

Physics 100 - February 26, 2007

EXAM - I heard it was lots of fun! 😊

Still being graded

Expect to have for you by Wednesday

LAST TIME



Nucleus Atom
Circular motion
Stable, discrete, fixed orbits
 γ emitted/absorbed as e^- makes transitions between orbits

Bohr Model of the atom

What characterizes it?

Why is it important?

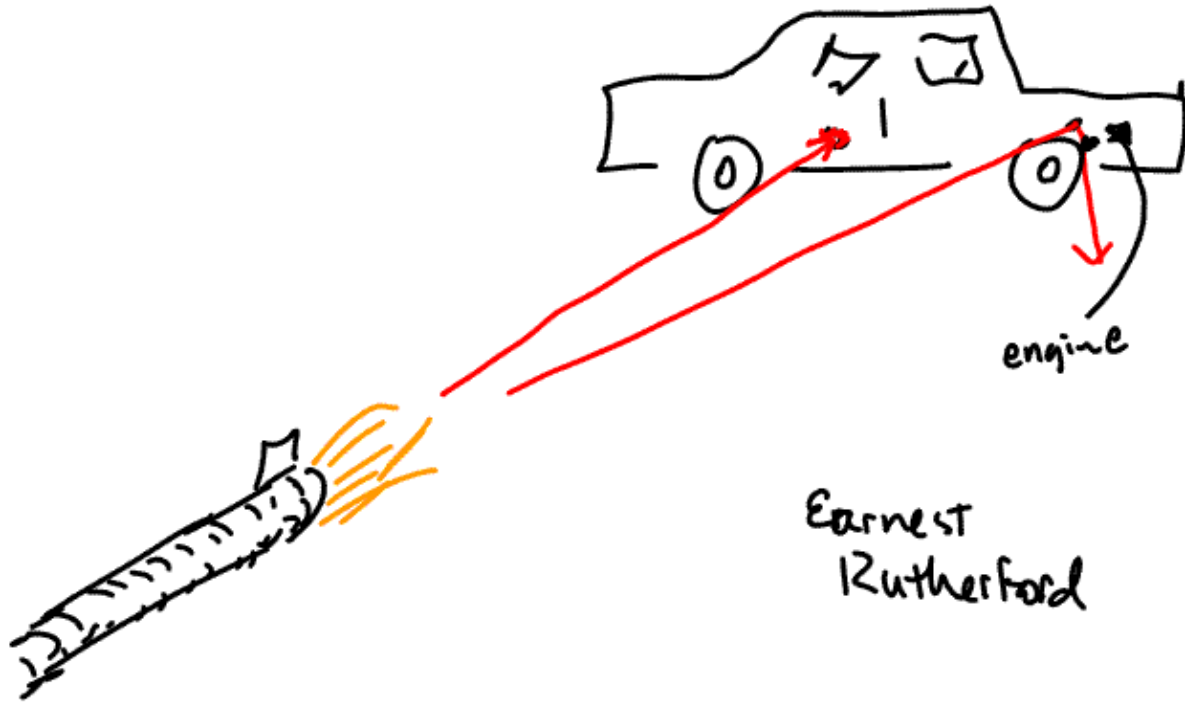
In what ways was it a successful model?

What were shortcomings?

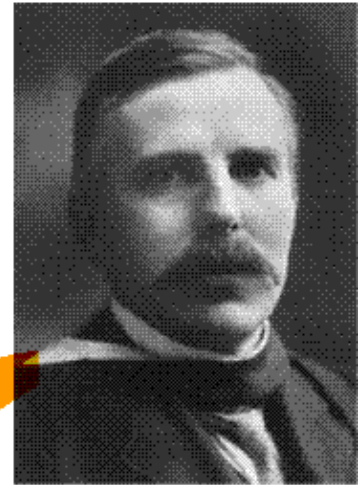
quantization ad hoc

1st quantum model of atom explained discrete atomic spectra

How did Bohr know to go with a "nuclear" atom?

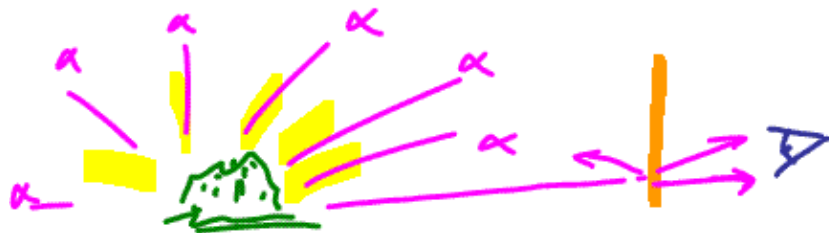


Ernest Rutherford



nuclear

Plum Pudding



Probability of scattering off thin gold foil
nucleus very small

Quantum Mechanics

wave equation for matter waves



Heisenberg



$$-\frac{\hbar^2}{2m} \frac{d^2 \psi(x)}{dx^2} + V \psi(x) = E \psi(x) \quad \text{Schrödinger's Equation}$$



Schrödinger

Plug in "potential" describing the physical situation

Solve for $\psi(x)$ and possible energies

Wave function

Put in e^- + Coulomb

↳ get discrete allowed orbitals and energies for e^- in atom.

QM treatment of H atom wave mechanics

Spherical Symmetry

Shapes of allowed electron states

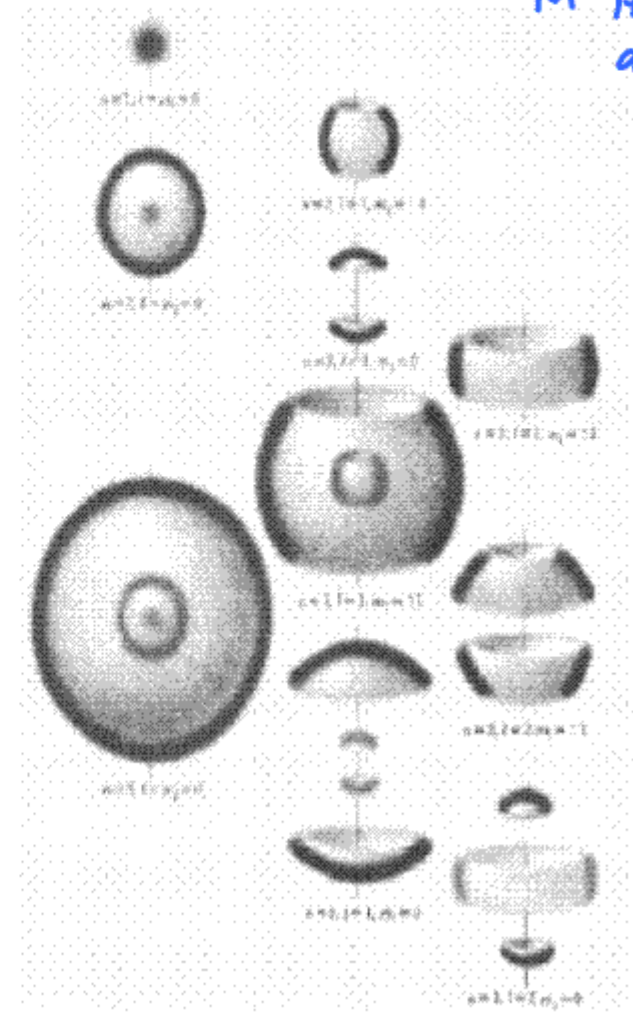
in hydrogen atom



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

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

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



Similar to Bohr - discrete states
But orbits are not circular

* Look at Falstad's Applet on [Lecture links page](#)

Schrödinger solved

$p \rightarrow e^-$ situation

\Rightarrow solutions for allowed energies and "orbitals"
for the H atom

These allowed orbitals have different energies

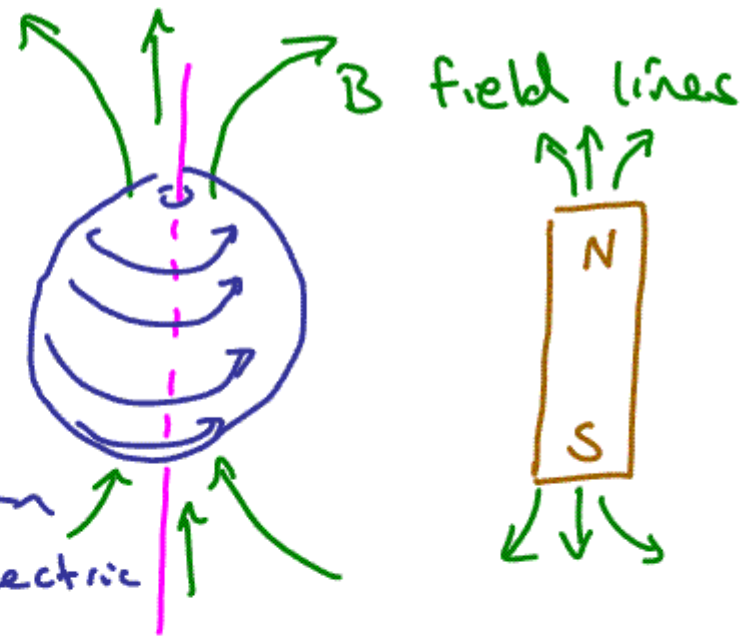
To really understand chemistry we need to see how
to put multiple electrons in a single atom.

How do electrons stack up in the orbitals??

To understand this we need to understand
something of a surprise discovery

Electrons and other particles
have intrinsic SPIN

Spin



Imagine that the electron is a uniform ball of electric charge that "spins"

It would be like a little current loop

current loops create magnetic fields that look like magnetic fields coming from a bar magnet

Particles w/ spin have "magnetic moments" and look like tiny little bar magnets

This was discovered in 1922 by Stern + Gerlach

Stern-Gerlach experiment - 1922

→ Discovery that electrons have spin

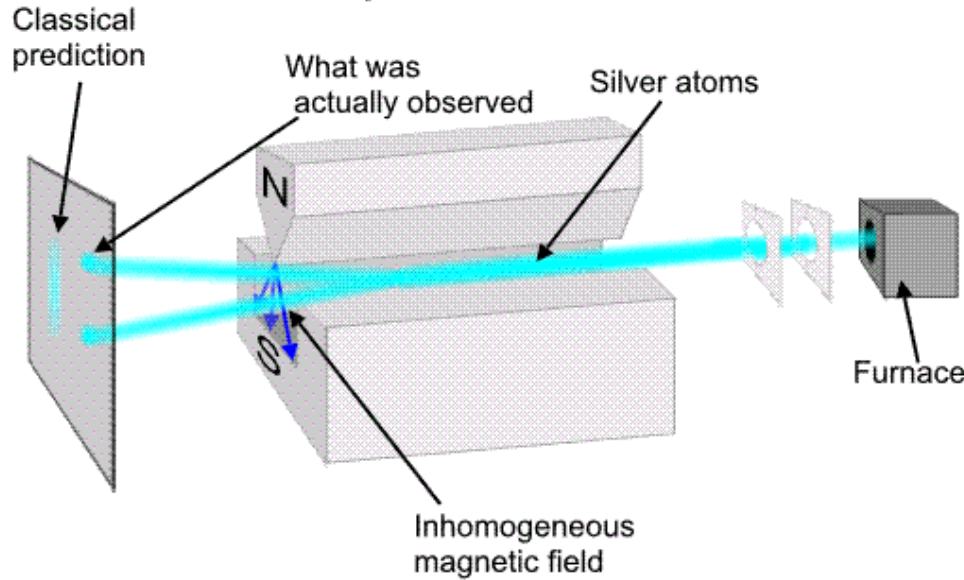


Diagram from
Wikipedia

OTTO STERN



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

(Stern vowed in 1913)

-Wikipedia

as quoted in Phys. Today Dec 03

Walther Gerlach



from phys Today article
(Dec. 03)

Spin is quantized

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

Integer Spin $0, 1, 2, \dots \Rightarrow$ Boson

$\frac{1}{2}$ -integer Spin $\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \dots \Rightarrow$ Fermion

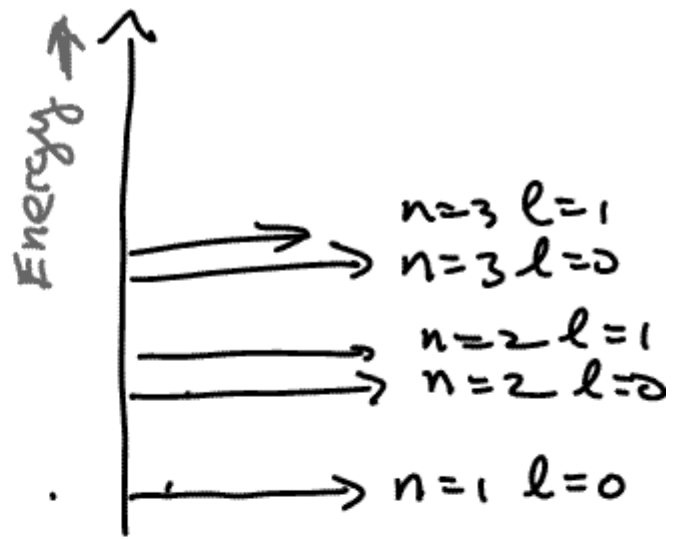
It's like you can only have bar magnets with certain discrete strengths

2 identical Fermions \rightarrow cannot occupy the same quantum state

2 identical Bosons \rightarrow can occupy the same quantum state

Schrödinger's eqn
gives allowed energy
states for e^- in
atom

They vary in energy like so \rightarrow



n = energy quantum number
 l = orbital angular momentum
quantum number

\rightarrow These characterize the
state... determine
the orbital

Z	ATOM	1	2	2	3	$\leftarrow n$
\downarrow	\downarrow	0	0	1	0	$\leftarrow l$
1	H	1	—	—	—	—
2	He	1↓	—	—	—	—
3	Li	1↓	1	—	—	—
4	Be	1↓	1↓	—	—	—
5	B	1↓	1↓	1	—	—
...						
11	Na	1↓	1↓	1↓	1↓	1↓

Electrons fill levels
lowest energy to highest

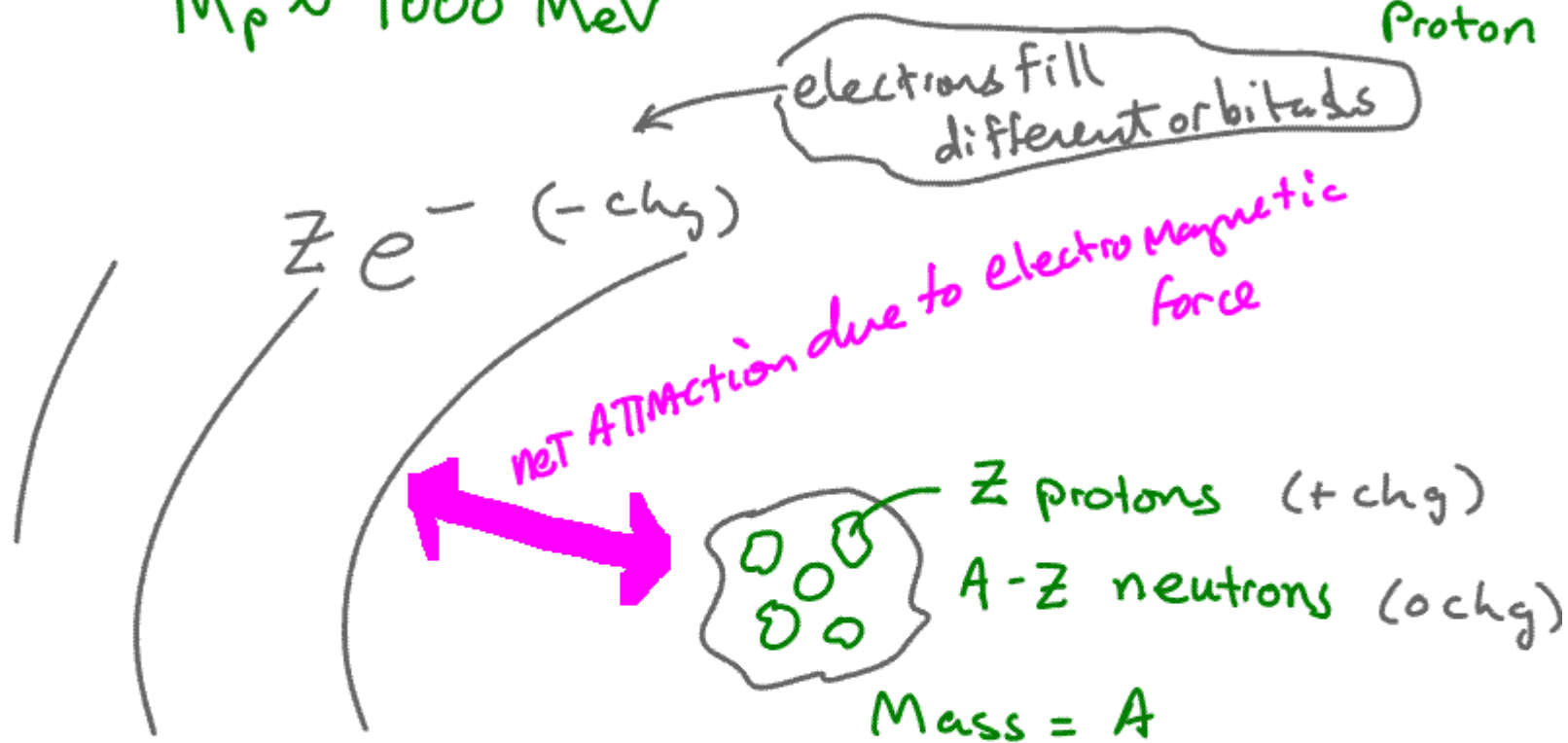
They do NOT all crowd
into lowest level
because they are

Fermions

$$M_e = .5 \text{ MeV}/c^2$$

$$M_p \sim 1000 \text{ MeV}$$

Mass of 1 A = Mass of Proton



The Atom

The way in which the orbitals are filled means there is periodicity in ATOMIC characteristics as Z increases

Periodic Table of the elements

John Newlands - English analytical chemist
(1837-1898) ... Arranged table of elements
by **ATOMIC MASSES**



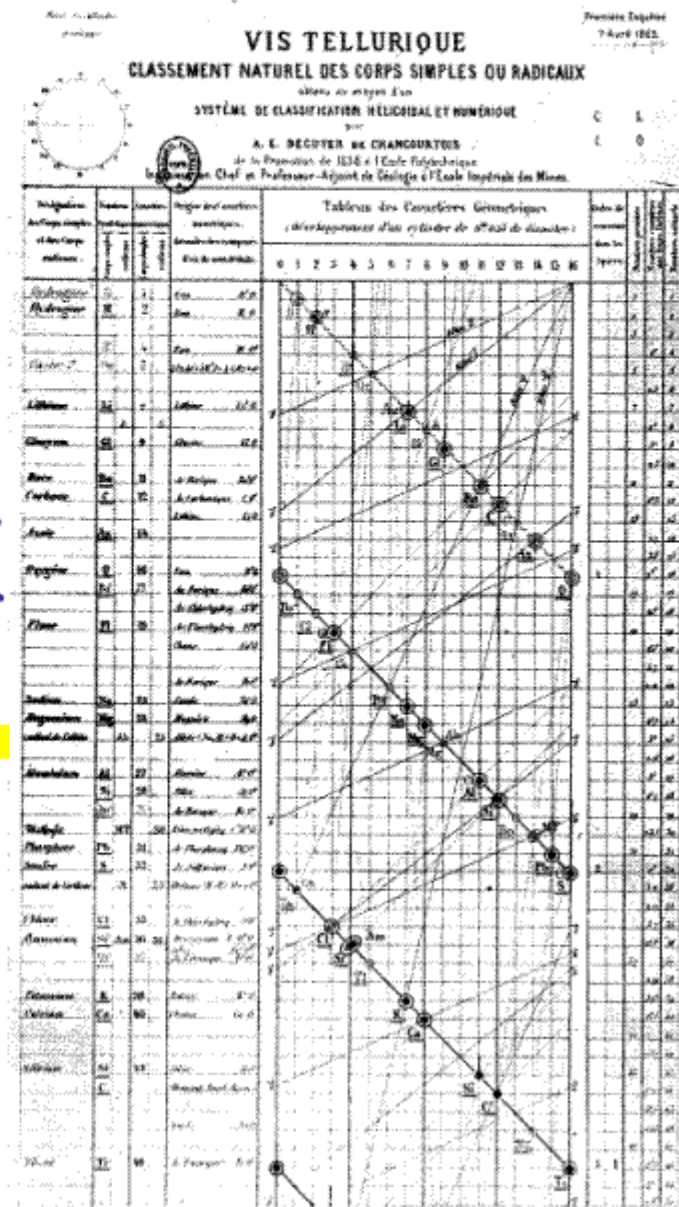
Antoine Lavoisier
France (1743-1794)

"Father of Modern
Chemistry"

quantitative analysis
guillotined during French Revolution



**Alexandre-Émile
Béguyer de Chancourtios**
France (1820-1886)





Dmitri Mendeleev
Russian (1834-1907)

THE PERIODICITY OF THE ELEMENTS

The Elements	Their Properties in the Free State				The Composition of the Hydrogen and Organic-metallic Compounds	Symbols and Atomic Weights	The Composition of the Saline Oxides			The Properties of the Saline Oxides	Small Periods or Series			
	<i>s</i>	<i>a</i>	<i>d</i>	<i>A</i>			R_2O_x							
	[1]	[2]	[3]	[4]			$\frac{x}{2}$	$\frac{x}{2}$	$\frac{x}{2}$			$\frac{x}{2}$		
Hydrogen	< -200°	< -200°	20		1	H	1	1	1	0.017	1.008	< -200	1	
Lithium	160°	< 0-10°	12		1	Li	7	1	1	2.9	6.94	< -20	2	
Beryllium	(500°)	< 100°	9.5		2	Be	9	2	2	9.96	9.012	< -20	2	
Boron	(1600°)	< 20°	11		3	B	11	3	3	1.8	10.81	< -20	3	
Carbon	> (3000°)	< 20°	6		4	C	12	4	4	> 10°	< 10°	< -10	4	
Nitrogen	-200°	< 0°	14		5	N	14	5	5	1.01	14.008	< 0	5	
Oxygen	< -200°	< 10°	16		6	O	16	6	6	1.01	15.999	< 0	6	
Fluorine	—	—	—		7	F	19	7	7	—	—	—	7	
Sodium	90°	0°	23		1	Na	23	1	1	Na ₂ O	28	23	< -20	8
Magnesium	500°	0°	24		2	Mg	24	2	2	—	—	—	8	
Aluminium	600°	0°	27		3	Al	27	3	3	Al ₂ O ₃	78	27	< -20	9
Silicon	(1800°)	0°	28		4	Si	28	4	4	—	—	—	9	
Phosphorus	44°	120°	31		5	P	31	5	5	—	—	—	9	
Sulphur	114°	0°	32		6	S	32	6	6	—	—	—	9	
Chlorine	-70°	10°	35.5		7	Cl	35.5	7	7	—	—	—	9	
Potassium	50°	0°	39		1	K	39	1	1	—	—	—	10	
Calcium	(900°)	0°	40		2	Ca	40	2	2	—	—	—	10	
Scandium	(2000°)	—	(31)	(34)	3	Sc	44	3	3	—	—	—	10	
Titanium	(2000°)	—	(31)	(34)	4	Ti	48	4	4	—	—	—	10	
Vanadium	(2000°)	—	51	52	5	V	51	5	5	—	—	—	10	
Chromium	(2000°)	—	52	53	6	Cr	52	6	6	—	—	—	10	
Manganese	(1500°)	—	55	55	7	Mn	55	7	7	—	—	—	10	
Iron	(1500°)	0°	56	56	8	Fe	56	8	8	—	—	—	10	
Cobalt	(1400°)	0°	59	59	9	Co	59	9	9	—	—	—	10	
Nickel	(1510°)	0°	59	59	10	Ni	59	10	10	—	—	—	10	
Copper	1084°	0°	63	63	11	Cu	63	11	11	—	—	—	10	
Zinc	420°	0°	65	65	12	Zn	65	12	12	—	—	—	10	
Gallium	30°	—	69	69	13	Ga	70	13	13	—	—	—	10	
Germanium	600°	—	72	72	14	Ge	72	14	14	—	—	—	10	
Arsenic	600°	0°	75	75	15	As	75	15	15	—	—	—	10	
Selenium	617°	—	79	79	16	Se	79	16	16	—	—	—	10	
Bromine	-7°	—	80	80	17	Br	80	17	17	—	—	—	10	
Krypton	—	—	84	84	18	Kr	84	18	18	—	—	—	10	
Rubidium	30°	—	85	85	19	Rb	85	19	19	—	—	—	10	
Strontium	(600°)	—	88	88	20	Sr	88	20	20	—	—	—	10	
Yttrium	(1500°)	—	89	89	21	Y	89	21	21	—	—	—	10	
Zirconium	(1500°)	—	91	91	22	Zr	91	22	22	—	—	—	10	
Niobium	—	—	93	93	23	Nb	93	23	23	—	—	—	10	
Molybdenum	—	—	96	96	24	Mo	96	24	24	—	—	—	10	
Technetium	—	—	—	—	25	Tc	—	—	—	—	—	—	10	
Ruthenium	(2000°)	0°	101	101	26	Ru	101	26	26	—	—	—	10	
Rhodium	(1800°)	0°	103	103	27	Rh	103	27	27	—	—	—	10	
Palladium	1300°	0°	107	107	28	Pd	107	28	28	—	—	—	10	
Silver	2000°	0°	108	108	29	Ag	108	29	29	—	—	—	10	
Cadmium	300°	0°	112	112	30	Cd	112	30	30	—	—	—	10	
Indium	170°	0°	115	115	31	In	115	31	31	—	—	—	10	
Tin	230°	0°	119	119	32	Sn	119	32	32	—	—	—	10	
Antimony	450°	0°	122	122	33	Sb	122	33	33	—	—	—	10	
Tellurium	450°	0°	128	128	34	Te	128	34	34	—	—	—	10	
Iodine	114°	—	127	127	35	I	127	35	35	—	—	—	10	
Cesium	28°	—	133	133	36	Cs	133	36	36	—	—	—	10	
Barium	—	—	137	137	37	Ba	137	37	37	—	—	—	10	
Lanthanum	(600°)	—	139	139	38	La	139	38	38	—	—	—	10	
Cerium	(700°)	—	140	140	39	Ce	140	39	39	—	—	—	10	
Dysprosium	(900°)	—	163	163	40	Dy	163	40	40	—	—	—	10	
Ytterbium	—	—	(163)	(163)	41	Yb	173	41	41	—	—	—	10	
Tantalum	—	—	182	182	42	Ta	182	42	42	—	—	—	10	
Tungsten	(1800°)	—	184	184	43	W	184	43	43	—	—	—	10	
Osmium	(2500°)	0°	192	192	44	Os	192	44	44	—	—	—	10	
Iridium	(2000°)	0°	194	194	45	Ir	194	45	45	—	—	—	10	
Platinum	1772°	0°	195	195	46	Pt	196	46	46	—	—	—	10	
Gold	2045°	0°	197	197	47	Au	198	47	47	—	—	—	10	
Mercury	-30°	—	200	200	48	Hg	200	48	48	—	—	—	10	
Thallium	204°	0°	204	204	49	Tl	204	49	49	—	—	—	10	
Lead	320°	0°	207	207	50	Pb	207	50	50	—	—	—	10	
Bismuth	268°	0°	209	209	51	Bi	209	51	51	—	—	—	10	
Polonium	—	—	210	210	52	Po	210	52	52	—	—	—	10	
Francium	(2000°)	—	223	223	53	Fr	223	53	53	—	—	—	10	
Radium	(2000°)	—	226	226	54	Ra	226	54	54	—	—	—	10	
Actinium	(2000°)	—	227	227	55	Ac	227	55	55	—	—	—	10	
Thorium	—	—	232	232	56	Th	232	56	56	—	—	—	10	
Uranium	(900°)	—	238	238	57	U	238	57	57	—	—	—	10	

when elements arranged by mass - see a certain periodicity in their chemical properties.

Los Alamos National Laboratory Chemistry Division

Periodic Table of the Elements

Very reactive in this column

Very inert in this column

1A 1 H Hydrogen 1.008	2A											3A	4A	5A	6A	7A	8A 2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31	3B	4B	5B	6B	7B	8B		11B	12B	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95	
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 72.58	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 183.9	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 200.5	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)
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 Uuu (272)	112 Uub (277)	114 Uuq (296)		116 Uuh (298)		118 Uuo (?)	

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 175.0
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Actinide Series~

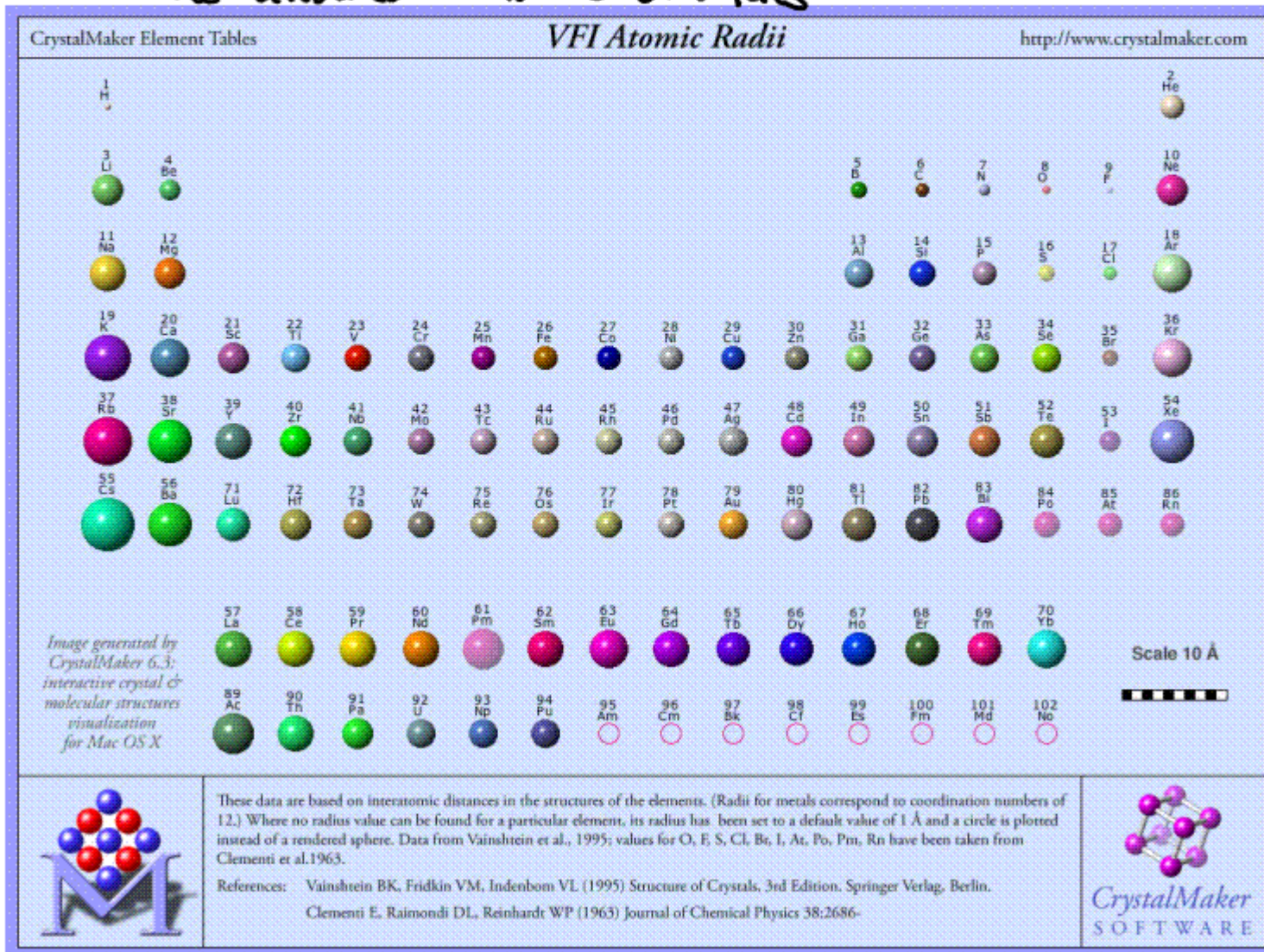
90 Th Thorium 232.0	91 Pa Protactinium (231)	92 U Uranium (238)	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (249)	99 Es Einsteinium (254)	100 Fm Fermium (253)	101 Md Mendelevium (256)	102 No Nobelium (254)	103 Lr Lawrencium (257)
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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

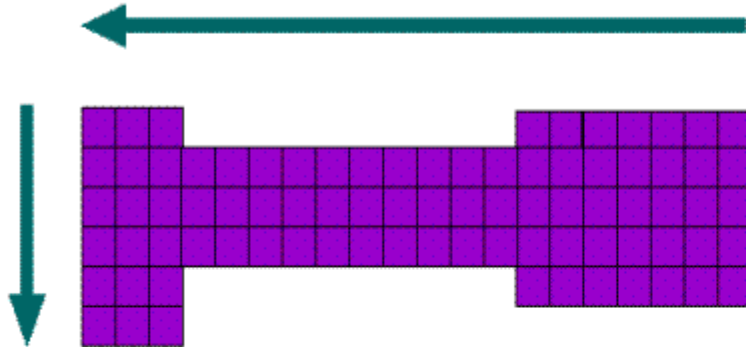
Variations in things like Atomic sizes and ionization energies and chemical reactivity can be understood by how electrons fill the allowed atomic orbitals



Figures from -

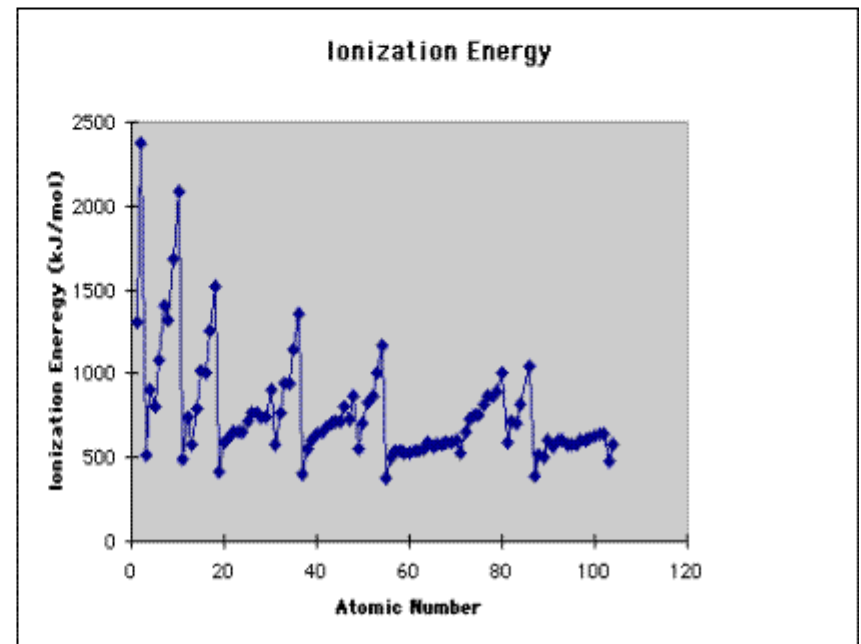
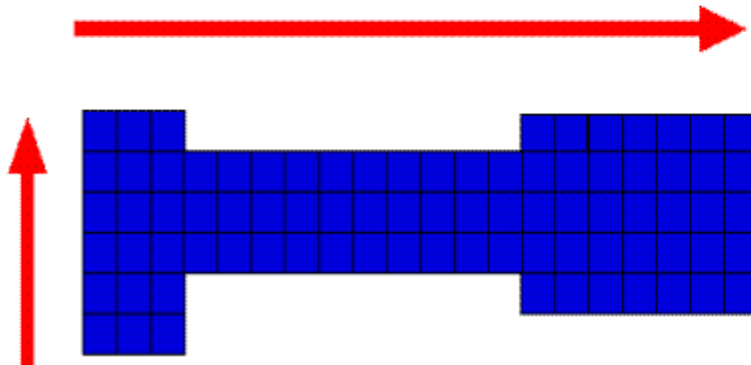
<http://www.shodor.org/chemviz/ionization/students/background.html>

Atomic Size Increases With Arrows

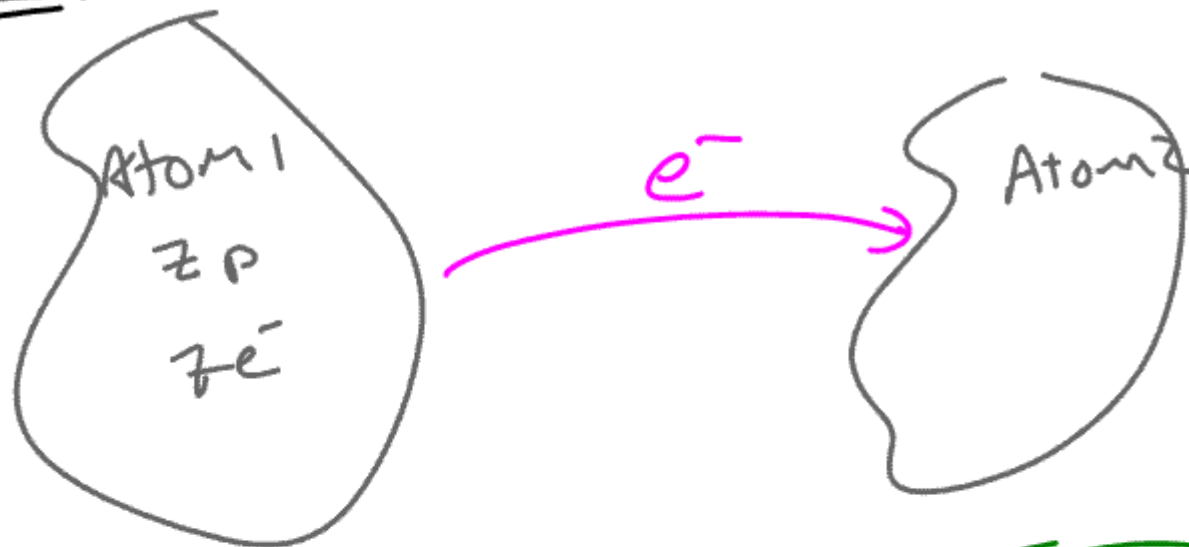


ionization Energy
energy to
remove an
electron

Ionization Energy Increases With Arrows



Chemistry - how Atoms interact with each other



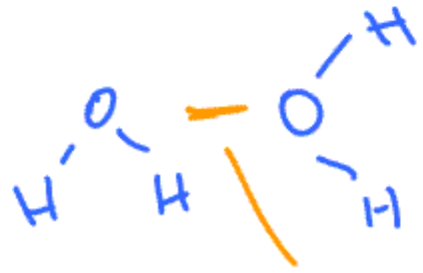
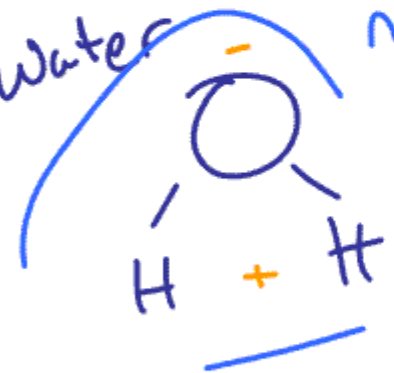
electrostatic
Attraction

Ionic
Bond





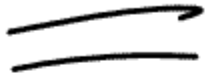
Water Molecules



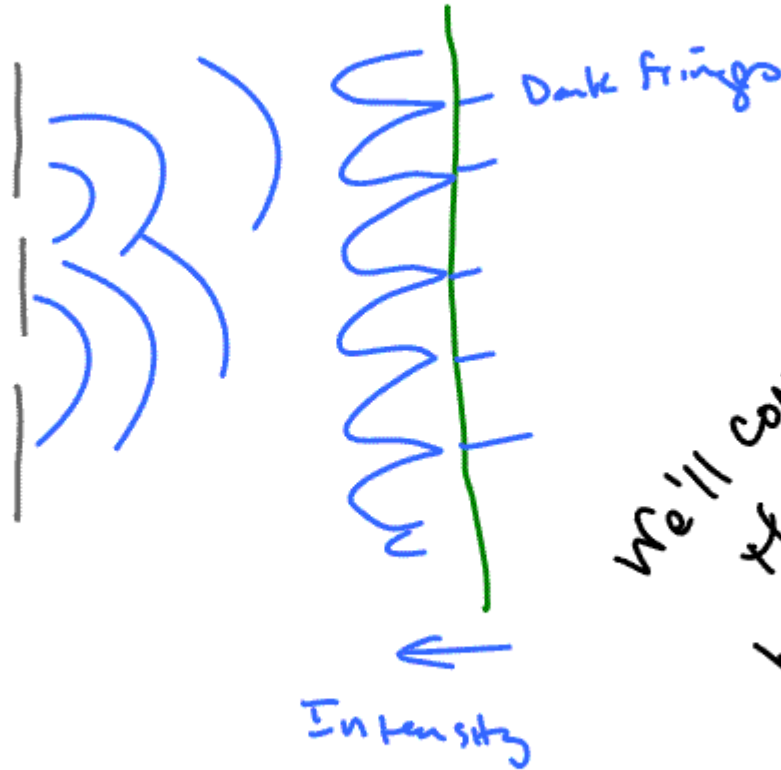
Intermolecular force

what is $\psi(x)$?

$\psi(x)$



$\Rightarrow e^-$



We'll come back to this — so I won't bother making notes better for now.

$$\Delta x \Delta p \sim h$$

uncertainty Principle