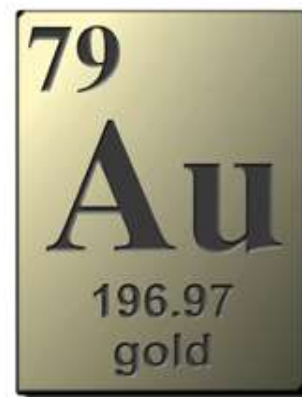


CHAPTER 6

A NATURAL APPROACH TO CHEMISTRY

Elements and the Periodic Table

6.1 The Periodic Table



Questions

Are you made of star dust?

Questions

Are you made of star dust?

**The Big Bang produced
hydrogen and helium
and a tiny bit of lithium**

Questions

Are you made of star dust?

**Other elements were
created in the cores of
exploding stars**

Key Concepts



Element	% by mole
Hydrogen	63.0
Oxygen	26.0
Carbon	9.0
Nitrogen	1.25
Calcium	0.25
Phosphorus	0.19
Potassium	0.06
Sulfur	0.06
Sodium	0.04
Chlorine	0.025
Magnesium	0.013
Iron	0.00004
Iodine	0.000002

99% of atoms in a human body come from only 4 elements

Key Concepts

Essential elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh		Uuo

Chemistry terms

macronutrients: elements needed in large quantities by your body.

trace elements: elements that are needed in very small quantities to maintain optimum health.

Review

Metals, nonmetals and metalloids

group 1																		group 18																	
1	H 1.0079 hydrogen	group 2																2	He 4.0026 helium																
3	Li 6.941 lithium	4	Be 9.0122 beryllium																	10	Ne 20.180 neon														
11	Na 22.990 sodium	12	Mg 24.305 magnesium																	18	Ar 39.948 argon														
				Atomic Number →		6																													
				Atomic Mass →		12.011 carbon																													
								metal metalloid nonmetal																											
group 13		group 14		group 15		group 16		group 17																											
5	B 10.811 boron	6	C 12.011 carbon	7	N 14.007 nitrogen	8	O 15.999 oxygen	9	F 18.998 fluorine	10	Ne 20.180 neon																								
13	Al 26.982 aluminum	14	Si 28.086 silicon	15	P 30.974 phosphorus	16	S 32.065 sulfur	17	Cl 35.453 chlorine	18	Ar 39.948 argon																								
19	K 39.098 potassium	20	Ca 40.078 calcium	21	Sc 44.956 scandium	22	Ti 47.867 titanium	23	V 50.942 vanadium	24	Cr 51.996 chromium	25	Mn 54.938 manganese	26	Fe 55.845 iron	27	Co 58.933 cobalt	28	Ni 58.693 nickel	29	Cu 63.546 copper	30	Zn 65.38 zinc	31	Ga 69.723 gallium	32	Ge 72.61 germanium	33	As 74.922 arsenic	34	Se 78.96 selenium	35	Br 79.904 bromine	36	Kr 83.80 krypton
37	Rb 85.468 rubidium	38	Sr 87.62 strontium	39	Y 88.906 yttrium	40	Zr 91.224 zirconium	41	Nb 92.906 niobium	42	Mo 95.96 molybdenum	43	Tc 98 technetium	44	Ru 101.07 ruthenium	45	Rh 102.91 rhodium	46	Pd 106.42 palladium	47	Ag 107.87 silver	48	Cd 112.41 cadmium	49	In 114.82 indium	50	Sn 118.71 tin	51	Sb 121.76 antimony	52	Te 127.60 tellurium	53	I 126.90 iodine	54	Xe 131.29 xenon
55	Cs 132.91 cesium	56	Ba 137.33 barium	57	La 138.91 lanthanum	58	Hf 178.49 hafnium	59	Ta 180.95 tantalum	60	W 183.84 tungsten	61	Re 186.21 rhenium	62	Os 190.23 osmium	63	Ir 192.22 iridium	64	Pt 195.08 platinum	65	Au 196.97 gold	66	Hg 200.59 mercury	67	Tl 204.38 thallium	68	Pb 207.2 lead	69	Bi 208.98 bismuth	70	Po (209) polonium	71	At (210) astatine	72	Rn (222) radon
87	Fr (223) francium	88	Ra (226) radium	89	Ac (227) actinium	90	Th 232.04 thorium	91	Pa 231.04 protactinium	92	U 238.03 uranium	93	Np (237) neptunium	94	Pu (244) plutonium	95	Am (243) americium	96	Cm (247) curium	97	Bk (247) berkelium	98	Cf (251) californium	99	Es (252) einsteinium	100	Fm (257) fermium	101	Md (258) mendelevium	102	No (259) nobelium				
103	Lr (260) lawrencium	104	Rf (261) rutherfordium	105	Db (262) dubnium	106	Sg (266) seaborgium	107	Bh (264) bohrium	108	Hs (277) hassium	109	Mt (268) meitnerium	110	Ds (285) darmstadtium	111	Rg (289) roentgenium	112	Uub (289) unbinilium	113	Uut (288) ununilium	114	Uuq (289) ununquadium	115	Uup (288) ununpentium	116	Uuh (293) ununhexium	117	Uus (294) ununseptium	118	Uuo (294) ununoctium				
103	La 138.91 lanthanum	58	Ce 140.12 cerium	59	Pr 140.91 praseodymium	60	Nd 144.24 neodymium	61	Pm 145 promethium	62	Sm 150.36 samarium	63	Eu 151.96 europium	64	Gd 157.25 gadolinium	65	Tb 158.93 terbium	66	Dy 162.50 dysprosium	67	Ho 164.93 holmium	68	Er 167.26 erbium	69	Tm 168.93 thulium	70	Yb 173.06 ytterbium								
89	Ac (227) actinium	90	Th 232.04 thorium	91	Pa 231.04 protactinium	92	U 238.03 uranium	93	Np (237) neptunium	94	Pu (244) plutonium	95	Am (243) americium	96	Cm (247) curium	97	Bk (247) berkelium	98	Cf (251) californium	99	Es (252) einsteinium	100	Fm (257) fermium	101	Md (258) mendelevium	102	No (259) nobelium								

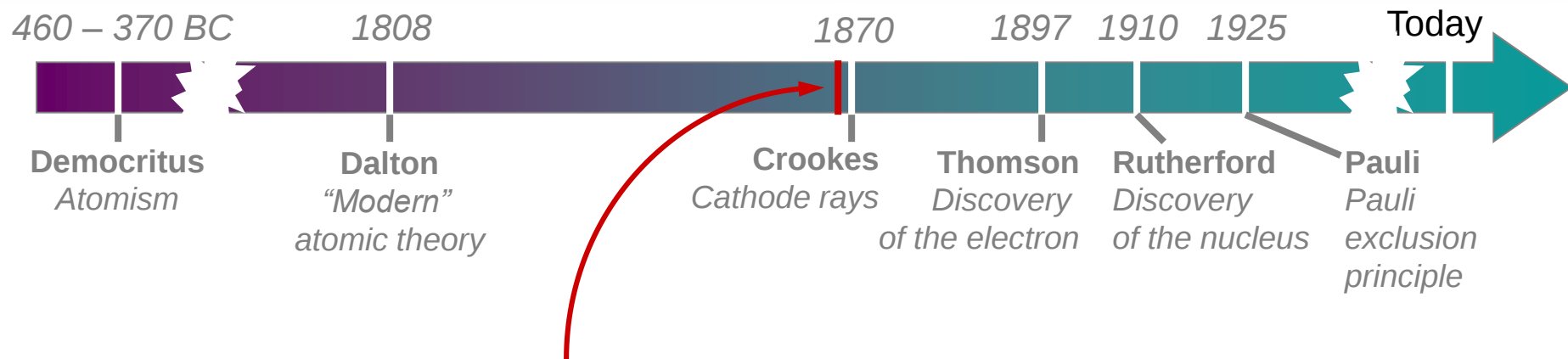
ionic compound:

one non-metal atom
bonded with one metal
atom

molecular compound:

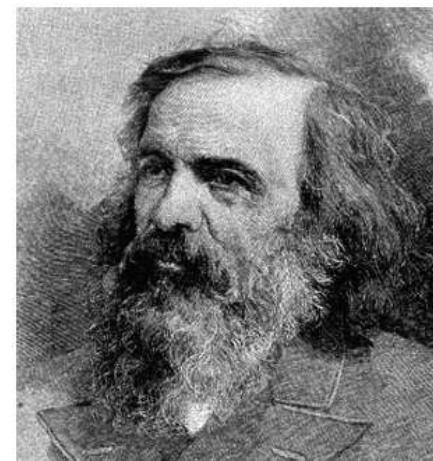
two non-metal atoms
bonded with each other

Key Concepts



1869

Mendeleev looks for a logical way to organize the elements known at the time.



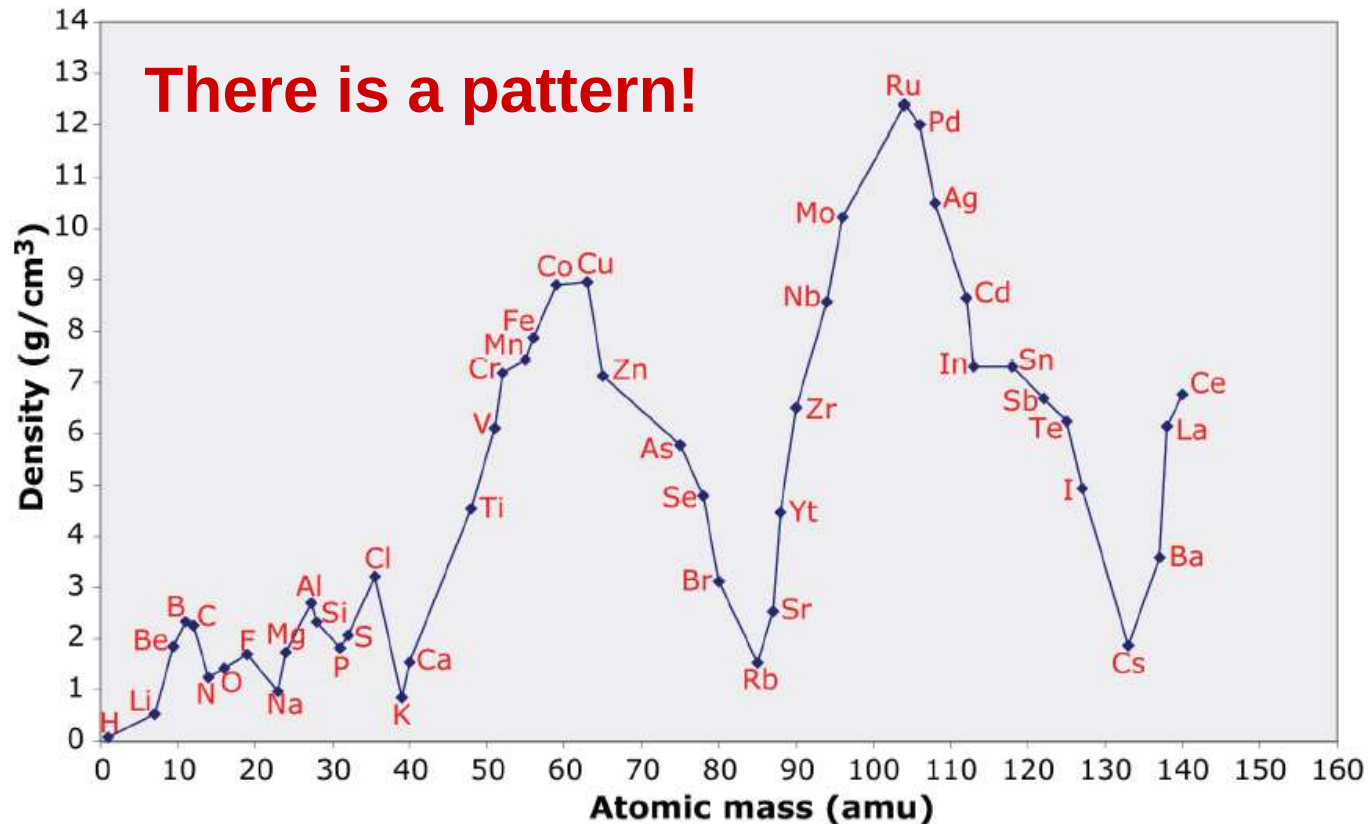
Dimitri Mendeleev

Note that at this time, very little is known about atoms.

Protons and atomic numbers were **not discovered yet**.

Key Concepts

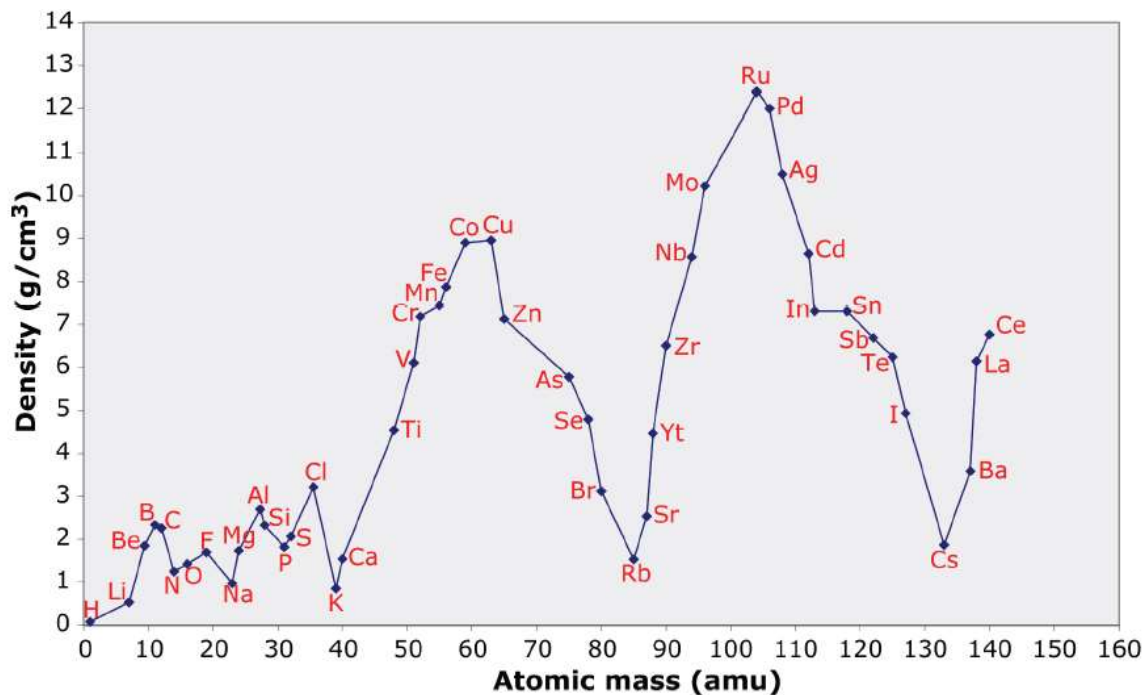
Mendeleev uses density (a physical property) of atoms, and organizes them in order of increasing atomic mass.



Vocabulary



The **periodic** table contains patterns that repeat at regular intervals

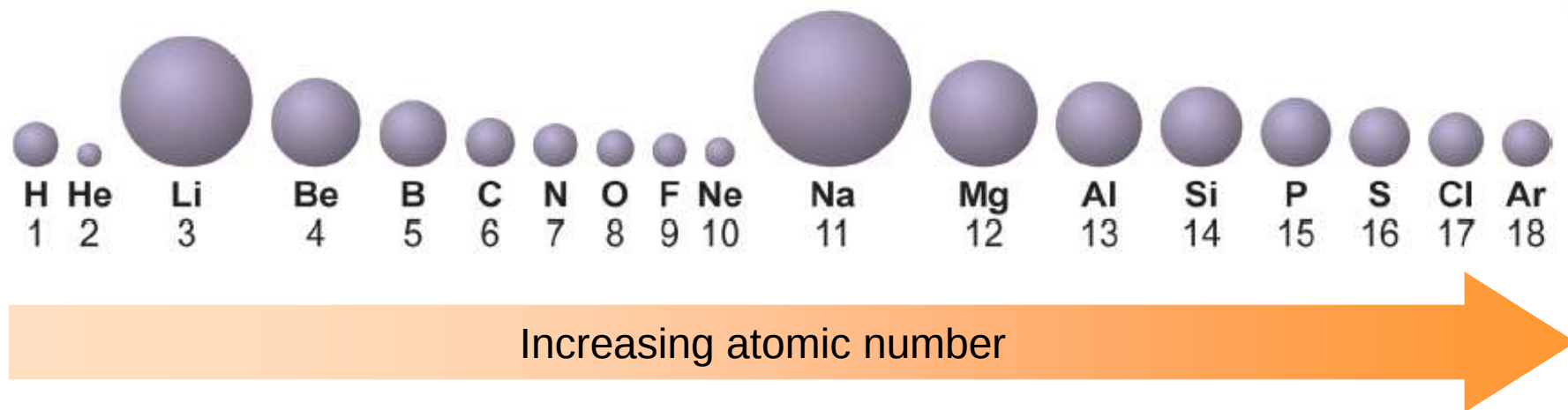


Chemistry
terms

periodic: repeating at regular intervals.

Key Concepts

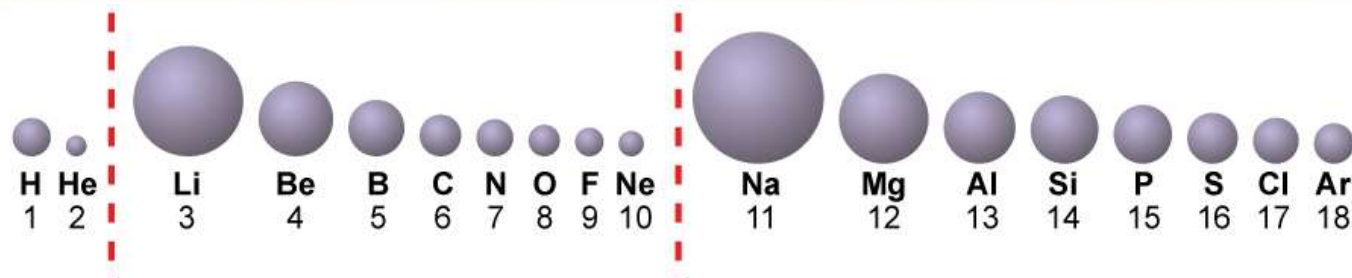
Atomic radius



Like for density, there is a **repeating pattern** in atomic radii.

Key Concepts

Atomic radius



Relative atom size arranged in a periodic table view

A new period

A new period

1 H							2 He
3 Li	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar

Key Concepts

Atomic radius

atomic radius: the distance from the center of an atom to its “outer edge.”

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh		Uuo

small



large

Key Concepts

Electronegativity

electronegativity: the ability of an atom to attract another atom's electrons when bound to that other atom.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh		Uuo

low



high

Key Concepts

Ionization energy

ionization energy: the energy required to remove an electron from an atom.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh		Uuo

low



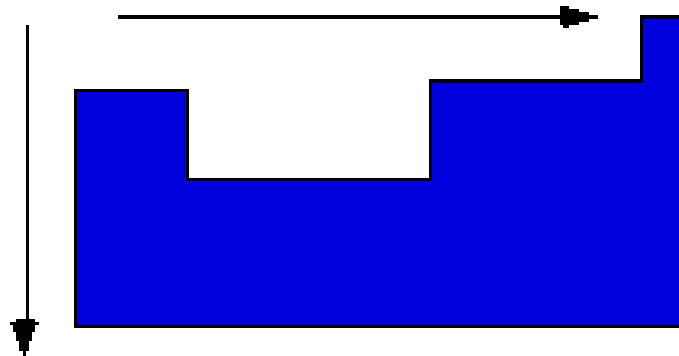
high

General Periodic Trends

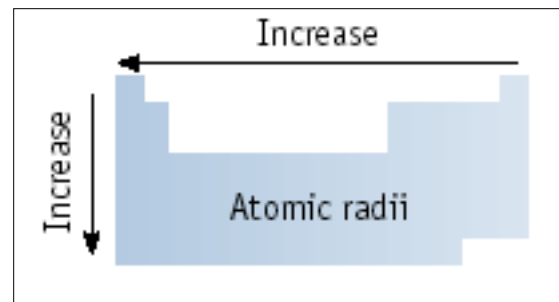
- Atomic and ionic size
- Ionization energy
- Electronegativity

**Higher effective nuclear charge
Electrons held more tightly**

**Larger orbitals.
Electrons held less
tightly.**



Atomic Size



- Size goes **UP** on going down a group.
- Because electrons are added further from the nucleus, there is less attraction. This is due to additional energy levels and the **shielding effect**. Each additional energy level “shields” the electrons from being pulled in toward the nucleus.
- Size goes **DOWN** on going across a period.

Atomic Size

Size **decreases** across a period owing to increase in the positive charge from the protons. Each added electron feels a greater and greater + charge because the protons are pulling in the same direction, where the electrons are scattered.



Na, 186



Mg, 160



Al, 143



Si, 117



P, 115



S, 104



Cl, 99

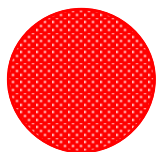
Large

Small

Which is Bigger?

- Na or K ?
- Na or Mg ?
- Al or I ?

Ion Sizes

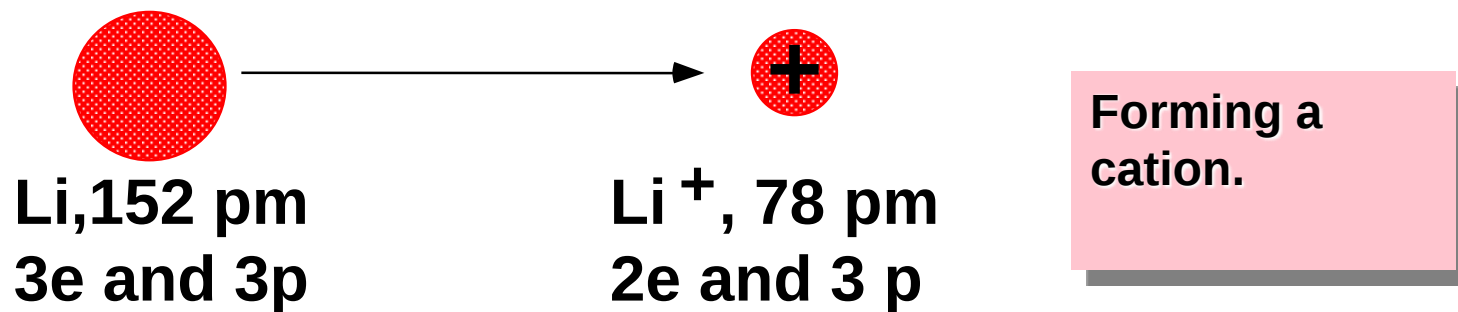


Li, 152 pm
3e and 3p



**Does the size go
up or down
when losing an
electron to form
a cation?**

Ion Sizes



- **CATIONS** are **SMALLER** than the atoms from which they come.
- The electron/proton attraction has gone UP and so size **DECREASES**.

Ion Sizes

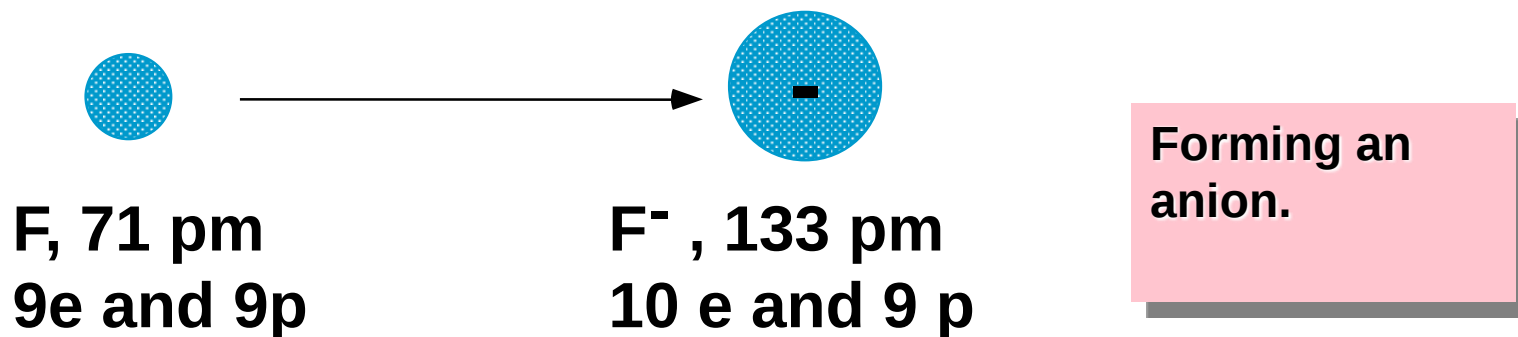


F, 64 pm
9e and 9p



Does the size go up or
down when gaining an
electron to form an
anion?

Ion Sizes



- **ANIONS** are **LARGER** than the atoms from which they come.
- The electron/proton attraction has gone DOWN and so size **INCREASES**.
- Trends in ion sizes are the same as atom sizes.

Trends in Ion Sizes

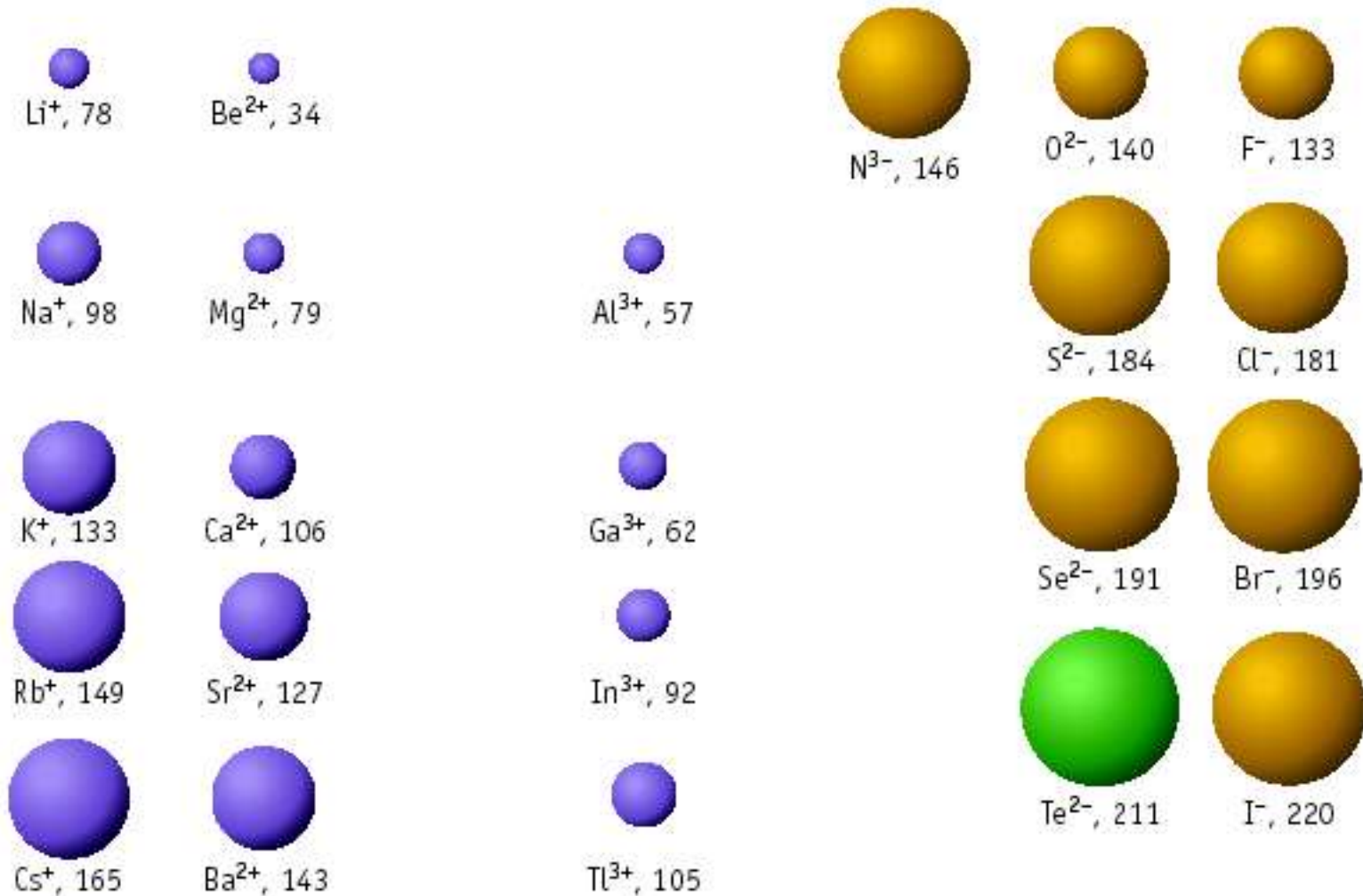


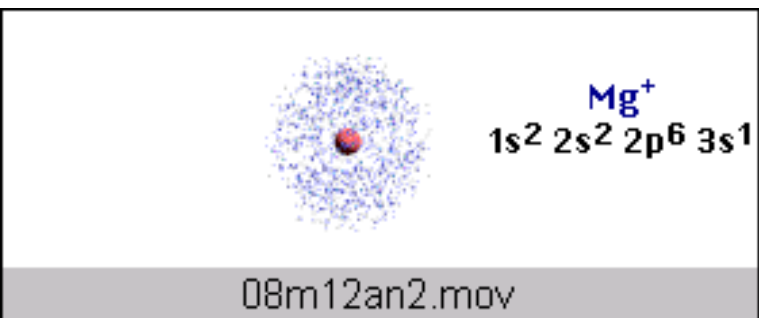
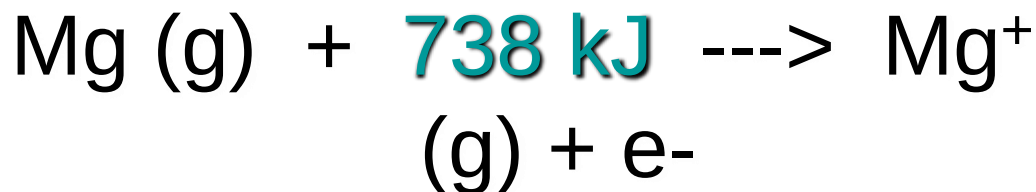
Figure 8.13

Which is Bigger?

- Cl or Cl^- ?
- K^+ or K ?
- Ca or Ca^{+2} ?
- I^- or Br^- ?

Ionization Energy

IE = energy required to remove an electron from an atom (in the gas phase).



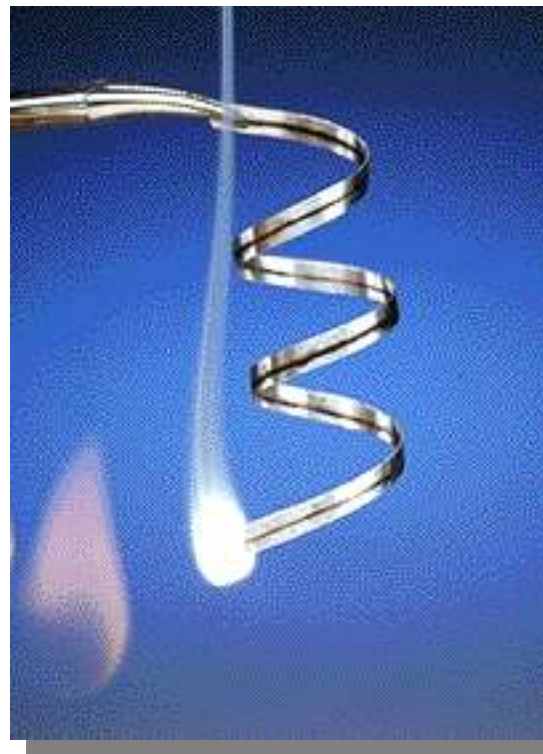
This is called the **FIRST** ionization energy because we removed only the **OUTERMOST** electron



This is the **SECOND IE**.

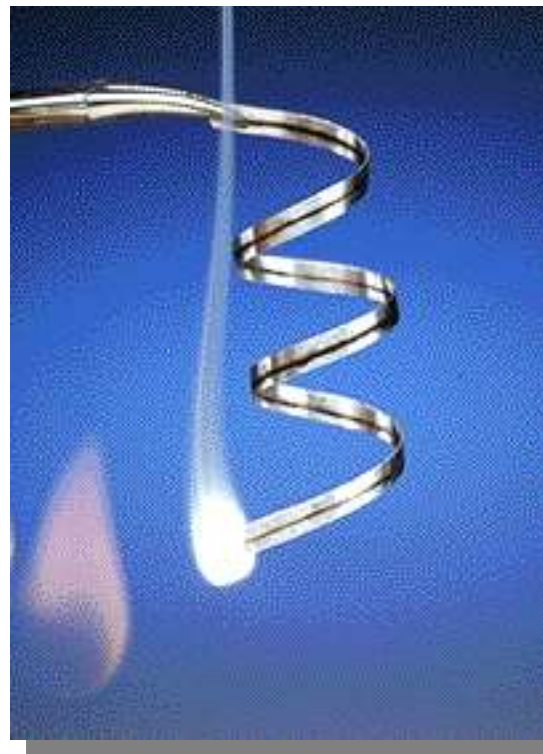
Trends in Ionization Energy

- IE increases across a period because the positive charge increases.
- Metals lose electrons more easily than nonmetals.
- Nonmetals lose electrons with difficulty (they like to GAIN electrons).



Trends in Ionization Energy

- IE increases UP a group
- Because size increases (Shielding Effect)



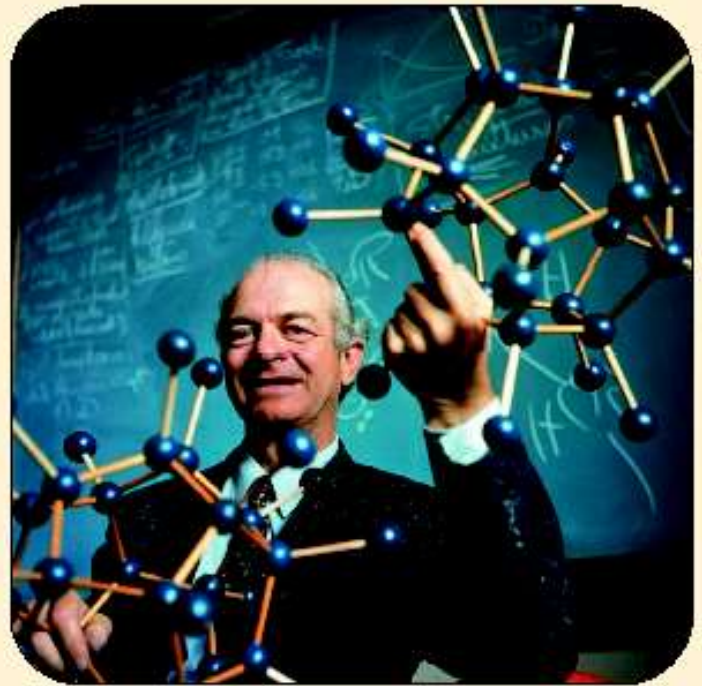
Which has a higher 1st ionization energy?

- Mg or Ca ?
- Al or S ?
- Cs or Ba ?

Electronegativity, χ

χ is a measure of the ability of an atom in a molecule to attract electrons to itself.

**Concept proposed by
Linus Pauling
1901-1994**



▲ Linus Pauling 1901–1994 (Thomas Hollyman/
Photo Researchers, Inc.)

Periodic Trends: Electronegativity

- *In a group:* Atoms with fewer energy levels can attract electrons better (less shielding). So, electronegativity **increases UP** a group of elements.
- *In a period:* More protons, while the energy levels are the same, means atoms can better attract electrons. So, electronegativity **increases RIGHT** in a period of elements.

Electronegativity

														H 2.1															
1A	2A											3A	4A	5A	6A	7A													
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0													
Na 0.9	Mg 1.2	3B	4B	5B	6B	7B	8B			1B	2B	Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0													
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8													
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5													
Cs 0.7	Ba 0.9	La 1.1	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2													
		<1.0 1.0–1.4 1.5–1.9 2.0–2.4 2.5–2.9 3.0–4.0																											

Figure 9.9 Electronegativity values for the elements according to Pauling. Trends for electronegativities are the opposite of the trends defining metallic character. Nonmetals have high values of electronegativity, the metalloids have intermediate values, and the metals have low values.

Which is more electronegative?

- F or Cl ?
- Na or K ?
- Sn or I ?

Key Concepts

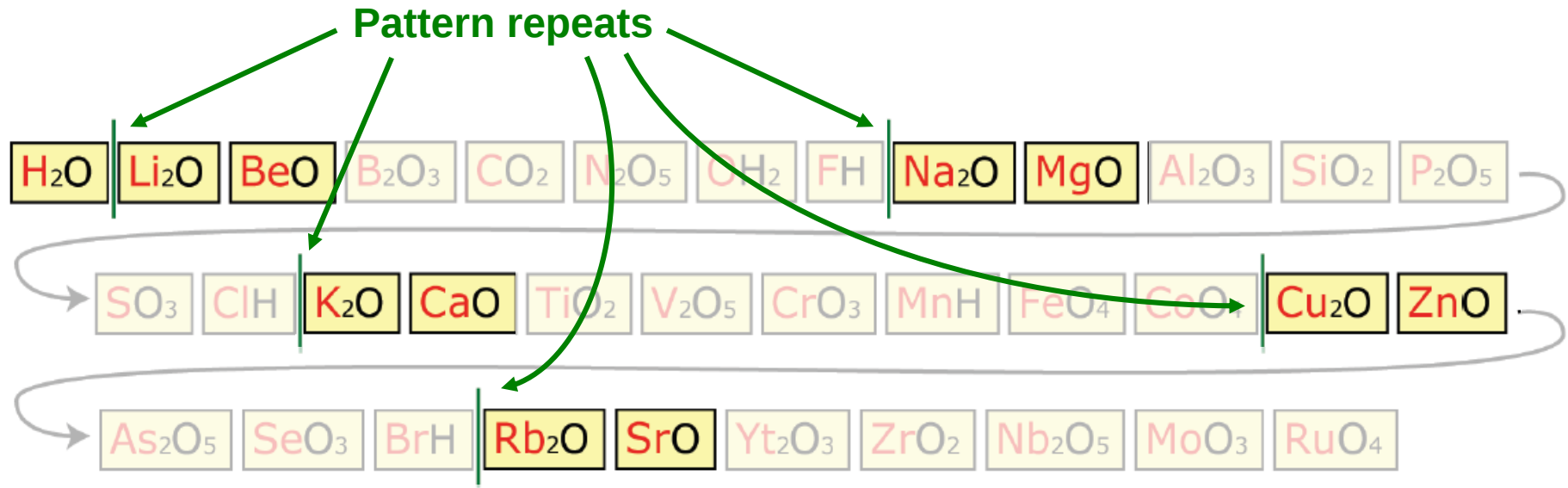
The first periodic table

H ₂ O	Li ₂ O	BeO	B ₂ O ₃	CO ₂	N ₂ O ₅	OH ₂	FH	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅
SO ₃	ClH	K ₂ O	CaO	TiO ₂	V ₂ O ₅	CrO ₃	MnH	FeO ₄	CoO ₄	Cu ₂ O	ZnO	
As ₂ O ₅	SeO ₃	BrH	Rb ₂ O	SrO	Yt ₂ O ₃	ZrO ₂	Nb ₂ O ₅	MoO ₃	RuO ₄			

Mendeleev placed the elements in order of increasing atomic mass and then noticed a repeating pattern in the oxide and hydride formula.

Key Concepts

The first periodic table



Mendeleev placed the elements in order of increasing atomic mass and then noticed a repeating pattern in the oxide and hydride formula.

A new pattern was discovered!

Key Concepts

The first periodic table

Oxides and hydrides sorted into rows:

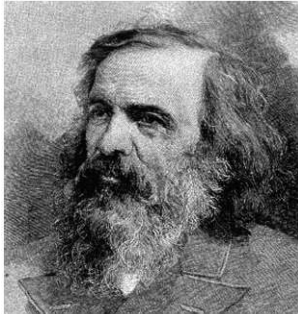
H ₂ O									
Li ₂ O	BeO	B ₂ O ₃	CO ₂	N ₂ O ₅	OH ₂	FH			
Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	ClH			
K ₂ O	CaO		TiO ₂	V ₂ O ₅	CrO ₃	MnH	FeO ₄	CoO ₄	
Cu ₂ O	ZnO			As ₂ O ₅	SeO ₃	BrH			
Rb ₂ O	SrO	Yt ₂ O ₃	ZrO ₂	Nb ₂ O ₅	MoO ₃				RuO ₄

The first periodic table as suggested by Mendeleev in 1869

Stop and Think

Mendeleev left empty spaces for **elements not yet discovered**

H ₂ O							
Li ₂ O	BeO	B ₂ O ₃	CO ₂	N ₂ O ₅	OH ₂	FH	
Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	ClH	
K ₂ O	CaO		TiO ₂	V ₂ O ₅	CrO ₃	MnH	FeO ₄ CoO ₄
Cu ₂ O	ZnO			As ₂ O ₅	SeO ₃	BrH	
Rb ₂ O	SrO	Yt ₂ O ₃	ZrO ₂	Nb ₂ O ₅	MoO ₃		RuO ₄

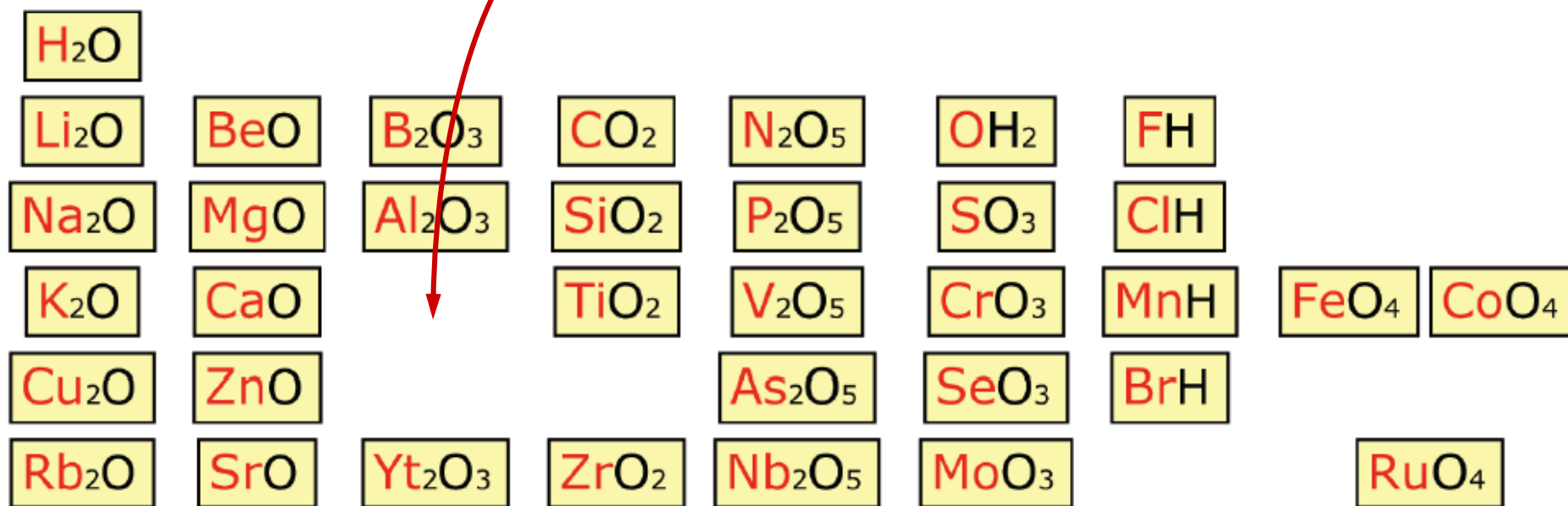


A diagram of Mendeleev's periodic table from 1869, showing chemical formulas in boxes. Red arrows point from empty spaces to the positions of elements later discovered: one from the space between B₂O₃ and CO₂ to the position of Gallium (Ga), and another from the space between TiO₂ and V₂O₅ to the position of Germanium (Ge).

The first periodic table as suggested by Mendeleev in 1869

Key Concepts

Gallium was discovered 6 years later!



H_2O									
Li_2O	BeO	B_2O_3	CO_2	N_2O_5	OH_2	FH			
Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClH			
K_2O	CaO		TiO_2	V_2O_5	CrO_3	MnH	FeO_4	CoO_4	
Cu_2O	ZnO			As_2O_5	SeO_3	BrH			
Rb_2O	SrO	Yt_2O_3	ZrO_2	Nb_2O_5	MoO_3			RuO_4	

The first periodic table as suggested by Mendeleev in 1869

Key Concepts

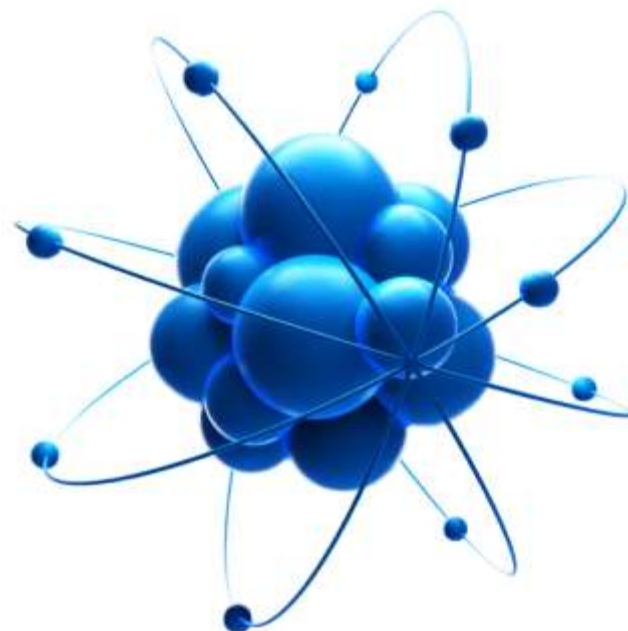
The modern periodic table

The modern periodic table arranges elements in order of **increasing atomic number**, not atomic mass.

Scientists have been adding elements to the periodic table, as more are discovered or created.

The last naturally occurring element to be discovered is Francium (Fr) in **1939**.

70 years after Mendeleev,
who had called it
eka-caesium



Key Concepts

Electron structure was discovered after the periodic table was developed...

5
B
10.811
boron

Electron configuration: $1s^2 2s^2 2p^1$

two electrons
located in the
orange 1s orbital

two electrons
located in the
green 2s orbital

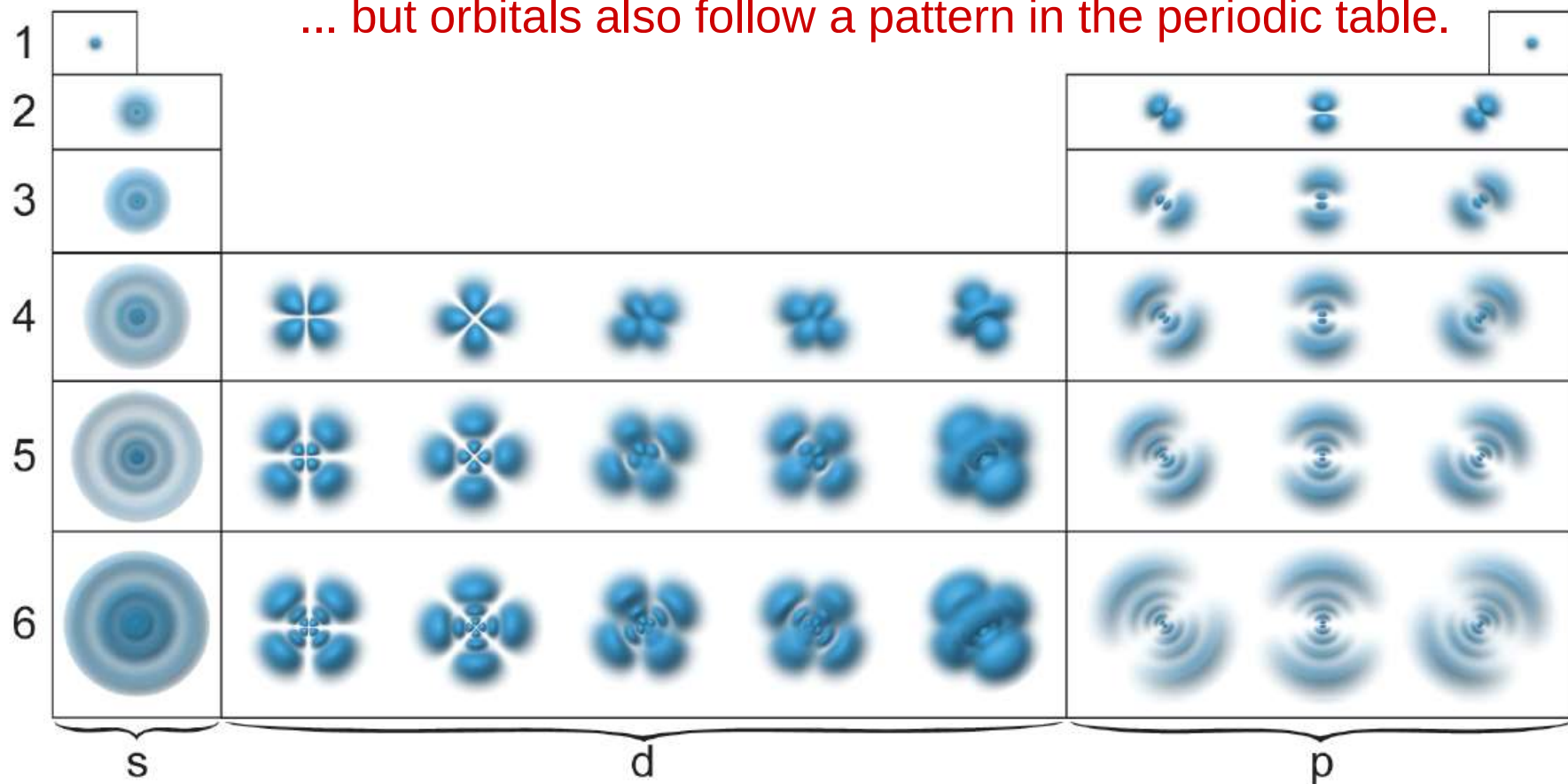
one electron
located in the
purple 2p orbital

Overlapping orbitals of boron

Key Concepts

Electron structure was discovered after the periodic table was developed...

... but orbitals also follow a pattern in the periodic table.



Key Concepts

group 1		metals										nonmetals								group 18															
1	H 1.0079 hydrogen																			2	He 4.0026 helium														
group 2												group 13	group 14	group 15	group 16	group 17																			
3	Li 6.941 lithium	4	Be 9.0122 beryllium											5	6	7	8	9	10																
11	Na 22.990 sodium	12	Mg 24.305 magnesium	21	Sc 44.956 scandium	22	Ti 47.867 titanium	23	V 50.942 vanadium	24	Cr 51.996 chromium	25	Mn 54.938 manganese	26	Fe 55.845 iron	27	Co 58.933 cobalt	28	Ni 58.693 nickel	29	Cu 63.546 copper	30	Zn 65.38 zinc	31	Ga 69.723 gallium	32	Ge 72.61 germanium	33	As 74.922 arsenic	34	Se 78.96 selenium	35	Br 79.904 bromine	36	Kr 83.80 krypton
37	Rb 85.468 rubidium	38	Sr 87.62 strontium	39	Y 88.906 yttrium	40	Zr 91.224 zirconium	41	Nb 92.906 niobium	42	Mo 95.96 molybdenum	43	Tc (98) technetium	44	Ru 101.07 ruthenium	45	Rh 102.91 rhodium	46	Pd 106.42 palladium	47	Ag 107.87 silver	48	Cd 112.41 cadmium	49	In 114.82 indium	50	Sn 118.71 tin	51	Sb 121.76 antimony	52	Te 127.60 tellurium	53	I 126.90 iodine	54	Xe 131.29 xenon
55	Cs 132.91 cesium	56	Ba 137.33 barium	71	Lu 174.97 lutetium	72	Hf 178.49 hafnium	73	Ta 180.95 tantalum	74	W 183.84 tungsten	75	Re 186.21 rhenium	76	Os 190.23 osmium	77	Ir 192.22 iridium	78	Pt 195.08 platinum	79	Au 196.97 gold	80	Hg 200.59 mercury	81	Tl 204.38 thallium	82	Pb 207.2 lead	83	Bi 208.98 bismuth	84	Po (209) polonium	85	At (210) astatine	86	Rn (222) radon
87	Fr (223) francium	88	Ra (226) radium	103	Lr (262) lawrencium	104	Rf (267) rutherfordium	105	Db (268) dubnium	106	Sg (271) seaborgium	107	Bh (272) bohrium	108	Hs (270) hassium	109	Mt (276) meitnerium	110	Ds (281) darmstadtium	111	Rg (280) roentgenium	112	Uub (285) ununbium	113	Uut (284) ununtrium	114	Uuq (289) ununquadium	115	Uup (288) ununpentium	116	Uuh (293) ununhexium	117	Uus (294) ununseptium	118	Uuo (294) ununoctium
		57	La 138.91 lanthanum	58	Ce 140.12 cerium	59	Pr 140.91 praseodymium	60	Nd 144.24 neodymium	61	Pm (145) promethium	62	Sm 150.36 samarium	63	Eu 151.96 europium	64	Gd 157.25 gadolinium	65	Tb 158.93 terbium	66	Dy 162.50 dysprosium	67	Ho 164.93 holmium	68	Er 167.26 erbium	69	Tm 168.93 thulium	70	Yb 173.06 ytterbium						
		89	Ac (227) actinium	90	Th 232.04 thorium	91	Pa 231.04 protactinium	92	U 238.03 uranium	93	Np (237) neptunium	94	Pu (244) plutonium	95	Am (243) americium	96	Cm (247) curium	97	Bk (247) berkelium	98	Cf (251) californium	99	Es (252) einsteinium	100	Fm (257) fermium	101	Md (258) mendelevium	102	No (259) nobelium						

alkali metals

alkaline earth metals

transition metals

rare earth metals

other metals

halogens

noble gases

Element
117
missing here

**Element
117
missing here**

Key Concepts

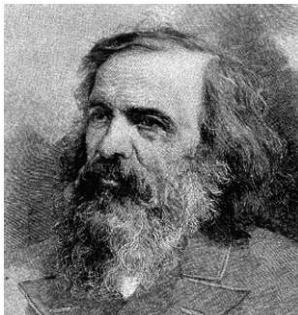
2009-2010

Element #117 was discovered through a Russian-US collaboration.
The discovery still needs to be confirmed.
It is temporarily named ununseptium (Uus).

Discoveries are made all the time!

Summary

Elements in **the first periodic table** were arranged in order of increasing **atomic mass**



H_2O						
Li_2O	BeO	B_2O_3	CO_2	N_2O_5	OH_2	FH
Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClH
K_2O	CaO		TiO_2	V_2O_5	CrO_3	MnH
Cu_2O	ZnO			As_2O_5	SeO_3	BrH
Rb_2O	SrO	Yt_2O_3	ZrO_2	Nb_2O_5	MoO_3	
						FeO_4 CoO_4
						RuO_4

The first periodic table as suggested by Mendeleev in 1869

Summary

Elements in **the modern periodic table** are arranged in order of increasing **atomic number**

The modern periodic table shows trends or repeating patterns in atomic radii, electronegativity and ionization energy

