⁹ 6s ¹	79 Au 5d ¹⁰ 6s ¹	80 Hg 5d ¹⁰ 6s ²	81 TI 6s ² 6p ¹	82 Pb 6s ² 6p ²	83 Bi 6s ² 6p ³	84 Po 6s ² 6p ⁴	85 At 6s ² 6p ⁵	86 Rn 6s ² 6p
87 Fr 7s ¹	88 Ra 7 <i>s</i> ²	89 †Ac 6d ¹ 7s ²	104 Rf 6d ² 7s ²	105 Db $6d^{3}7s^{2}$	106 Sg 6d ⁴ 7s ²	107 Bh	108 Hs	109 Mt	110	111	112	Unknown	114	Unknown	**116	Unknown	^{††} 118

"	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	$4f^26s^2$	$4f^{3}6s^{2}$	$4f^46s^2$	$4f^{5}6s^{2}$	$4f^{6}6s^{2}$	$4f^{7}6s^{2}$	$4f^{7}5d^{1}6s^{2}$	$4f^{9}6s^{2}$	$4f^{10}6s^2$	$4f^{11}6s^2$	$4f^{12}6s^2$	$4f^{13}6s^2$	$4f^{14}6s^2$	$4f^{14}5d^{1}6s^{2}$
î	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
	$6d^27s^2$	$5f^26d^17s^2$	$5f^{3}6d^{1}7s^{2}$	$5f^46d^17s^2$	$5f^{6}7s^{2}$	$5f^{7}7s^{2}$	$5f^{7}6d^{1}7s^{2}$	$5f^{9}7s^{2}$	$5f^{10}7s^2$	$5f^{11}7s^2$	$5f^{12}7s^2$	$5f^{13}7s^2$	$5f^{14}7s^2$	$5f^{14}6d^{1}7s^{2}$

...Answer: Ag is 4d¹⁰ 5s¹

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Samuel Goudsmit, in 1971...

What the historians forget - and also the physicists - is that in the discoveries in physics chance, luck plays a very, very great role. Of course, we do not always recognize this. If someone is rich then he says "Yes, I have been clever, that is why I am rich"! And the same is being said of some one who does something in physics "yes, a really clever guy.....". Admittedly, there are cases like Heisenberg, Dirac and Einstein, there are some exceptions. But for most of us luck plays a very important role and that should not be forgotten.

I think you and Uhlenbeck have been very lucky to get your spinning electron published and talked about before Pauli heard of it. It appears that more than a year ago Kronig believed in the spinning election and worked out something; the first person he showed it to was Pauli. Pauli indiculed the whole thing so much that the first person become also the last and no one else heard anything of it. Which all goes to show that the infallibrity of the Derty does not extend to his self-styled view mearth.

Part of a letter by L.H.Thomas to Goudsmit (25 March 1926). Reproduced from a transparency shown by Goudsmit during his 1971 lecture. The original is presumably in the <u>Goudsmit</u> <u>archive</u> kept by the AIP Center for History of Physics.



A memorial plaque honoring Otto Stern and Walther Gerlach, mounted in February 2002 near the entrance to the building in Frankfurt, Germany, where their experiment took place. The inscription, in translation, reads: "In February 1922 ... was made the fundamental discovery of space quantization of the magnetic moments of atoms. The Stern-Gerlach experiment is the basis of important scientific and technological developments in the 20th century, such as nuclear magnetic resonance, atomic clocks, or lasers...."

So who was more lucky: Sam Goudsmit and George Uhlenbeck, or Otto Stern and Walther Gerlach?

By the way...

Otto Stern was awarded the 1943 Nobel Prize in Physics, the first to be awarded since 1939. He was the sole recipient in Physics that year, and the award citation omitted mention of the Stern-Gerlach experiment, as Gerlach had remained active in Nazi-led Germany.



Otto Stern 1888- 1969

$$|n,l,m_l,m_s\rangle$$

n is called the principal quantum number.

n = 1, 2, 3....

I is called the orbital angular momentum quantum number.

m_l is called the magnetic quantum number.

$$m_l = I, I-1, ... - I$$
 : a total of $2I + 1$; $I = 0$ to $n-1$

m_s is called the spin magnetic quantum number.

$$m_s = 1/2, -1/2$$
 : a total of $2s + 1$; $s = 1/2$

Looks aren't everything...



Okay, now we're ready to explain the Periodic Table.

- multi-electron atoms
- Atomic Spectroscopy

(Let's take a spin).