

Physics 123 – April 22, 2013

Time Independent Schrödinger equation (1d, nonrelativistic)

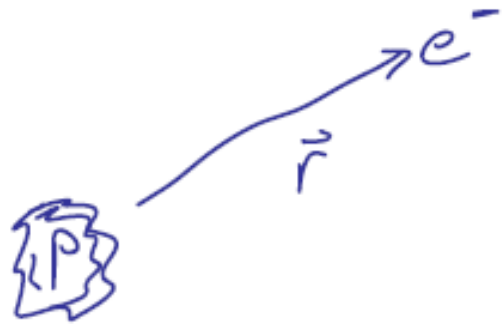
$$-\frac{\hbar^2}{2m} \frac{\partial^2 \Psi(x)}{\partial x^2} + V(x) \Psi(x) = E \Psi(x)$$

$|\Psi(x)|^2 dx \equiv$  probability of finding particle in  $dx$

$$\int_{\text{all space}} |\Psi(x)|^2 dx = 1 \quad \text{Particle is } \underline{\text{Someplace}}$$

Sub in for  $V$ , Solve for  $\Psi$  and  $E$

H atom



$$V(r) = \frac{1}{4\pi\epsilon_0} \frac{|e|^2}{r^2}$$

Schr. eqn in 3d

$$-\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi = E\psi$$

plug in  $v$  and solve

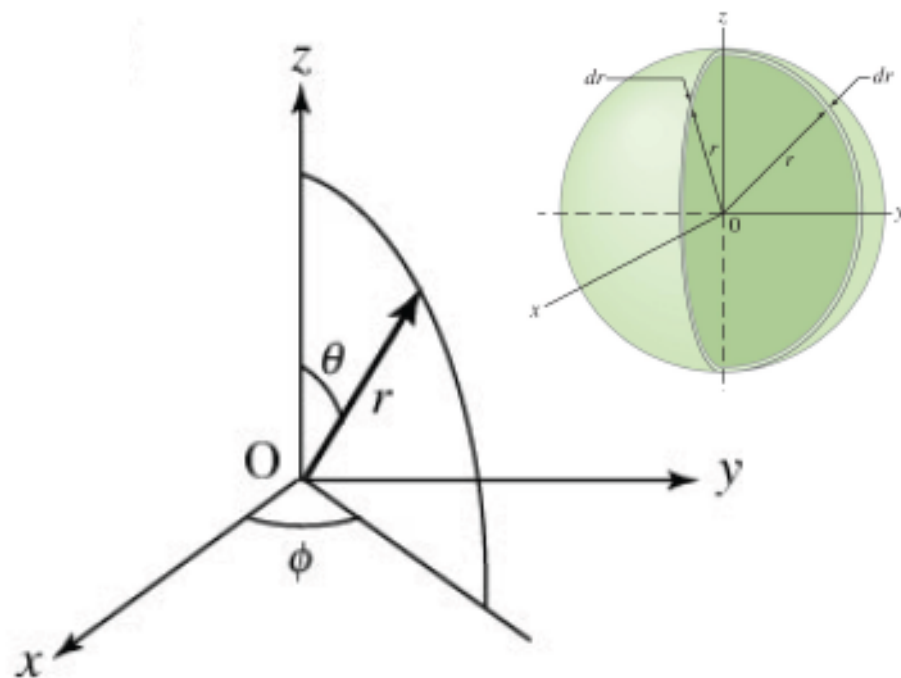
need to use spherical polar coordinates

# Spherical Coordinates

$$x = r \sin \theta \cos \varphi$$

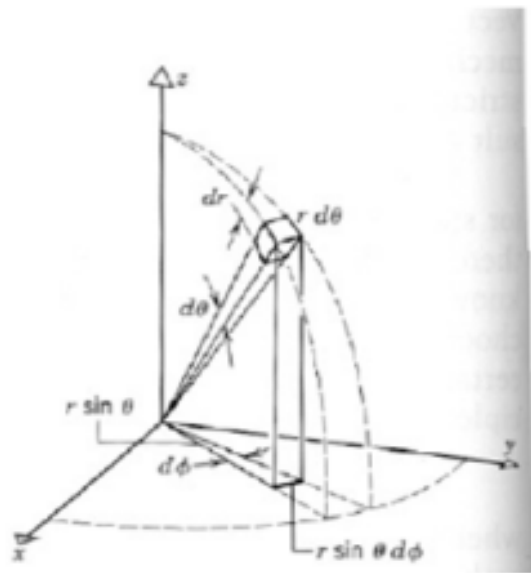
$$y = r \sin \theta \sin \varphi$$

$$z = r \cos \theta$$



$$\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2} =$$

$$= \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial f}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial f}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 f}{\partial \varphi^2}$$



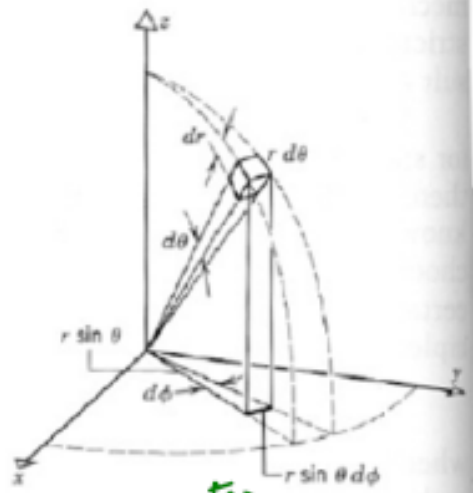
$$\psi \rightarrow \psi(r, \theta, \phi)$$

$$V(r) = -\frac{1}{4\pi\epsilon_0} \frac{e|e|^2}{r^2}$$

$$-\frac{\hbar^2}{2m} \left[ \frac{1}{r^2} \frac{\partial}{\partial r} r^2 \frac{\partial \psi}{\partial r} + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \psi}{\partial \phi^2} + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \sin \theta \frac{\partial \psi}{\partial \theta} \right] - \frac{1}{4\pi\epsilon_0} \frac{e|e|^2}{r^2} \psi = E \psi$$

Now solve





Can be solved exactly ...

$$\Psi(r, \theta, \phi) \rightarrow \Psi(R) \Psi(\Theta) \Psi(\Phi)$$

Can separate Schr. equation into eqns for  $\Psi(R)$ ,  $\Psi(\Theta)$ ,  $\Psi(\Phi)$  + Solve

"Energy" or "principle" quantum #  $n = 1, 2, 3, \dots$

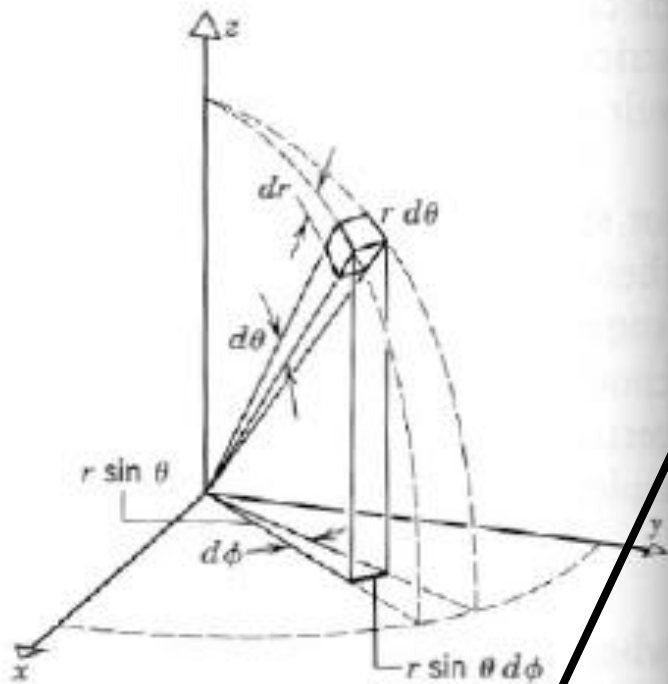
"orbital" quantum #  $l = 0, 1, \dots, n-1$

"Magnetic" quantum #  $-l, -(l-1), \dots, 0, \dots, l-1, l$

Table 7.1 Some Hydrogen Atom Wave Functions

$n$	$l$	$m_l$	$R(r)$	$\Theta(\theta)$	$\Phi(\phi)$
1	0	0	$\frac{2}{a_0^{3/2}} e^{-r/a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	0	0	$\frac{1}{(2a_0)^{3/2}} \left(2 - \frac{r}{a_0}\right) e^{-r/2a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	1	0	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\sqrt{\frac{3}{2}} \cos \theta$	$\frac{1}{\sqrt{2\pi}}$
2	1	$\pm 1$	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\frac{\sqrt{3}}{2} \sin \theta$	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$

Bound system  
 $\rightarrow$  Discrete states  
 $R, \Phi, \Theta$  parts tied together  
 $n \sim$  Similar to Bohr's  $n$



Energy or principal quantum number  
 $n = 1, 2, 3 \dots$

Orbital quantum number  
 $l = 0, 1, \dots n-1$

Magnetic quantum number  
 $-l, -|l-1|, \dots, 0, 1, \dots l-1, l$

Table 7.1 Some Hydrogen Atom Wave Functions

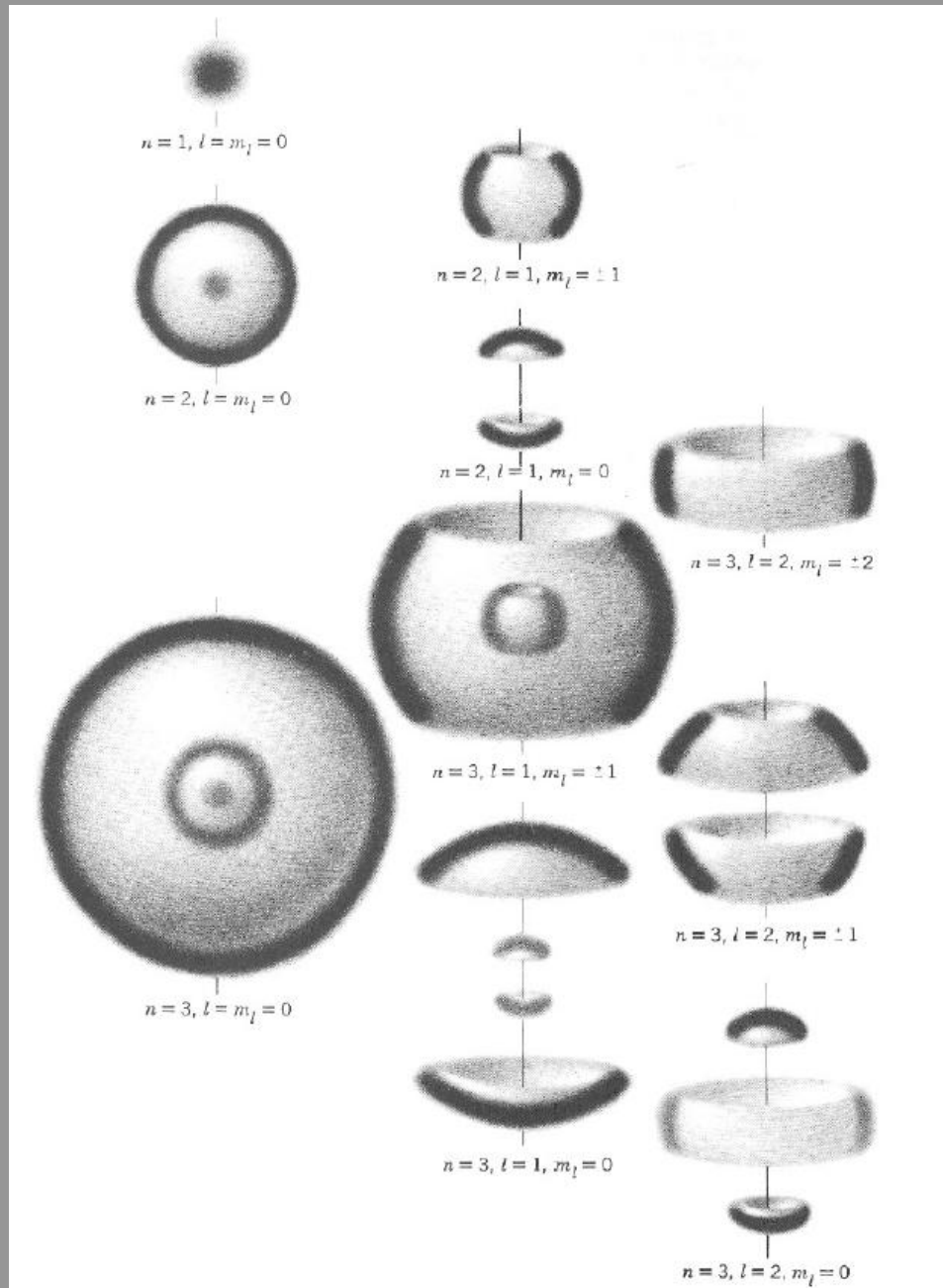
$n$	$l$	$m_l$	$R(r)$	$\Theta(\theta)$	$\Phi(\phi)$
1	0	0	$\frac{2}{a_0^{3/2}} e^{-r/a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	0	0	$\frac{1}{(2a_0)^{3/2}} \left(2 - \frac{r}{a_0}\right) e^{-r/2a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	1	0	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\sqrt{\frac{3}{2}} \cos \theta$	$\frac{1}{\sqrt{2\pi}}$
2	1	$\pm 1$	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\frac{\sqrt{3}}{2} \sin \theta$	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$

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

$n = 1$	$l = 0$	$m_l = 0$	$\Psi_{100} = \frac{2}{\sqrt{r_0^3}} e^{-r/r_0} \sqrt{\frac{1}{4\pi}}$
$n = 2$	$l = 0$	$m_l = 0$	$\Psi_{200} = \frac{1}{\sqrt{2r_0^3}} \left(1 - \frac{r}{2r_0}\right) e^{-r/2r_0} \sqrt{\frac{1}{4\pi}}$
$n = 2$	$l = 1$	$m_l = +1$	$\Psi_{211} = \frac{1}{2\sqrt{6r_0^3}} \left(\frac{r}{r_0}\right) e^{-r/2r_0} \sqrt{\frac{3}{8\pi}} \sin\theta e^{i\phi}$
$n = 2$	$l = 1$	$m_l = 0$	$\Psi_{210} = \frac{1}{2\sqrt{6r_0^3}} \left(\frac{r}{r_0}\right) e^{-r/2r_0} \sqrt{\frac{3}{4\pi}} \cos\theta$
$n = 2$	$l = 1$	$m_l = -1$	$\Psi_{21-1} = \frac{1}{2\sqrt{6r_0^3}} \left(\frac{r}{r_0}\right) e^{-r/2r_0} \sqrt{\frac{3}{8\pi}} \sin\theta e^{-i\phi}$

Probability distributions for several allowed atomic states for the 1-electron atom

Increasing  $n$  adds new radial layers,  $l=0$  give spherical symmetry,  $l$  not 0 brings in angular dependence





only discrete energies and spatial states allowed for the electron to occupy  $\rightarrow$  orbital

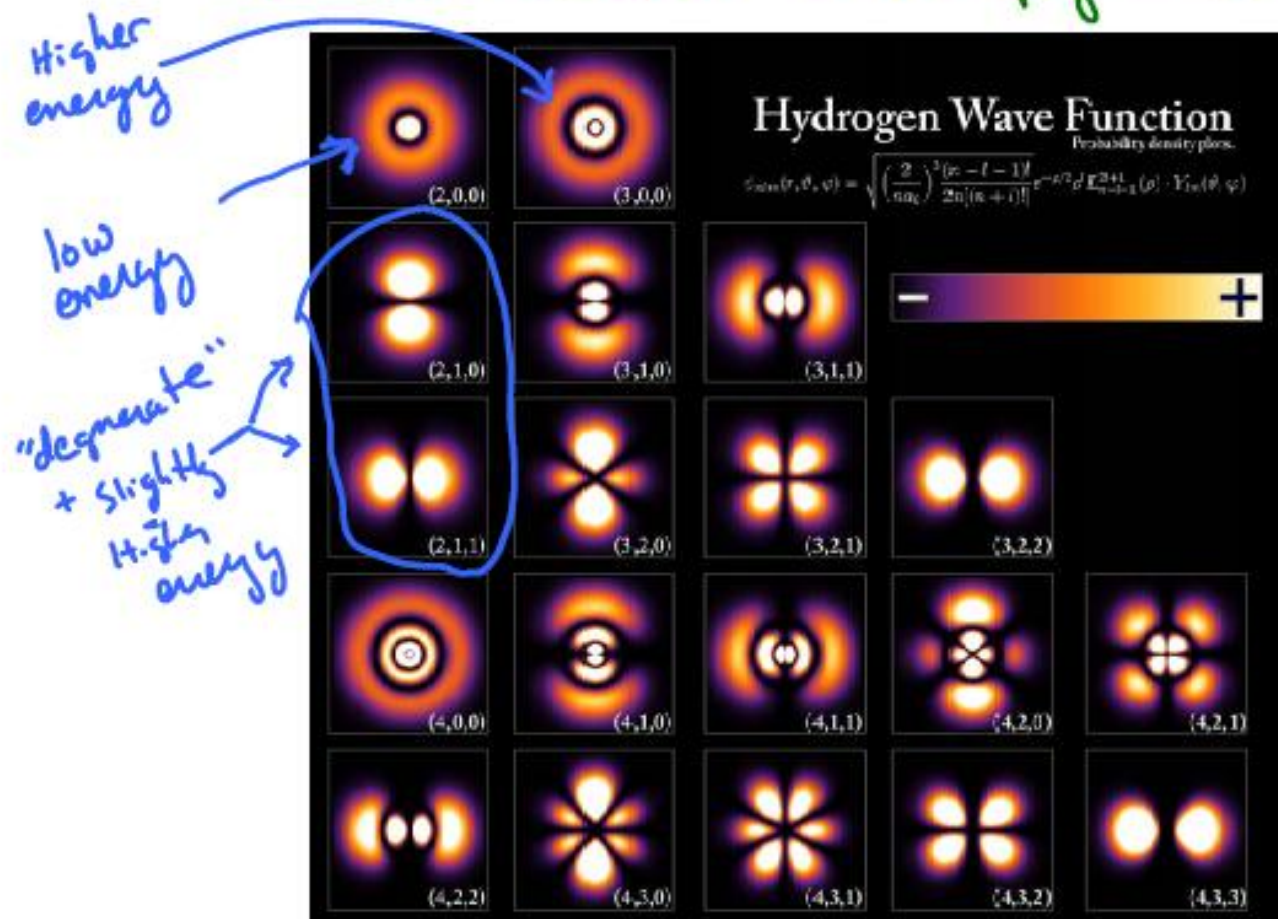
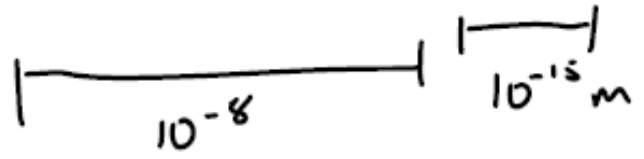
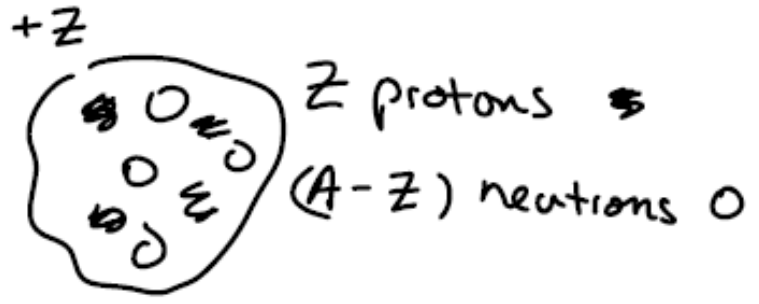
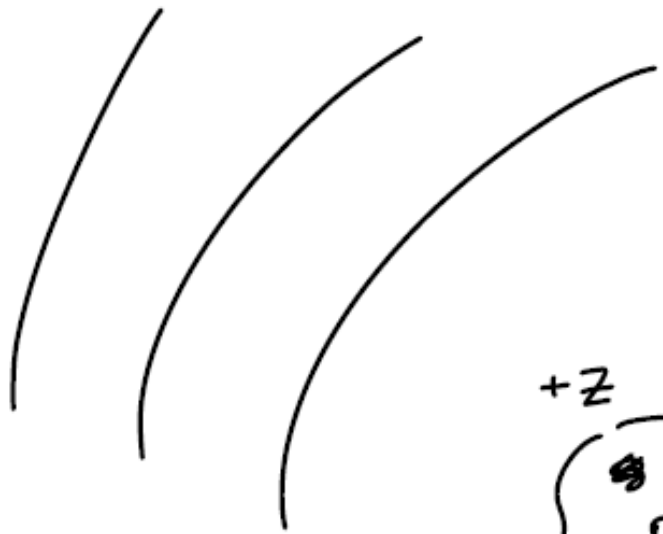
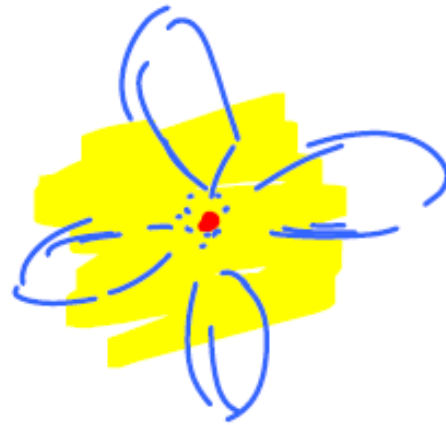


figure from [http://en.wikipedia.org/wiki/File:Hydrogen\\_Density\\_Plots.png](http://en.wikipedia.org/wiki/File:Hydrogen_Density_Plots.png)

Hydrogen  $Z=1$   
Helium  $Z=2$   
Lithium  $Z=3$   
 $\vdots$   
 $Z=120$



Basic Structure of atom



as  $Z$  increases  $\rightarrow$  # electrons increase  
 $\uparrow$   
# protons in nucleus

How do these electrons populate the available orbitals?

To answer this we need to investigate

Particle Promiscuity

# Stern-Gerlach experiment - 1922

→ Discovery that electrons have Spin

# Spin

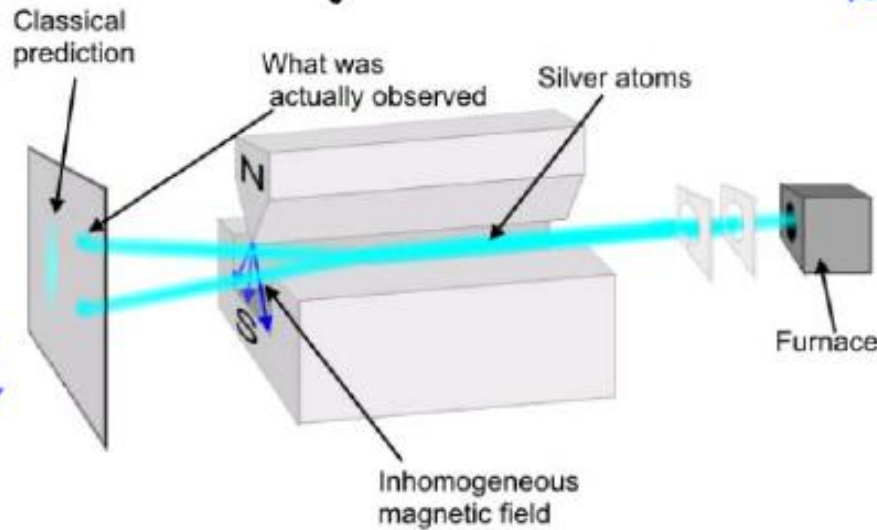


Diagram from  
Wikipedia

Otto Stern



-Wikipedia

"If this nonsense from Bohr will prove to be right we will quit physics."

(Stern vowed in 1913)

as quoted in Phys. Today Dec 03

Walther Gerlach



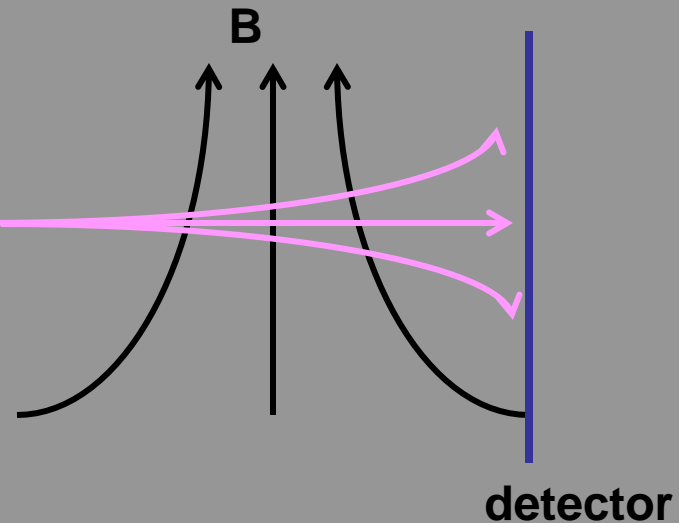
from phys Today article  
(Dec. 03)

# General Quant. Mech. result regarding force on magnetic dipole in a non-uniform magnetic field

$$\vec{F}_z = \frac{\partial B_z}{\partial z} |\vec{\mu}_z| = \frac{\partial B_z}{\partial z} m$$

## Stern-Gerlach experiment

e- beam in  $l=1$  state  
has  $m=1,0,-1$  components  
expect to see this



# General Quant. Mech. result regarding force on magnetic dipole in a non-uniform magnetic field

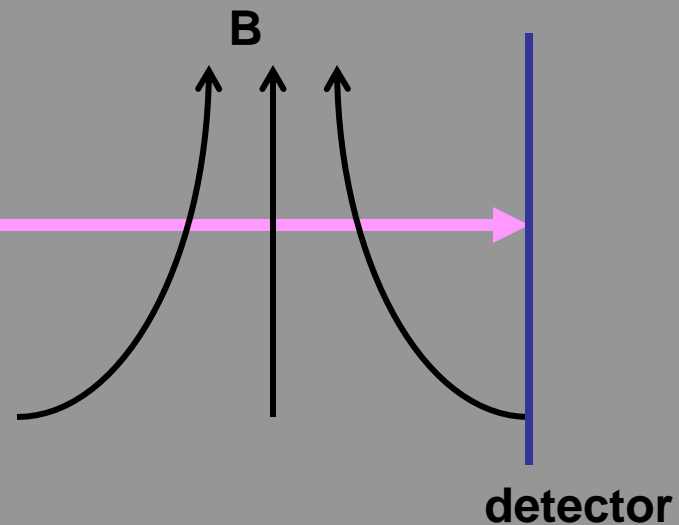
$$\vec{F}_z = \frac{\partial B_z}{\partial z} |\vec{\mu}_z| = \frac{\partial B_z}{\partial z} m$$

## Stern-Gerlach experiment

e- beam in  $l=0$  state

Has  $m=0$  component only

expect to see this



**SURPRISE! ... fundamental particles have an intrinsic magnetic moment. Call it spin.**

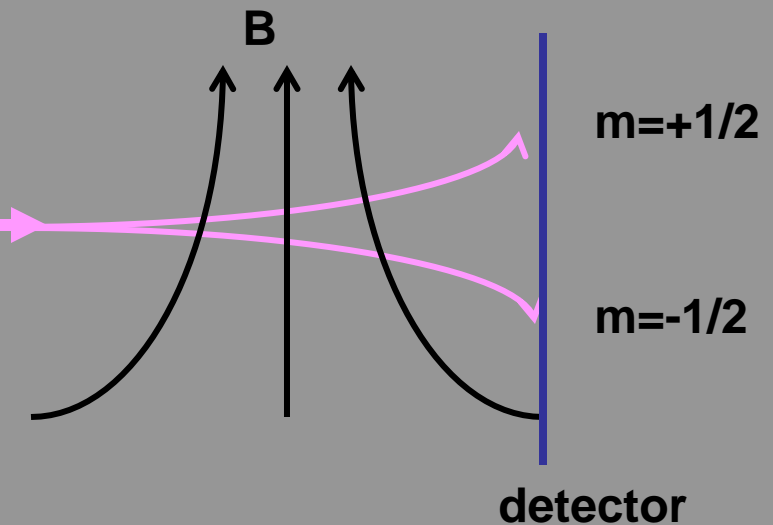
$$\vec{F}_z = \frac{\partial B_z}{\partial z} |\vec{\mu}_z| = \frac{\partial B_z}{\partial z} m$$

### Stern-Gerlach experiment

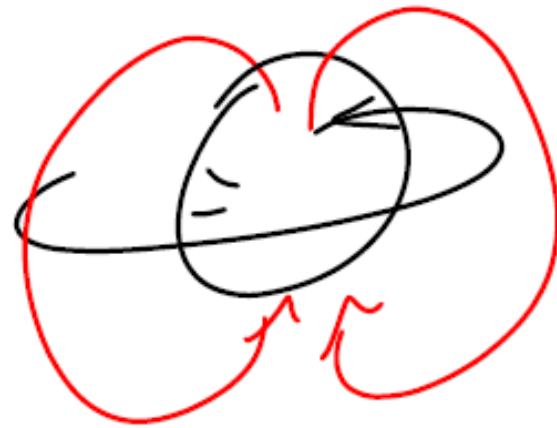
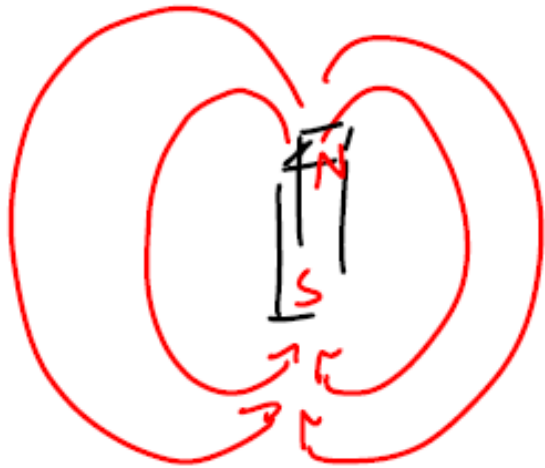
e- beam in  $l=0$  state

Has  $m=0$  component only

Actually see this



Particles have intrinsic Spin



Spin is quantized

$0, \frac{1}{2}, 1, \frac{3}{2}, 2, \frac{5}{2}$



# Intrinsic spin - two varieties

Huge effect on  
multi-electron  
atoms

Fermions = half integral spin, such as  $1/2, 3/2, 5/2, \dots, 73/2 \dots$   
protons, neutrons, electrons are all fermions ( $s=1/2$ )  
no two fermions can occupy the same exact quantum state

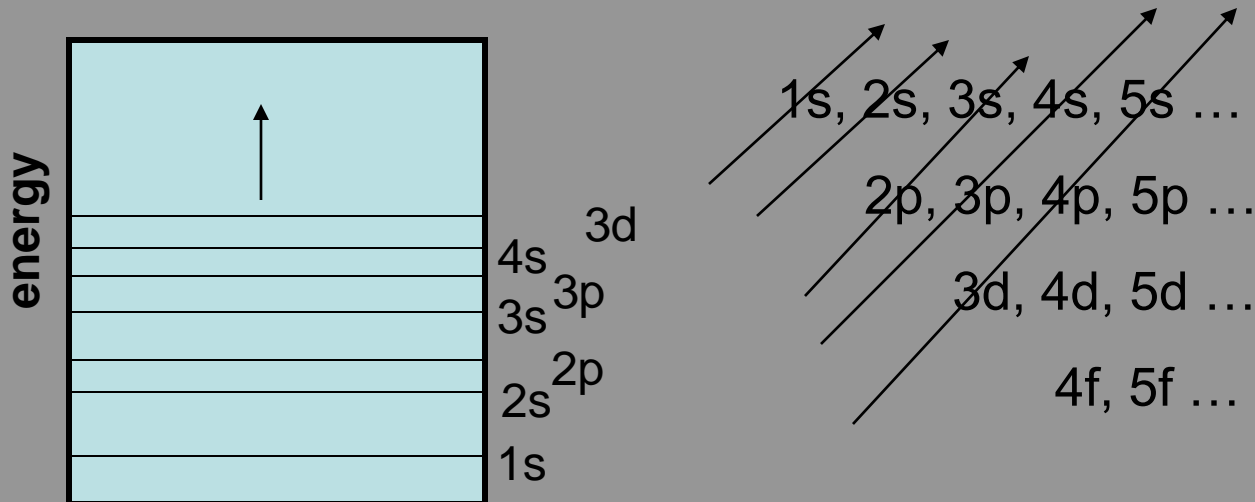
Bosons = integral spin, such as  $0, 1, 2 \dots$   
photons ( $s=1$ ) and pions ( $s=0$ ) are examples of bosons  
bosons can occupy the same exact quantum state

# Rules for Filling of state for multi-electron atom

## $n, l, m_l, m_s$

Spectroscopic notation - s:  $l=0$ , p:  $l=1$ , d:  $l=2$ , f:  $l=3$ , ...

- No two electrons in same state (Pauli exclusion)
- Electrons go into the state with the lowest possible energy (Aufbau)
- Within a sublevel, electrons will have their spin unpaired as much as possible (due to spin-spin interaction contribution to energy)



**TABLE 39–1 Quantum Numbers for an Electron**

Name	Symbol	Possible Values
Principal	$n$	1, 2, 3, $\dots$ , $\infty$ .
Orbital	$\ell$	For a given $n$ : $\ell$ can be 0, 1, 2, $\dots$ , $n - 1$ .
Magnetic	$m_\ell$	For given $n$ and $\ell$ : $m_\ell$ can be $\ell$ , $\ell - 1$ , $\dots$ , 0, $\dots$ , $-\ell$ .
Spin	$m_s$	For each set of $n$ , $\ell$ , and $m_\ell$ : $m_s$ can be $+\frac{1}{2}$ or $-\frac{1}{2}$ .





P.A.M. Dirac - on the development of quantum mechanics

"The underlying laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known."

Very reactive in this column

Very inert in this column

Los Alamos National Laboratory Chemistry Division

Periodic Table of the Elements

1A 1 H Hydrogen 1.008	2A 4 Be Beryllium 9.012											3A 5 B Boron 10.81	4A 6 C Carbon 12.01	5A 7 N Nitrogen 14.01	6A 8 O Oxygen 16.00	7A 9 F Fluorine 18.99	8A 2 He Helium 4.003																		
3 Li Lithium 6.941	11 Na Sodium 22.99	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80																
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3	55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La* Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 208.9	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon 222.0
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac- Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (271)	111 Uuh Ununennium (272)	112 Uub Unbibium (277)	114 Uuq Ununquadium (289)	116 Uuh Ununhexium (289)	118 Uuo Ununoctium (?)																					
Lanthanide Series* 58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (147)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 174.9																						
Actinide Series- 90 Th Thorium 232.0	91 Pa Protactinium (231)	92 U Uranium (238)	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)																						

Very reactive in this column



element names in blue are liquids at room temperature  
element names in red are gases at room temperature  
element names in black are solids at room temperature

I A												II A												III A	IV A	V A	VI A	VII A	VIII	IX	X	XI	XII	O																																																						
1 H 1.0079	2 He 4.00260	3 Li 6.94	4 Be 9.01218	5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179	11 Na 22.98977	12 Mg 24.305	13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.066	17 Cl 35.453	18 Ar 39.948	19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 55.9381	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc 98.9072	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.75	52 Te 127.60	53 I 126.9047	54 Xe 131.30	55 Cs 132.9054	56 Ba 137.33	57 La 138.905	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.965	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9303	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)	87 Fr (223)	88 Ra (226, 226.0254)	89 Ac (227)

58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.965	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9303	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
80 Th 232.0381	81 Pa (231.036)	82 U 238.029	83 Np 237.0482	84 Pu (244.069)	85 Am (243.06)	86 Cm (247.07)	87 Bk (247.07)	88 Cf (251.08)	89 Es (262.083)	90 Fm (267.096)	91 Md (268.10)	92 No (269.101)	93 Lr (260.11)

Energy level

sublevel (l)

$Z = +e^-$

		K shell			L shell			M shell			4F	5F
		1	2	3	4	5	6	7	8	9	10	11
		s	s	p	s	p	d	d	d	f	f	f
				$m_l = -1 \quad m_l = 0 \quad m_l = 1$								
1	H	1										1s <sup>1</sup>
2	He	1k										1s <sup>2</sup>
3	Li	1k	1									1s <sup>2</sup> 2s <sup>1</sup>
4	Be	1k	1k									1s <sup>2</sup> 2s <sup>2</sup>
5	B	1k	1k	1								1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>1</sup>
6	C	1k	1k	1	1							
7	N	1k	1k	1	1	1						
8	O	1k	1k	1k	1	1						1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>4</sup>
9	F	1k	1k	1k	1k	1						
10	Ne	1k	1k	1k	1k	1k						
11	Na	1k	1k	1k	1k	1k	1					1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>1</sup>

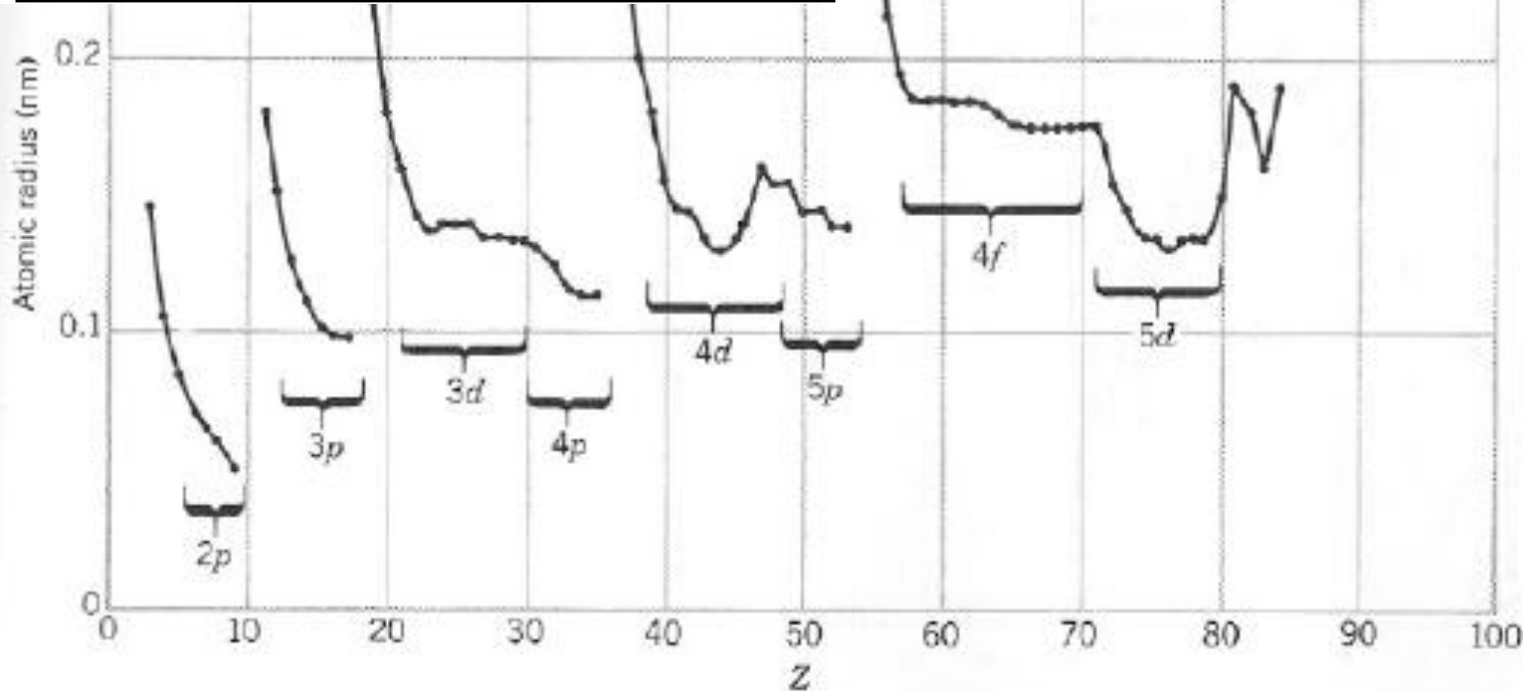
Check out

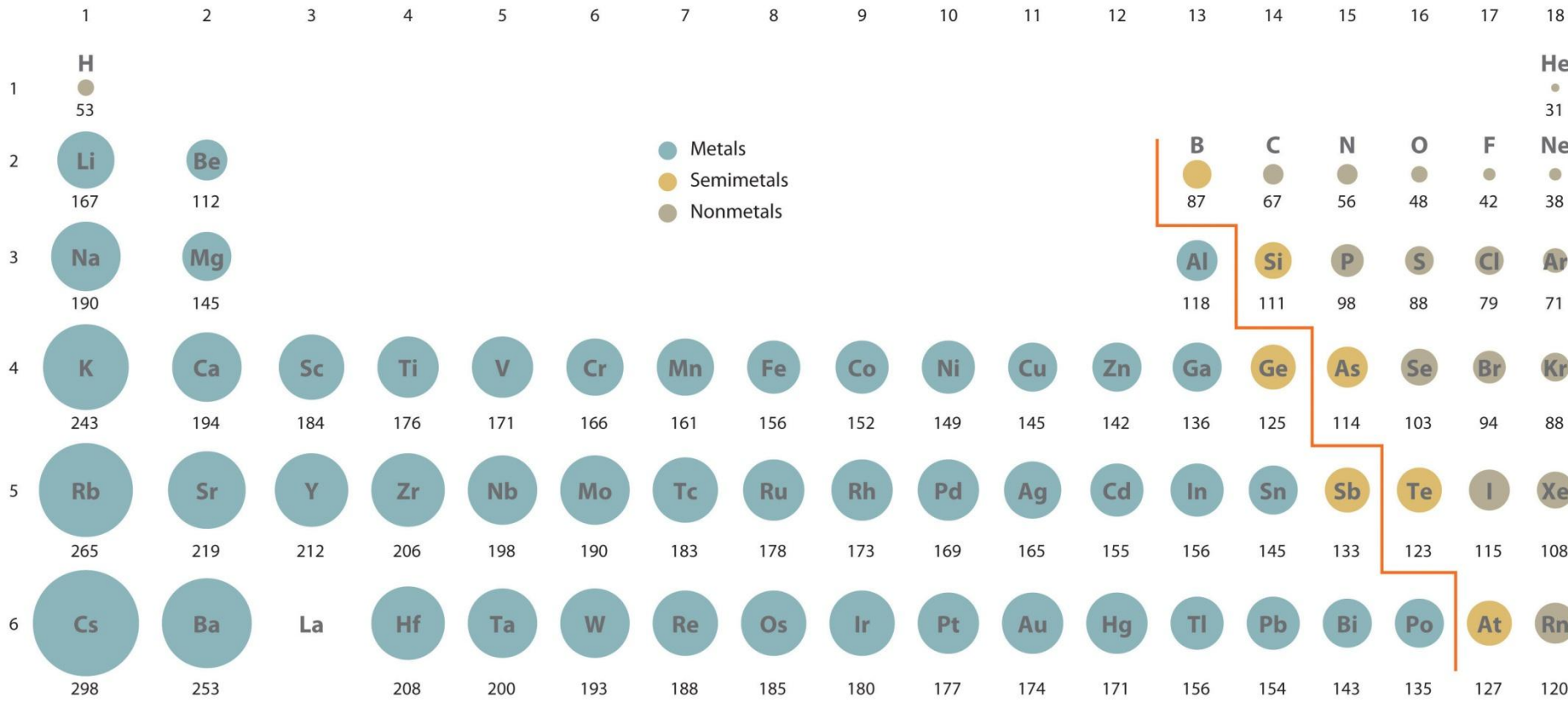
<http://www.chemicool.com>

Interactive periodic chart



IA		<div style="display: flex; align-items: center; justify-content: space-around;"> <div style="border: 1px solid black; padding: 5px; text-align: center;">             47  <b>Ag</b>              107.868           </div> <div style="text-align: left;">             — Atomic number              — Symbol              — Atomic mass           </div> </div>																O					
1 H 1.0079																	2 He 4.00260						
IIA		IIIA IVA VA VIA VIIA																					
3 Li 6.94	4 Be 9.01218	5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179																
III B		VIII						II B															
11 Na 22.98977	12 Mg 24.305	13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.066	17 Cl 35.453	18 Ar 39.948																
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58 Ce 140.12 59 Pr 140.9077 60 Nd 144.24 61 Pm (145) 62 Sm 150.4 63 Eu 151.965 64 Gd 157.25 65 Tb 158.9254 66 Dy 162.50 67 Ho 164.9303 68 Er 167.26 69 Tm 168.9342 70 Yb 173.04 71 Lu 174.967																							
90 Th 232.0381 91 Pa (231, 036) 92 U 238.029 93 Np 237.0482 94 Pu (244, 069) 95 Am (243, 06) 96 Cm (247, 070) 97 Bk (247, 070) 98 Cf (251, 08) 99 Es (252, 083) 100 Fm (257, 096) 101 Md (258, 18) 102 No (259, 101) 103 Lr (260, 11)																							



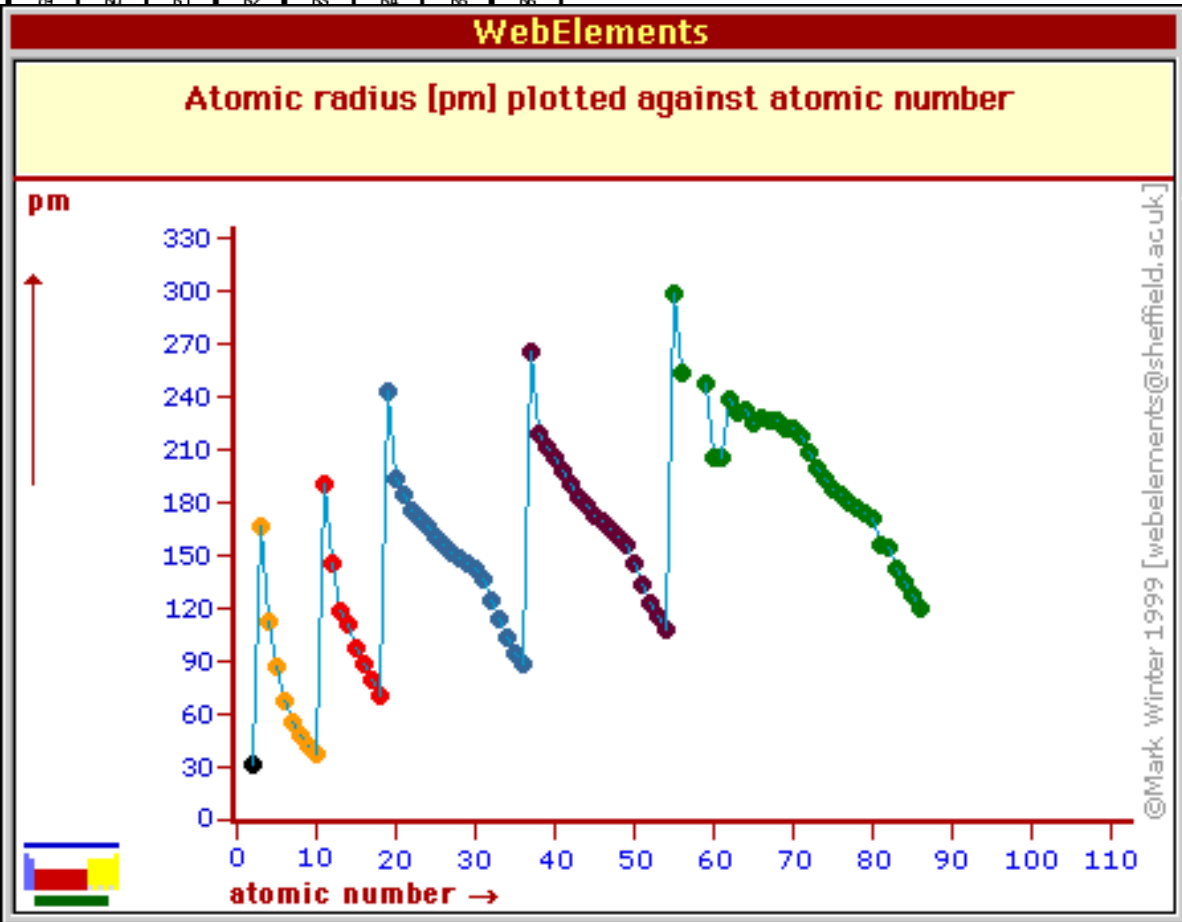


IA												IIA																		O																																	
1	H											2	He																																																		
1.0079												4.00260																																																			
3	Li	4	Be											5	B	6	C	7	N	8	O	9	F	10	Ne																																						
6.94		9.01218												10.811	12.011	14.0067	15.9994	18.998403	20.179																																												
11	Na	12	Mg											13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																																						
22.98977		24.305												26.98154	28.0855	30.97376	32.066	35.453	39.948																																												
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr																												
39.0983	40.08	44.9559	47.88	50.9415	51.996	55.9381	58.847	58.9332	58.69	63.546	65.39	69.723	72.61	74.9216	78.96	79.904	83.80																																														
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe																												
85.4678	87.62	88.9059	91.224	92.9064	95.94	98.9072	101.07	102.9055	106.42	107.868	112.41	114.82	118.710	121.75	127.80	128.9047	131.30																																														
55	Cs	56	Ba	57	La	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn																												
132.9054	137.33	138.33	178.49	180.9479	183.85	186.207	190.2	192.22	195.08	196.967	200.59	200.59	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804	208.9804																													
87	Fr	88	Ra	89	Ac																																																										
(223)	(226.0254)	(227)																																																													
				VIII										IB		IIB																																															
				III B										IV B		V B		VI B		VII B																																											
				58										59										60										61										62										63									
				Ce										Pr										Nd										Pm										Sm										Eu									
				140.12										140.9077										144.24										(145)										150.4										151.968									
				80										91										92										93										94										95									
				Th										Pa										U										Np										Pu										Am									
				232.0381										231.036										238.029										237.0482										244.069										(243.06)									

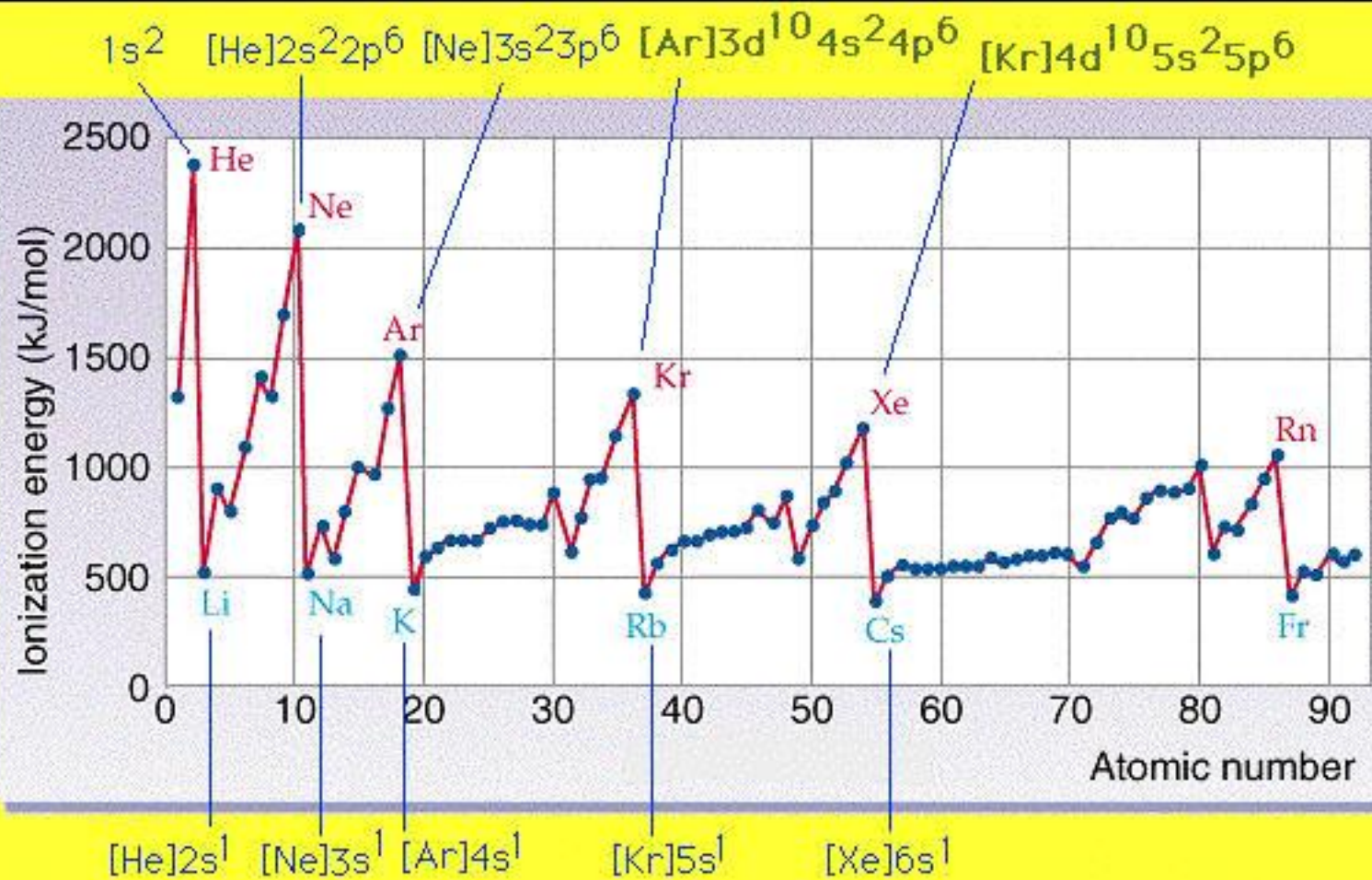
47 — Atomic number

Ag — Symbol

107.868 — Atomic mass



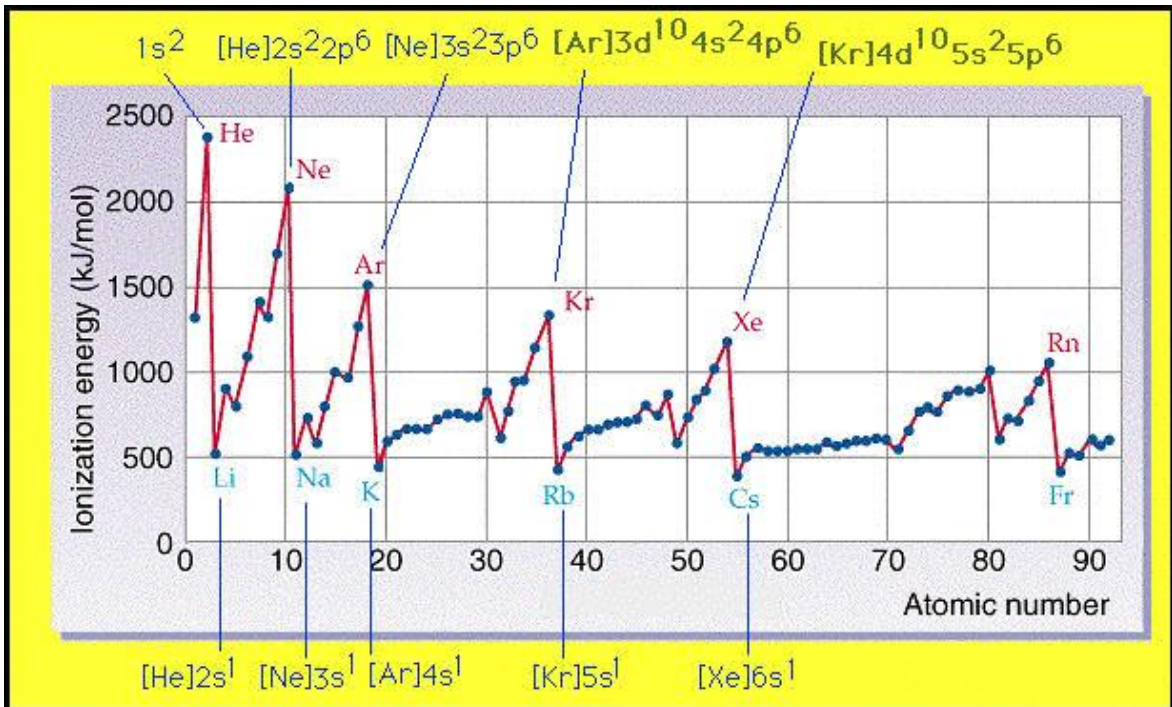


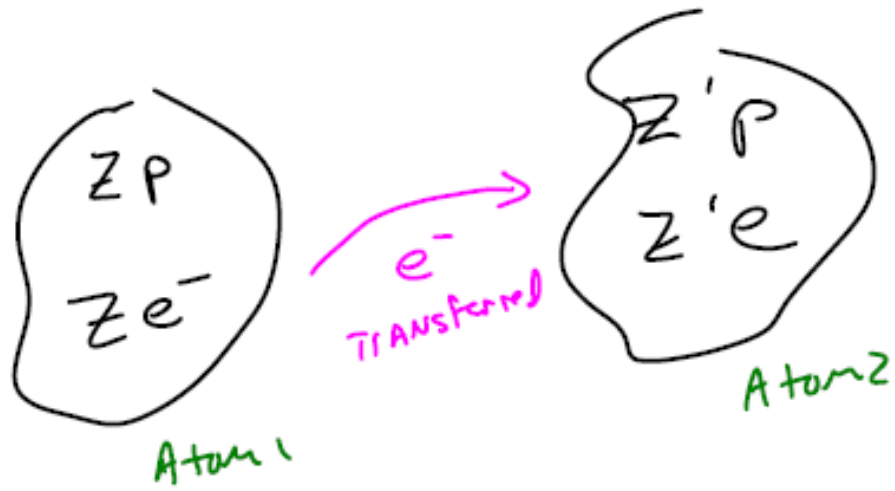


Atomic number: 47  
 Symbol: Ag  
 Atomic mass: 107.868

I A												O					
1 H 1.0079	II A										2 He 4.00260						
3 Li 6.94	4 Be 9.01218											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179
11 Na 22.98977	12 Mg 24.305	VIII										13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 55.9381	26 Fe 58.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc 98.9072	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.75	52 Te 127.60	53 I 126.9047	54 Xe 131.30
55 Cs 132.9054	56 Ba 137.33	57 La 138.905	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226, 0254)	89 Ac (227)															

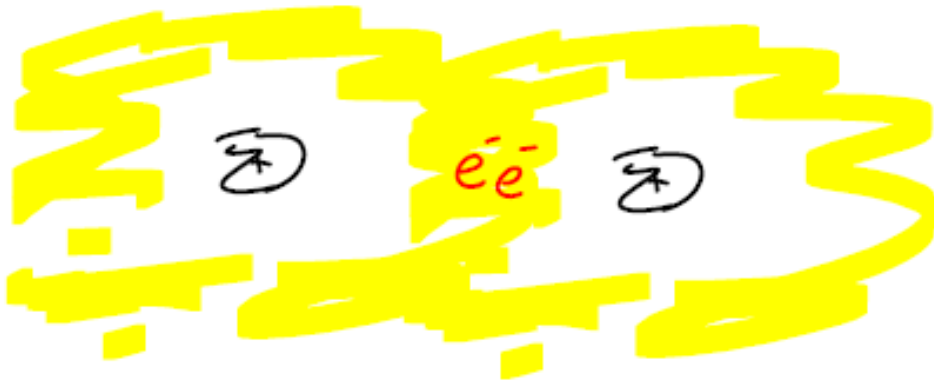
58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.965	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9303	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa (231.036)	92 U 238.029	93 Np 237.0482	94 Pu (244.069)	95 Am (243.06)	96 Cm (247.070)	97 Bk (247.070)	98 Cf (251.08)	99 Es (252.083)	100 Fm (257.095)	101 Md (258.10)	102 No (259.101)	103 Lr (260.11)





ionic bond





covalent  
bond