Chemistry 1010

The Periodic Table:
How the Elements are Organized

Review

Name some elements that you remember from the previous lecture, and what you remember about them.

gold and copper are the only metals that aren't gray

Where do the names of the elements come from?

from names of substances, what they were found in, mythology, scientists, places

What are the symbols for the following elements?

argon Ar

arsenic As

astatine At

antimony Sb

nickel Ni

neptunium Np

nitrogen N

niobium Nb

What is the most common element in the universe? What is next?

hydrogen, helium (99.75%)

What are the two most common elements on the earth?

oxygen, silicon (75%)

What are the four most common elements in your body?

oxygen, carbon, hydrogen, nitrogen (96%)

What are the three categories of elements based on what they look like in their pure form?

metals (74)

nonmetals (17)

metalloids (6)

?

unknown (21)

If a pure element can exist in two or more different forms, what are these forms called?

allotropes

How many elements can be found native (in their pure form in nature)?

gold, silver, copper, platinum, iron, carbon, sulfur – 7

How are the other elements found?

in compounds and mixtures

Introduction

Take a good look at the Periodic Table of Elements that you were given. What objective observations can you make about it?

Periodic Table of the Elements
2011

1 H hydrogen 1.008																	2 He helium 4.00
3 Li lithium 6.94	4 Be beryllium 9.01											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											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 39.20	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 72.61	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 101.0	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.8	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.7	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.2
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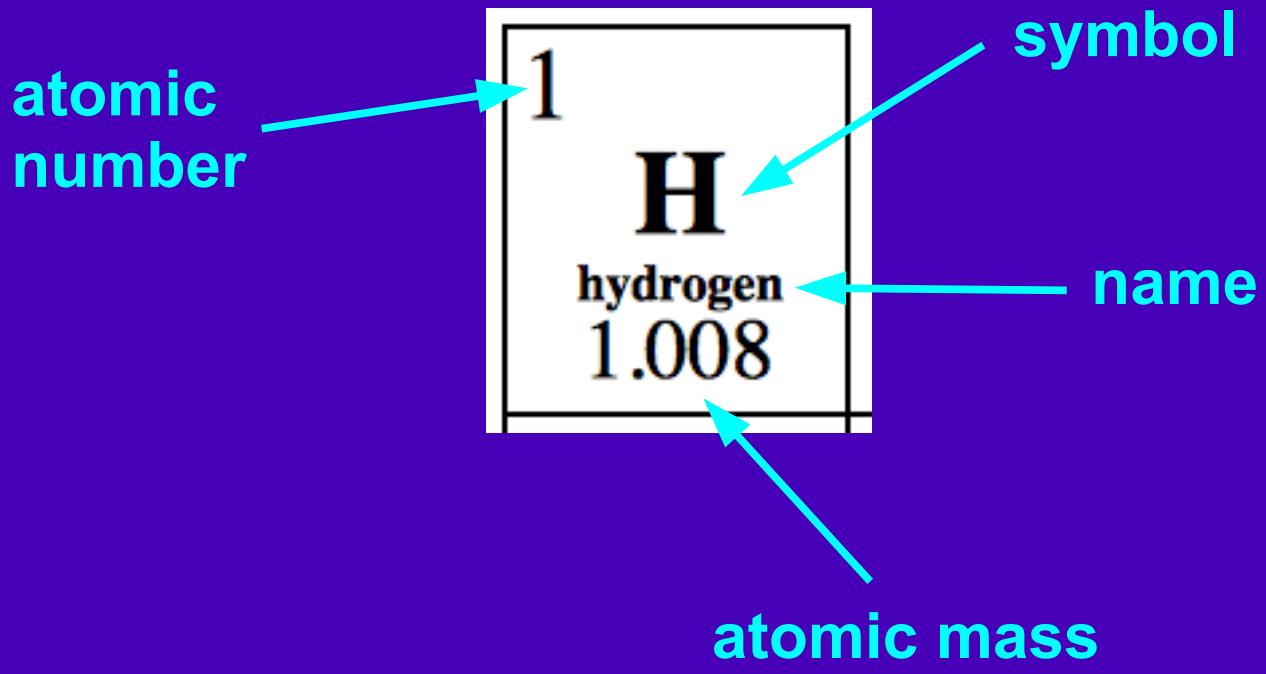
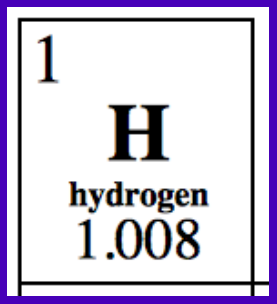
What does each block of the Periodic Table contain?

each block represents one element



Why isn't the atomic mass a whole number?



more than one isotope exists in nature

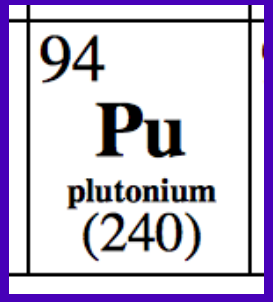
99.98% have 1 proton; mass = 1

0.015% have 1 proton, 1 neutron; mass = 2

1 in 1018 have 1 proton, 2 neutrons; mass = 3

mass of hydrogen found in nature: 1.007

What about atoms whose mass is a whole number in parenthesis?



for most radioactive elements, the mass of the most stable isotope is shown

Today we will discuss the Periodic Table.

1. Why did chemists need a new way to organize the elements?

2. What does “periodic” mean?

3. How does the Periodic Table show repeating patterns?

4. How can the Periodic Table be used to predict the properties of elements?

1. Why did chemists need a new way to organize the elements?

There are lots of ways that you could organize a list of elements.

How is this list organized? alphabetically

actinium
aluminum
americium
antimony
argon
arsenic
astatine
barium
berkelium
beryllium
bismuth
bohrium
boron
bromine
cadmium
calcium
californium
carbon
cerium
cesium
chlorine
chromium
cobalt
copernicium
copper
curium
darmstradtium
dubnium
dysprosium
einsteinium
erbium
europium
fermium
fluorine
francium
gadolinium
gallium
germanium
gold
hafnium
hassium
helium
holmium
hydrogen
indium
iodine
iridium
iron
krypton
lanthanum
lawrencium
lead
lithium
lutetium
magnesium
manganese
meitnerium
mendelevium
mercury
molybdenum
neodymium
neon
neptunium
nickel
niobium
nitrogen
nobelium
osmium
oxygen
palladium
phosphorus
platinum
plutonium
polonium
potassium
praseodymium
promethium
protactinium
radium
radon
rhenium
rhodium
roentgenium
rubidium
ruthenium
rutherfordium
samarium
scandium
seaborgium
selenium
silicon
silver
sodium
strontium
sulfur
tantalum
technetium
tellurium
terbium
thallium
thorium
thulium
tin
titanium
tungsten
uranium
vanadium
xenon
ytterbium
yttrium
zinc
zirconium

advantage: easy to find an element

problem: doesn't tell us anything about properties

How was Dalton's 1805 list of elements organized? by mass

advantage: you can see what elements are lighter and which are heavier

problem: you can't predict any other properties

How is the list that I gave you organized? by atomic number

elements go up in mass and atomic number almost identically

As more and more elements were being discovered, chemists tried to find a way to organize them that would show how their properties were related.

A chemist named Dmitri Mendeleev discovered the key.

Mendeleev was a card player. He wrote the names, masses, and properties of the 63 known elements on playing cards and shuffled and dealt them again and again, looking for a good way to organize them.

Eventually he realized that:

when elements are listed in order
of their mass, their properties are periodic

2. What does “periodic” mean?

If something is periodic, then it:

has properties with a repeating pattern

Let's consider some examples of things you are familiar with: numbers, letters, days of the month, temperature, and wind speed.

Numbers:

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 etc

Is there a pattern to how we write the numbers?

yes – 0 to 9 are different, but then it starts over at 10 - 19

How could you make a chart to represent this?

0	1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18	19
20	21	22	23	24	25	26	27	28	29
30	31	32	33	34	35	36	37	38	39
40	41	42	43	44	45	46	47	48	49
50	51	52	53	54	55	56	57	58	59
60	61	62	63	64	65	66	67	68	69
70	71	72	73	74	75	76	77	78	79
80	81	82	83	84	85	86	87	88	89
90	91	92	93	94	95	96	97	98	99

If you go across the rows of this table:

the first digit is the same
the last digit is in order of size

If you go down a column of this table:

all of the numbers end in the same digit

Are numbers periodic? yes – pattern repeats itself exactly

Letters:

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Are there any repeating patterns in the letters? not really

We could make a chart by starting a new row every time there is a vowel.

A	B	C	D		
E	F	G	H		
I	J	K	L	M	N
O	P	Q	R	S	T
U	V	W	X	Y	Z

Across the rows: goes up one letter

Down the columns: nothing in common

Are the letters periodic? no

Days in a month:

Sat, Dec 1
Mon, Dec 2
Tues, Dec 3
Wed, Dec 4
Thurs, Dec 5
Fri, Dec 6
Sat, Dec 6
Sun, Dec 7
Mon, Dec 8

Are there any repeating patterns? days of the week repeat

How can we make a chart showing this?

Sun	Mon	Tues	Wed	Thurs	Fri	Sat
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

rows – dates go across, then continue on the next row

columns – all the same day of the week

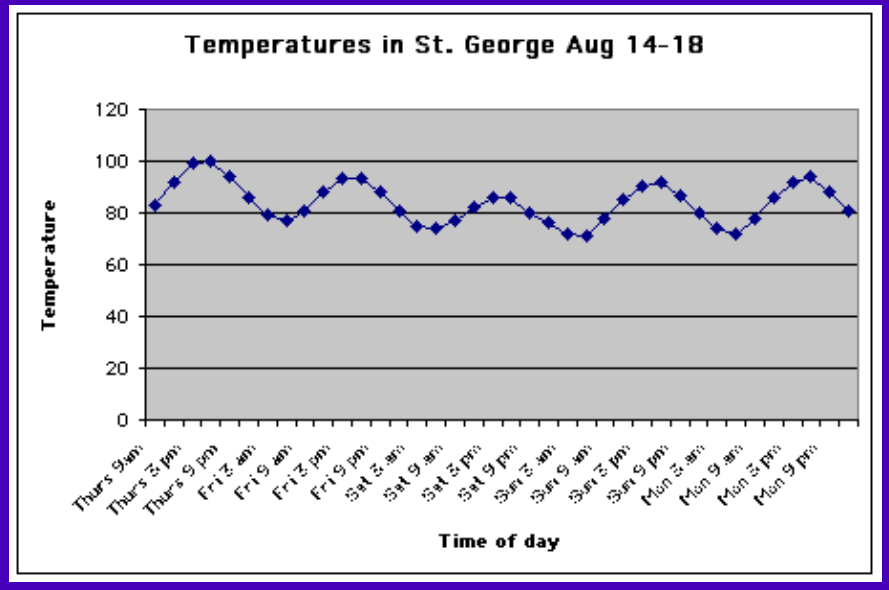
Are days of the month periodic? yes!

Temperature:

If you took the outside temperature every three hours for five days, what pattern would you see?

it would get colder in the night, then warmer in the day

We can show this by making a graph.



the graph shows the repeating pattern

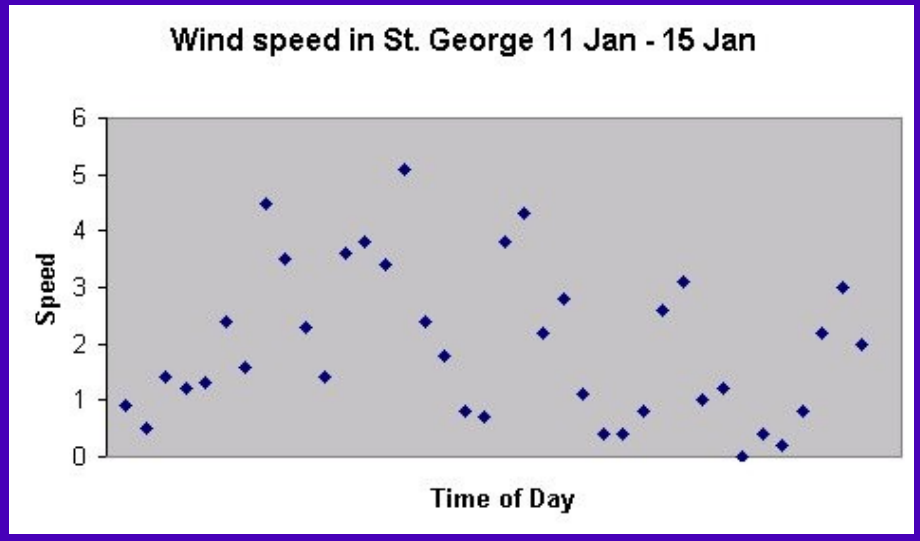
Is temperature periodic? yes

Wind speed:

If you took the wind speed every three hours for five days, what pattern would you see?

there probably wouldn't be one

Here's what the graph would look like:



no repeating pattern

Is wind speed periodic? no

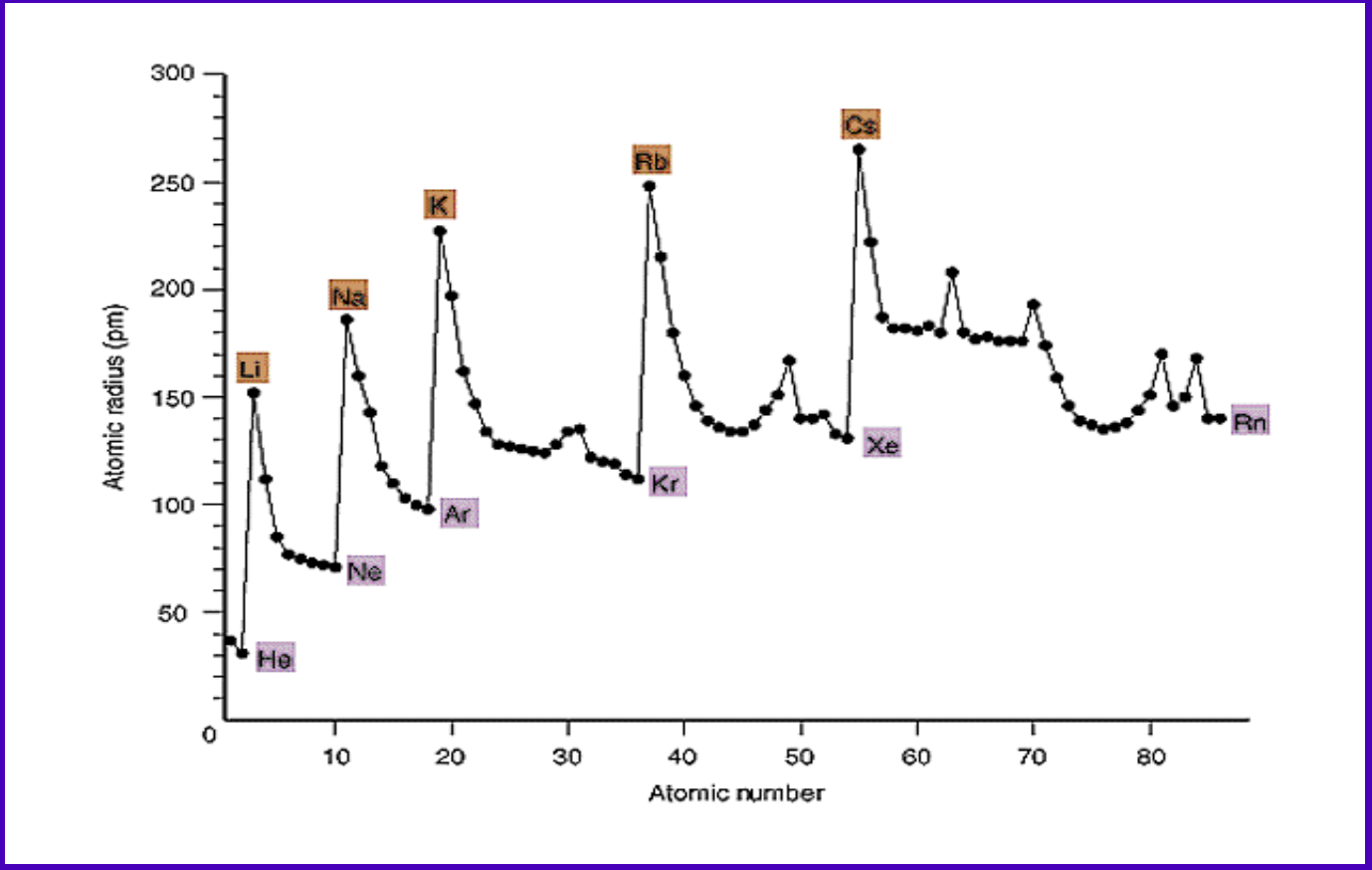
Graphs can show whether something is periodic or not.

If something is periodic, a table will show a relationship both across rows and down columns.

Elements:

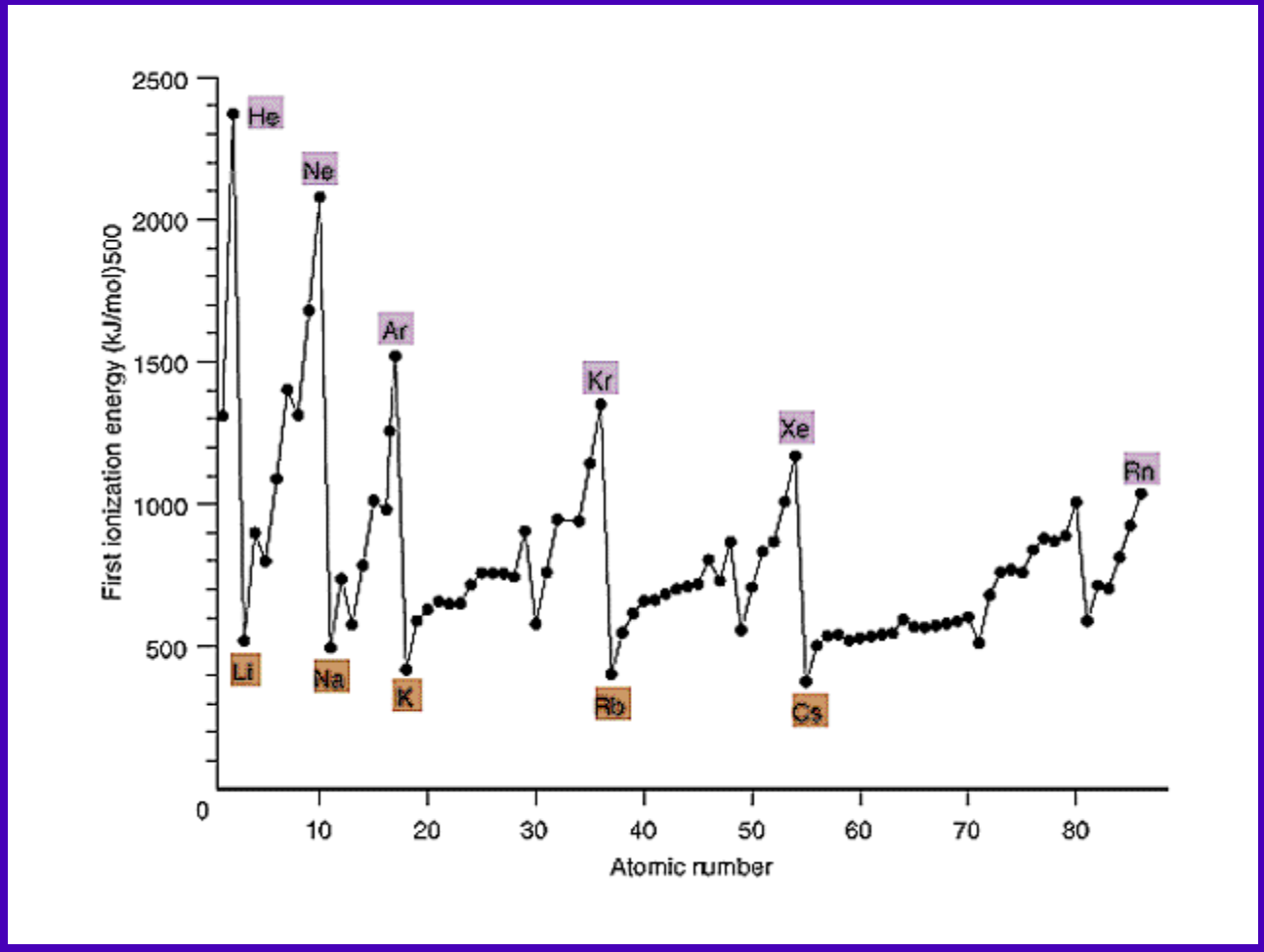
Here are three graphs showing different properties of the elements.

Is there a repeating pattern?



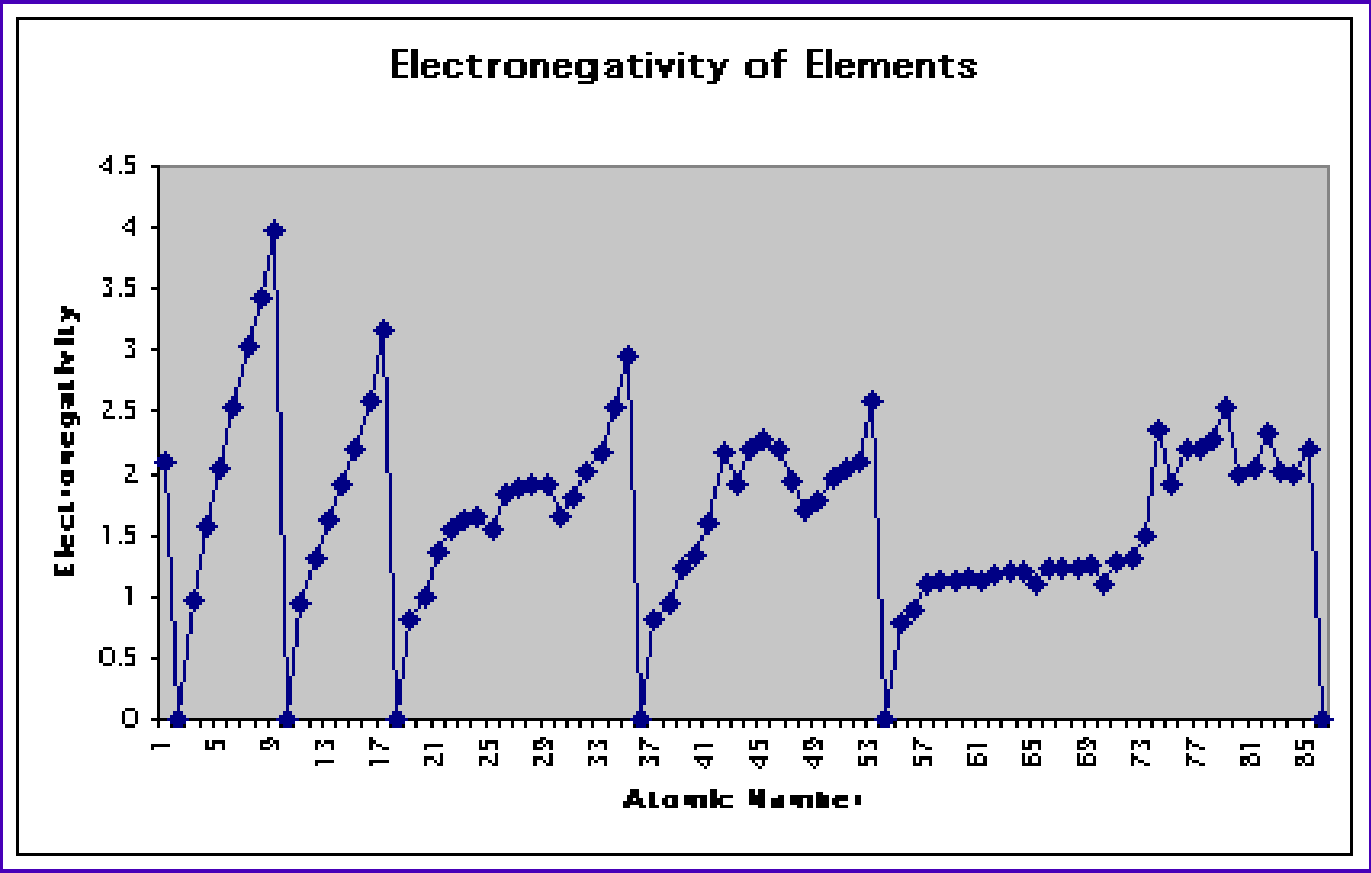
yes

size of atoms (atomic radius)



yes

first ionization potential



yes

electronegativity

Since the elements are periodic, there must be a way to make a chart which will make use of these repeating patterns.

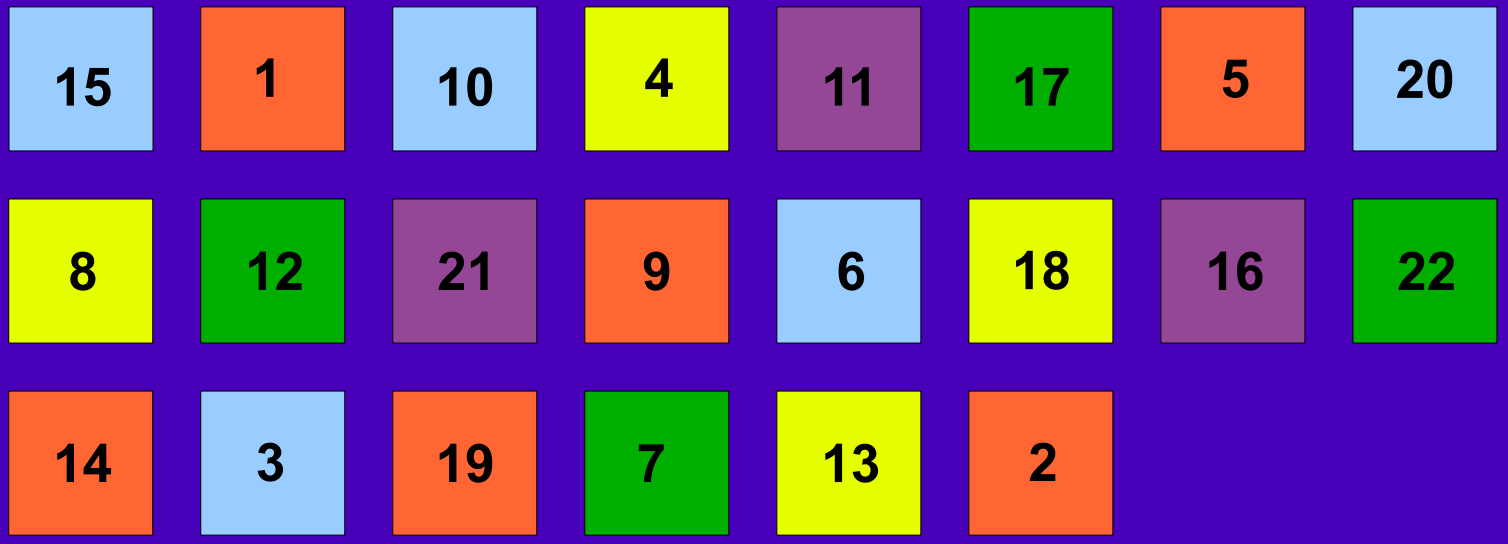
3. How does the Periodic Table show repeating patterns?

To show how Mendeleev used the repeating patterns in the elements to create the Periodic table, we'll use a set of colored cards with numbers on them.

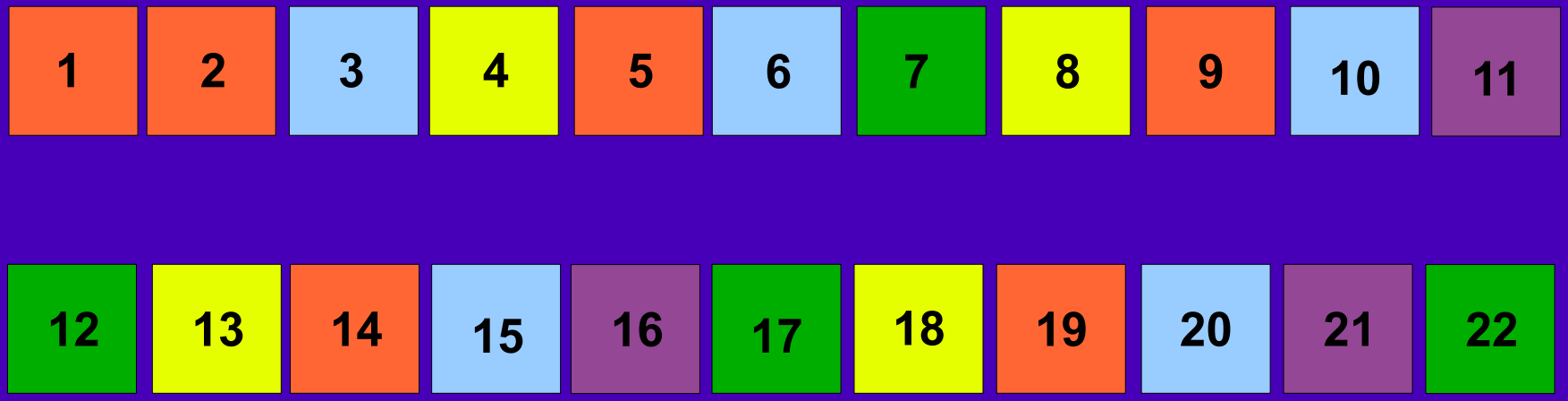
numbers = mass of the element

colors = properties of the element

Step 1: Random order (this is like an alphabetic list of the elements)



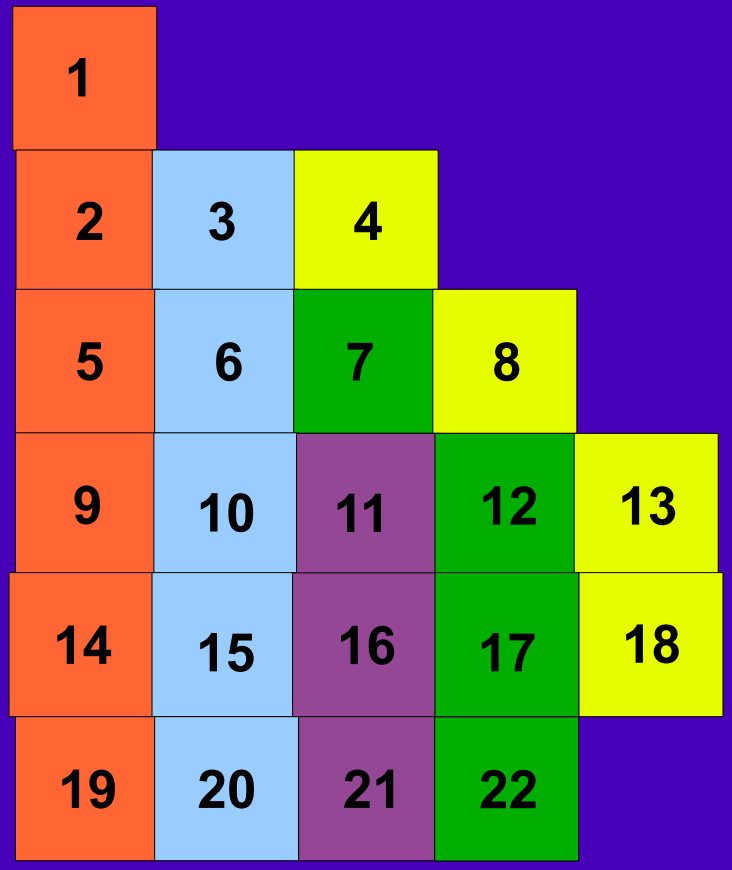
Step 2: Arrange the cards in a long row in numerical order (this is like a list of the elements in order of mass)



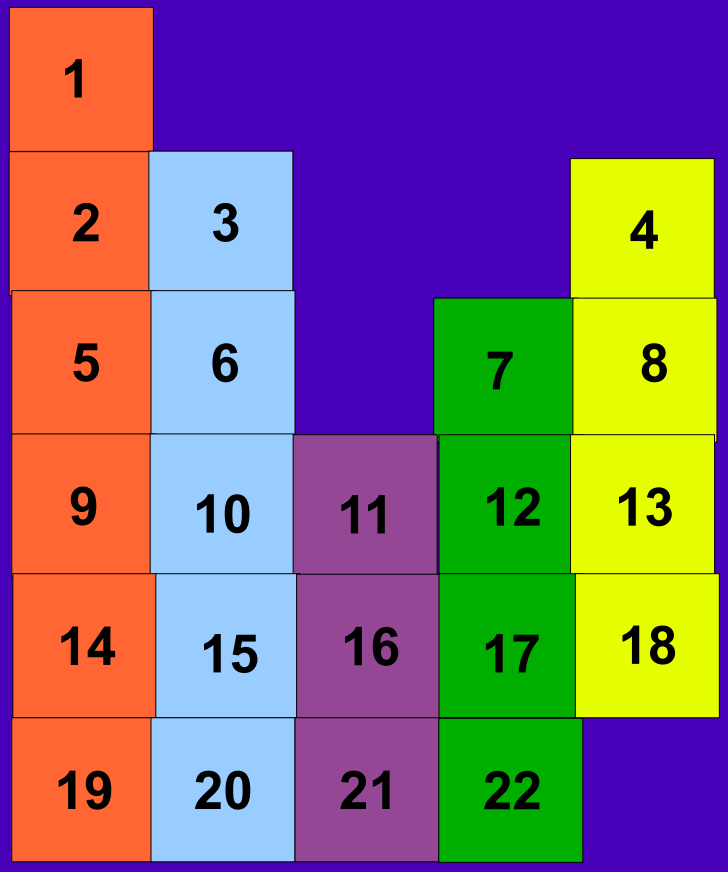
What patterns do you see here?

- blue always comes after orange
- green is always followed by yellow
- purple is always between a blue and a green
- yellow always has an orange after it
- and so on

Step 3: Turn the row into a table by starting over every time there is an orange card.



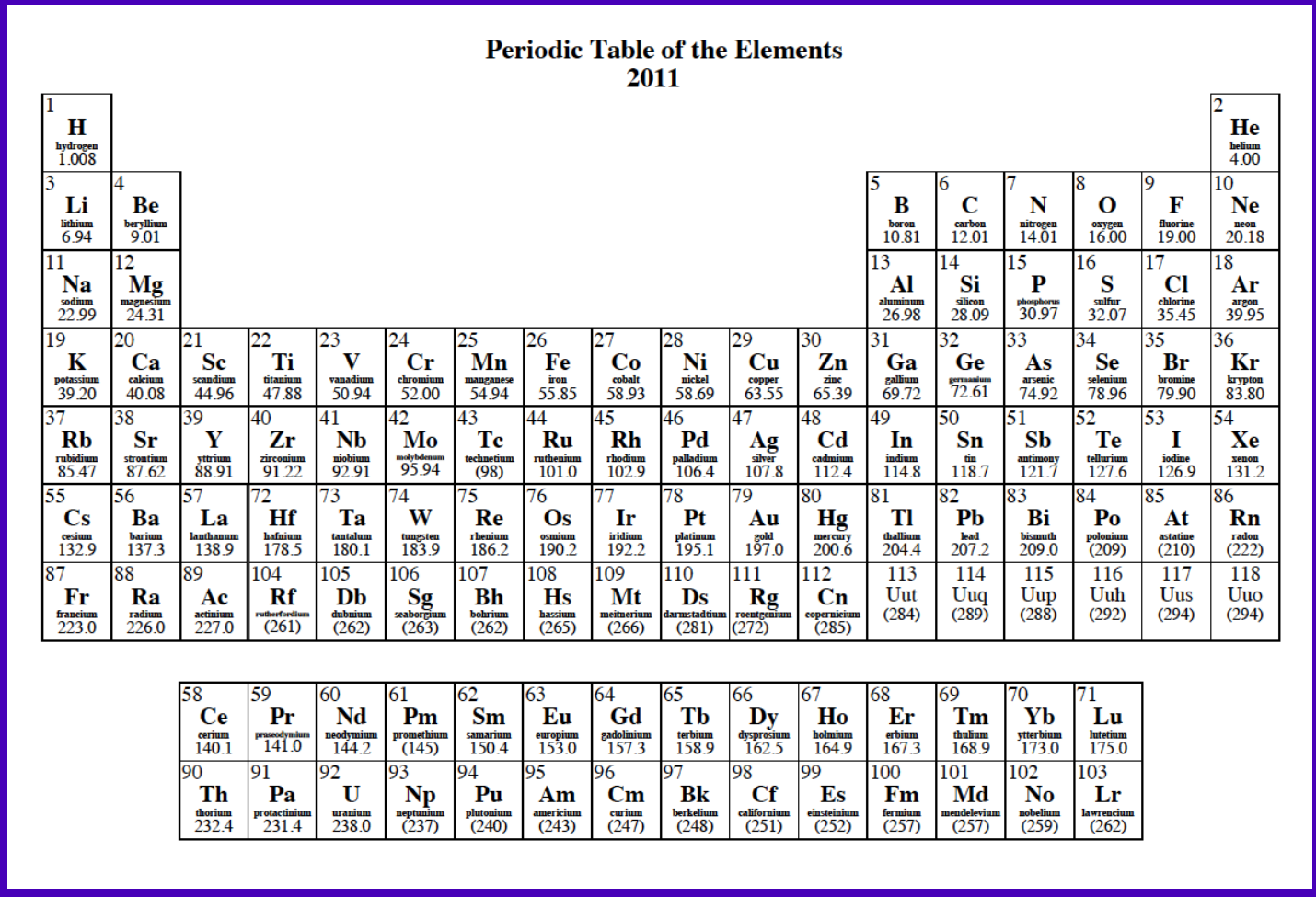
Step 4: Slide the cards over so that the columns match up.



rows: numbers go up by one (may jump across)

columns: same color

How does the table you have made compare to the Periodic Table of Elements?



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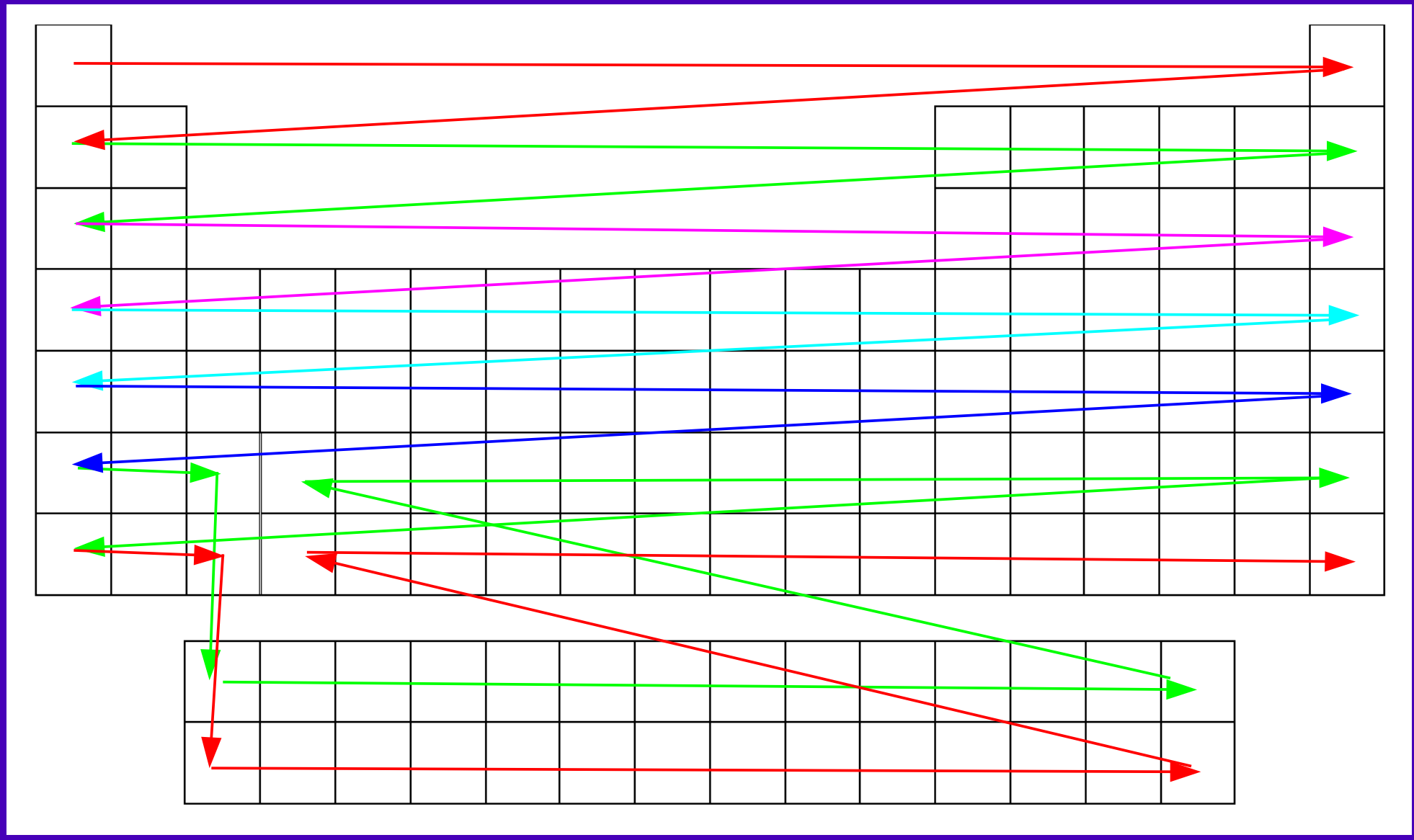
rows: increase in both atomic number and mass

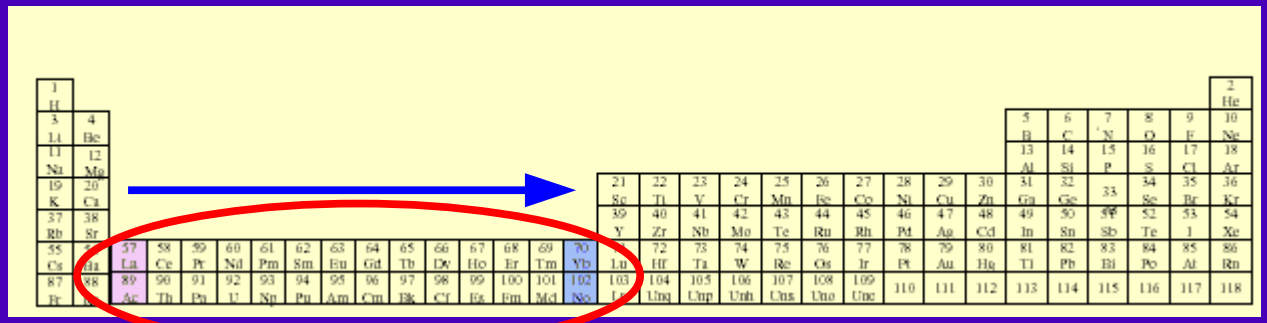
columns: elements with similar properties

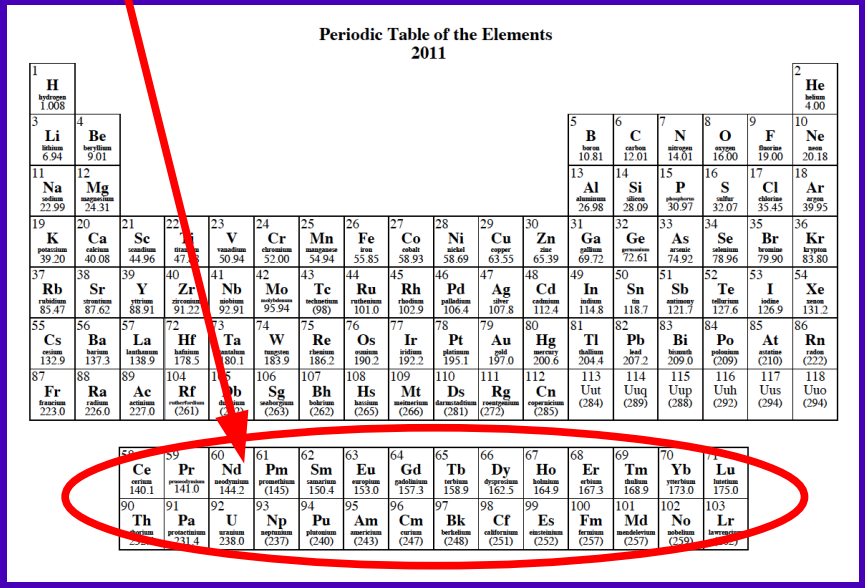
Draw arrows to show how the atomic number increases:



What's going on with the two rows at the bottom of the table?

Here's what the Periodic Table should really look like:





To make the table smaller, they took some elements out of the middle and made them into two separate rows.

If a new element with the atomic number 119 was created, where would it go?

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119

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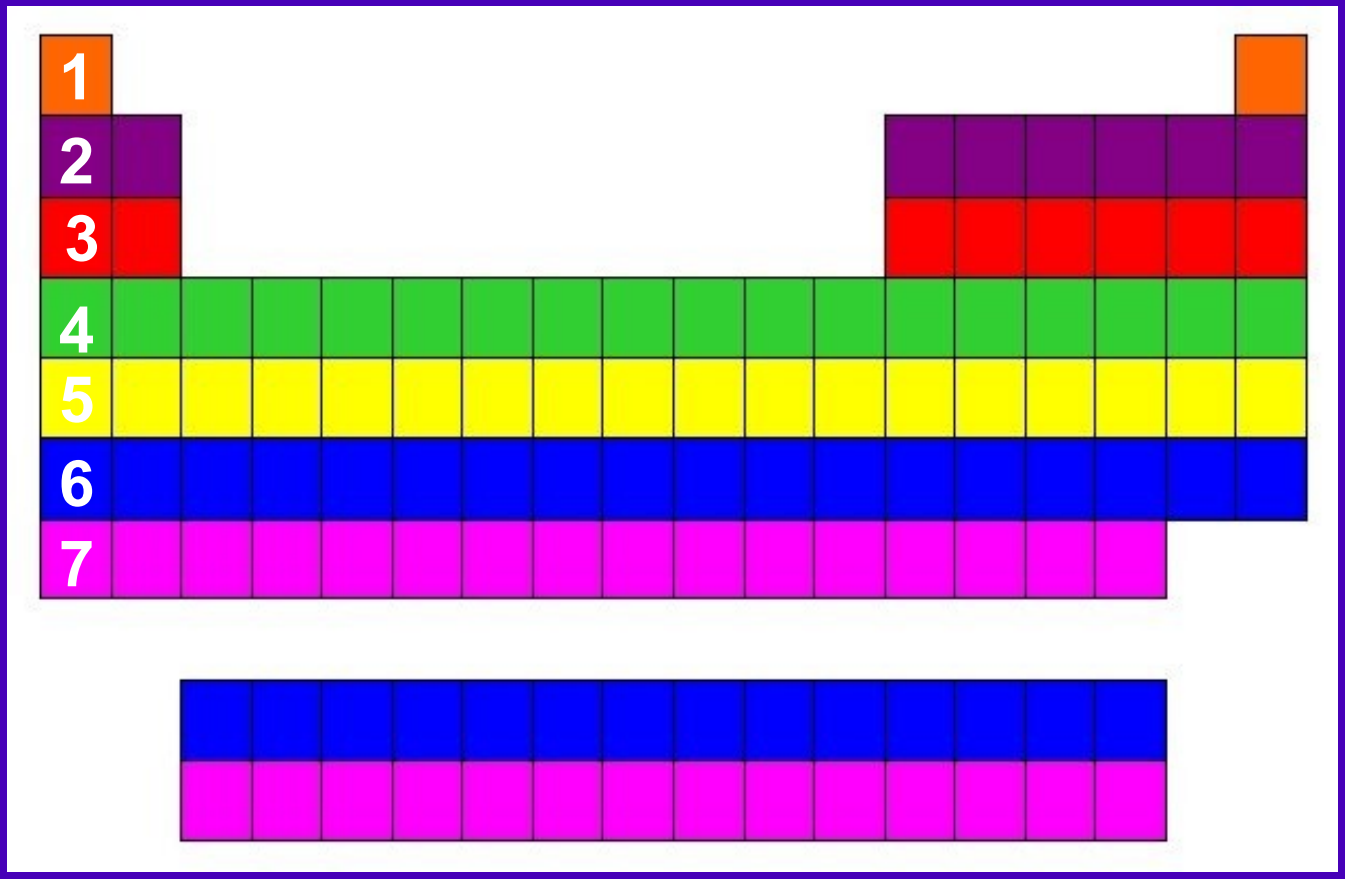
It would start a new row beneath francium.

Rows are called periods.

Periods are numbered from the top.



What period are the following elements in?

beryllium (4) 2nd period

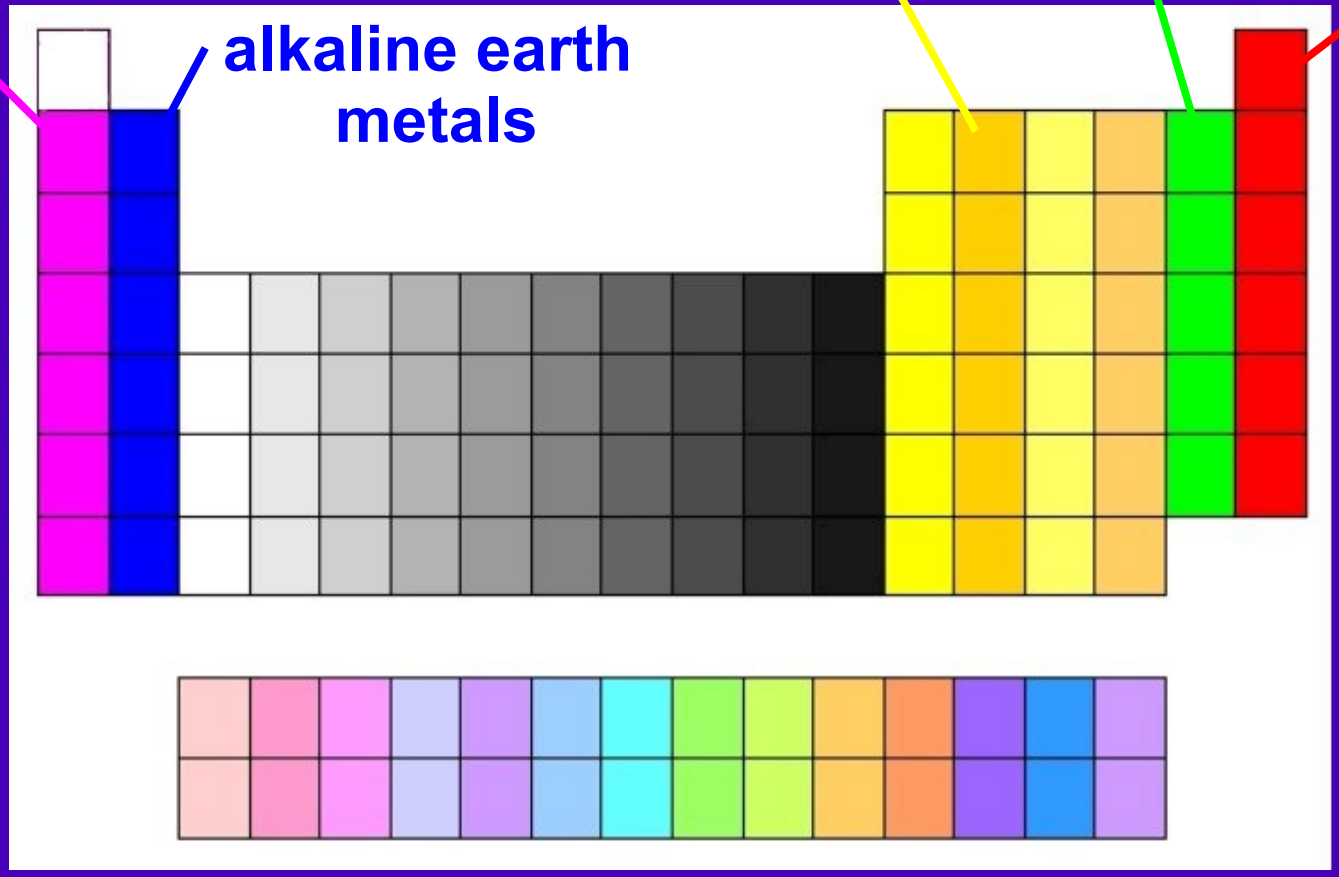
titanium (22) 4th period

tungsten (74) 6th period

curium (96) 7th period

Columns are called families or groups.

Some families have names.

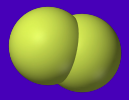


All other columns are named after the first element in the family.

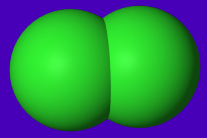
Elements in the same family have similar properties.

Halogens

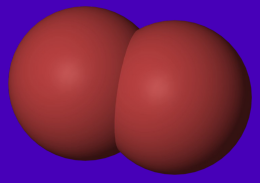
all occur in pure form as diatomic molecules which are highly reactive



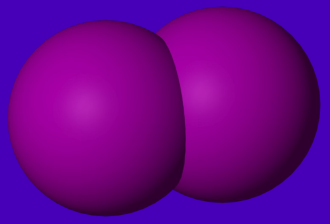
fluorine



chlorine



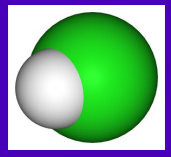
bromine



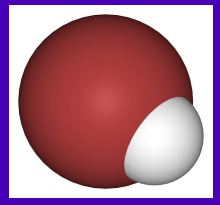
iodine

all form a highly acidic compound with one hydrogen atom and one halogen atom

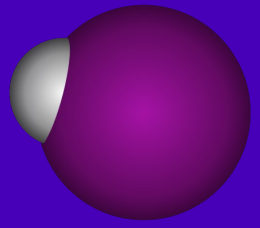
hydrogen fluoride



hydrogen chloride

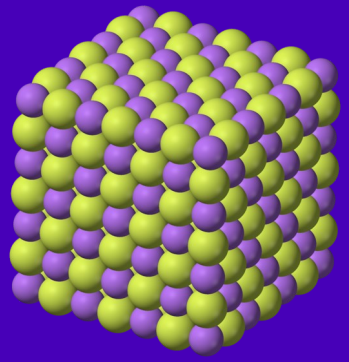


hydrogen bromide

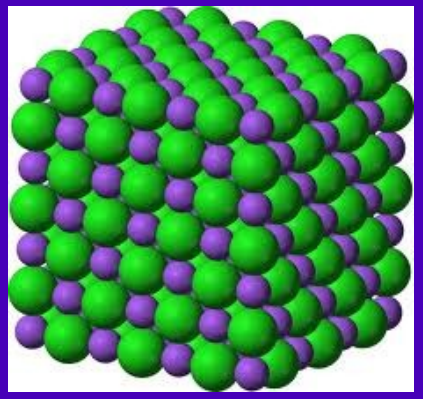


hydrogen iodide

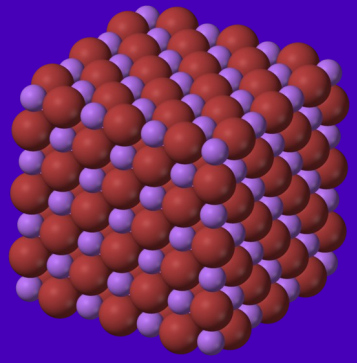
all form a 1:1 compound with sodium where the halogen has a -1 charge



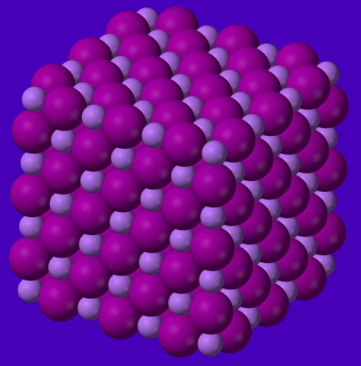
sodium fluoride



sodium chloride

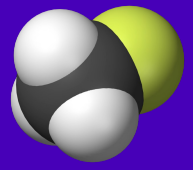


sodium bromide

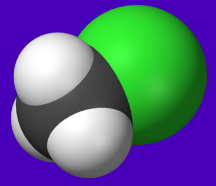


sodium iodide

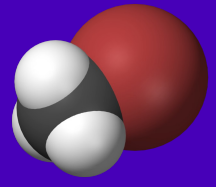
all form a compound with one halogen atom, one carbon atom, and three hydrogen atoms



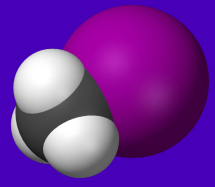
fluoromethane



chloromethane



bromomethane

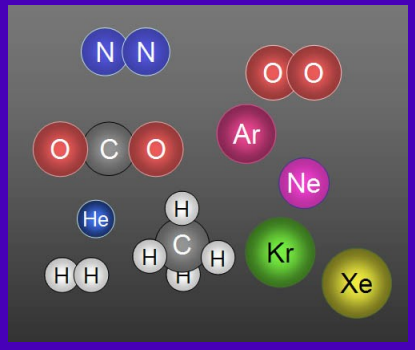


iodomethane

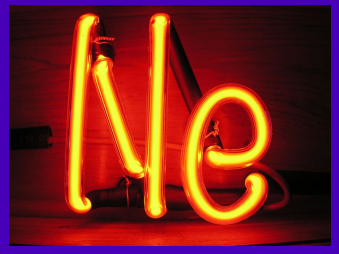
noble gases

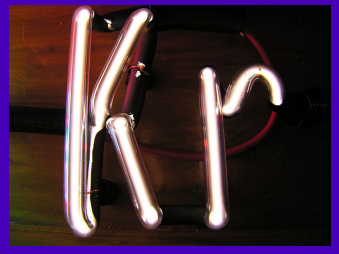
all occur in pure form as colorless gases

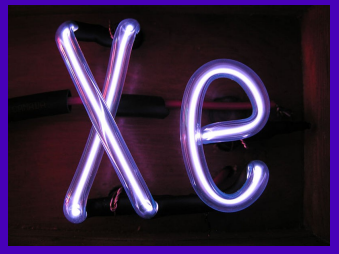
all are highly unreactive, forming few if any compounds with themselves or other elements



all give off light in gas discharge lamps

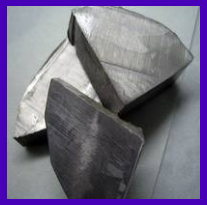






alkali metals

all are soft, highly reactive metals in pure form


lithium sodium potassium rubidium cesium

all easily lose one electron to form +1 ions

all react with water to form hydrogen gas (which ignites!)





lithium + water | sodium + water | potassium + water | rubidium + water | cesium + water

alkaline earth metals

all are reactive silver colored, soft metals
(but less reactive and harder than alkali metals)


beryllium


magnesium


calcium


stronium


barium

all are more dense than alkali metals and melt at very high temperatures – stay solid in a fire

Li 180°C	Na 98°C	K 63°C	Rb 38°C	Cs 28°C	Fr 27°C
Be 1278°C	Mg 650°C	Ca 839°C	Sr 764°C	Ba 725°C	Ra 700°C

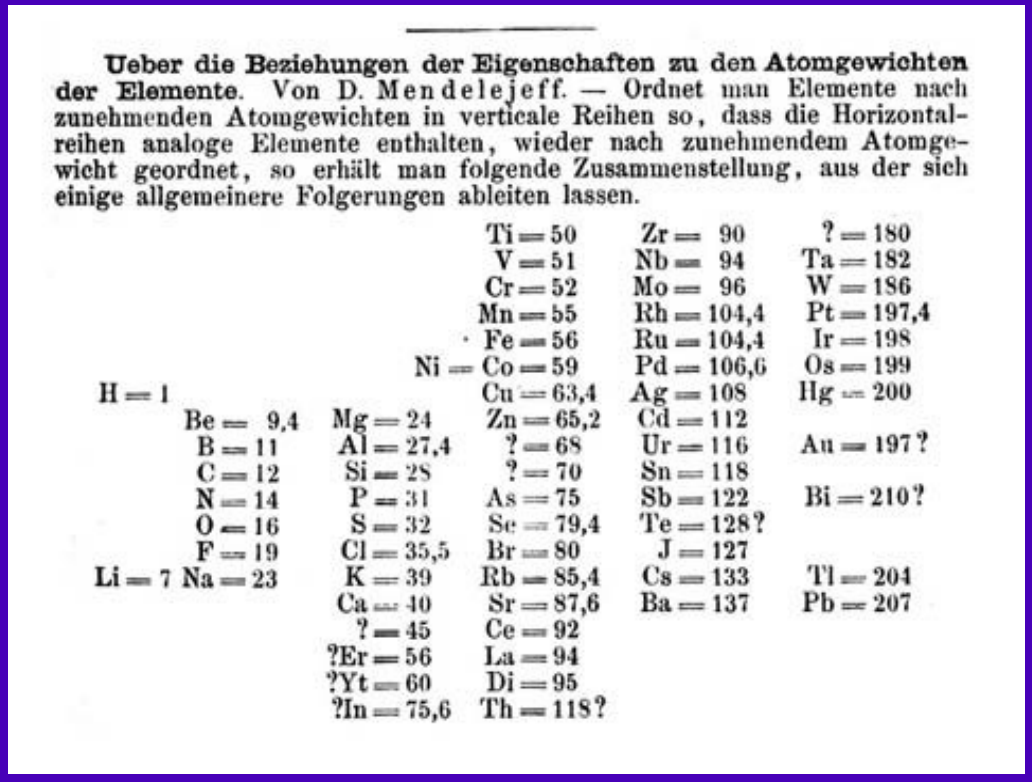
all react with water, but not as vigorously as alkali metals

all form compounds with chlorine with a 1:2 ratio

LiCl	NaCl	KCl	RbCl	CsCl	FrCl
$BeCl_2$	$MgCl_2$	$CaCl_2$	$SrCl_2$	$BaCl_2$	$RaCl_2$

4. How can the Periodic Table of Elements be used to predict the properties of elements?

When Mendeleev first published his Periodic Table in 1869, there were only 63 known elements, which is only about 2/3 of the naturally occurring elements.

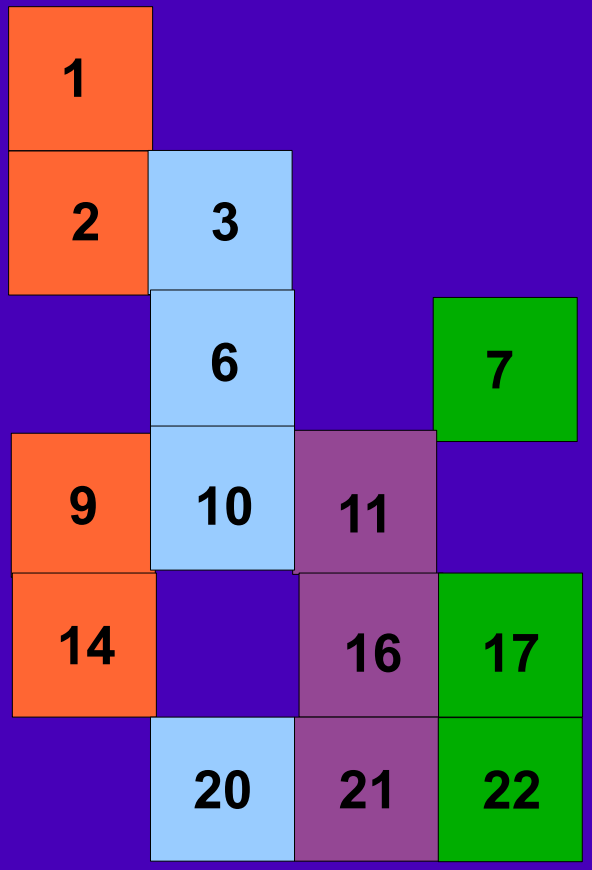


Ueber die Beziehungen der Eigenschaften zu den Atomgewichten der Elemente. Von D. Mendelejeff. — Ordnet man Elemente nach zunehmenden Atomgewichten in verticale Reihen so, dass die Horizontalreihen analoge Elemente enthalten, wieder nach zunehmendem Atomgewicht geordnet, so erhält man folgende Zusammenstellung, aus der sich einige allgemeinere Folgerungen ableiten lassen.

			Ti = 50	Zr = 90	? = 180	
			V = 51	Nb = 94	Ta = 182	
			Cr = 52	Mo = 96	W = 186	
			Mn = 55	Rh = 104,4	Pt = 197,4	
			Fe = 56	Ru = 104,4	Ir = 198	
			Ni = Co = 59	Pd = 106,6	Os = 199	
H = 1			Cu = 63,4	Ag = 108	Hg = 200	
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112		
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?	
	C = 12	Si = 28	? = 70	Sn = 118		
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?	
	O = 16	S = 32	Se = 79,4	Te = 128?		
	F = 19	Cl = 35,5	Br = 80	J = 127		
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204	
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207	
		? = 45	Ce = 92			
		?Er = 56	La = 94			
		?Yt = 60	Di = 95			
		?In = 75,6	Th = 118?			

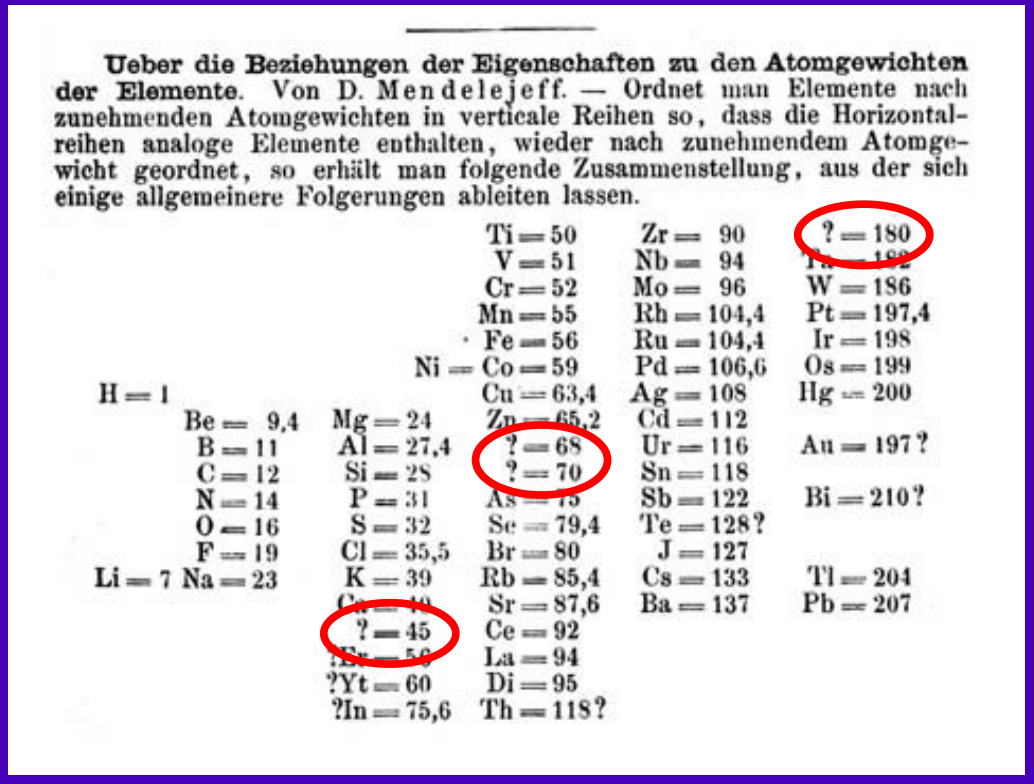
mass increase down

similar elements are across



So his cards actually looked more like this!

Mendeleev used the patterns that he had found to do something rather astonishing. When there was a space in the pattern with no element to fill it, he left a space open and predicted that a new element would be found to fill it.



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			Ti = 50	Zr = 90	? = 180
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			Mn = 55	Rh = 104,4	Pt = 197,4
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		Ni =	Co = 59	Pd = 106,6	Os = 199
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	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
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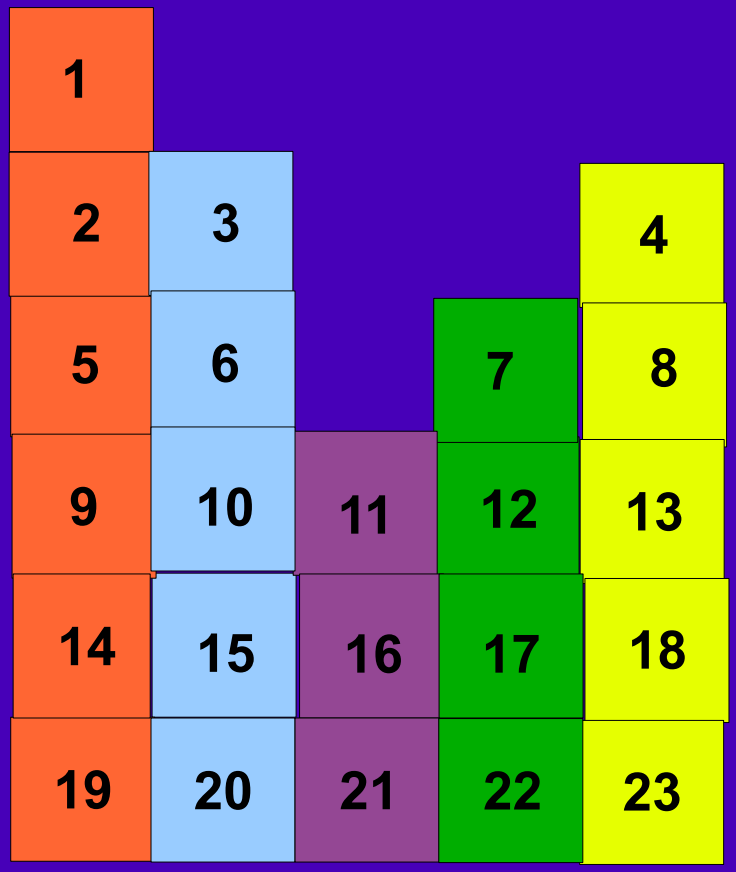
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Within a few years, three of these elements were found in nature.

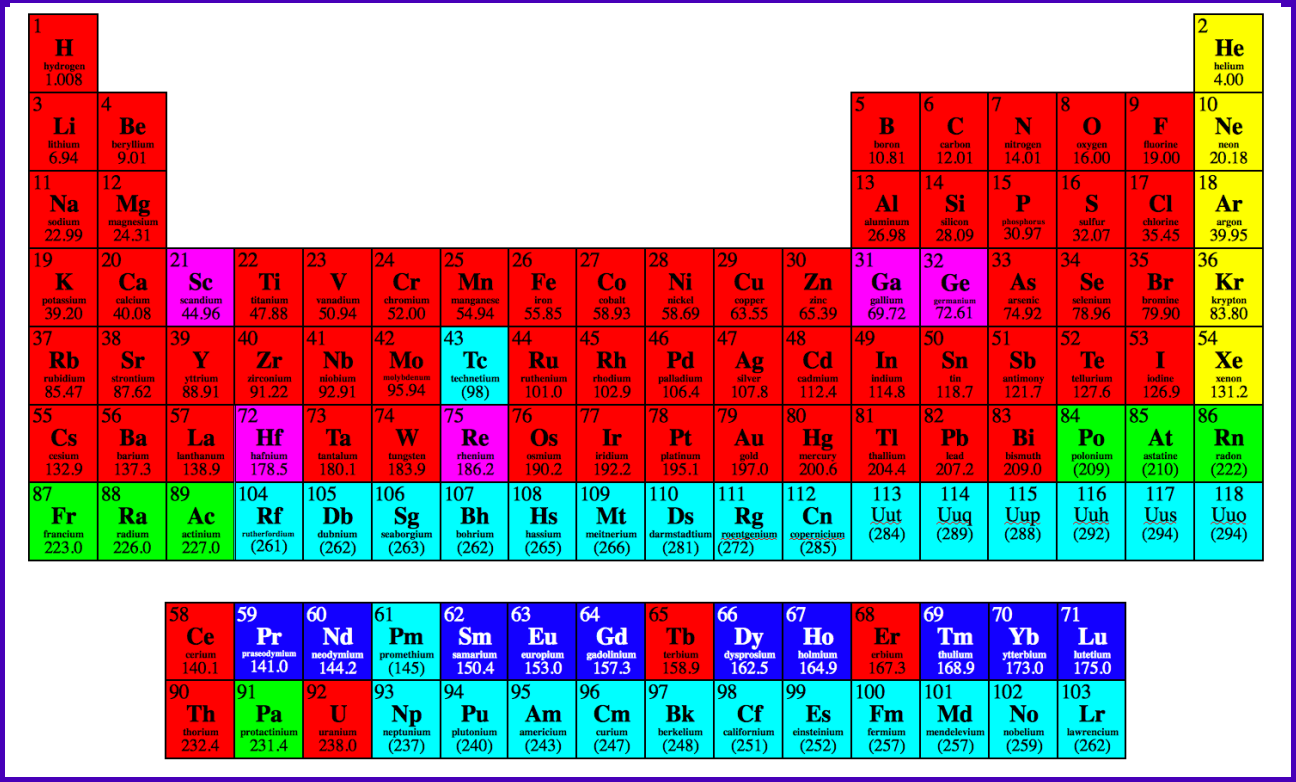
1875 ? = 68 gallium (actual mass 69.72)
1879 ? = 45 scandium (actual mass 44.96)
1886 ? = 70 germanium (actual mass 72.61)
1925 ? = 180 rhenium (actual mass 186.2)

Can you predict the cards that are missing in this table?



What else is missing?

Here is what our current table looks like with only the elements Mendeleev knew:



1 H hydrogen 1.008																	2 He helium 4.00
3 Li lithium 6.94	4 Be beryllium 9.01											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											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 39.20	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 72.61	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 101.0	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.8	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.7	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.2
55 Cs cesium 132.9	56 Ba barium 137.3	57 La lanthanum 138.9	72 Hf hafnium 178.5	73 Ta tantalum 180.1	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 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium 223.0	88 Ra radium 226.0	89 Ac actinium 227.0	104 Rf rutherfordium (261)	105 Db dubnium (262)	106 Sg seaborgium (263)	107 Bh bohrium (262)	108 Hs hassium (265)	109 Mt meitnerium (266)	110 Ds darmstadtium (281)	111 Rg roentgenium (272)	112 Cn copernicium (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)	117 Uus (294)	118 Uuo (294)

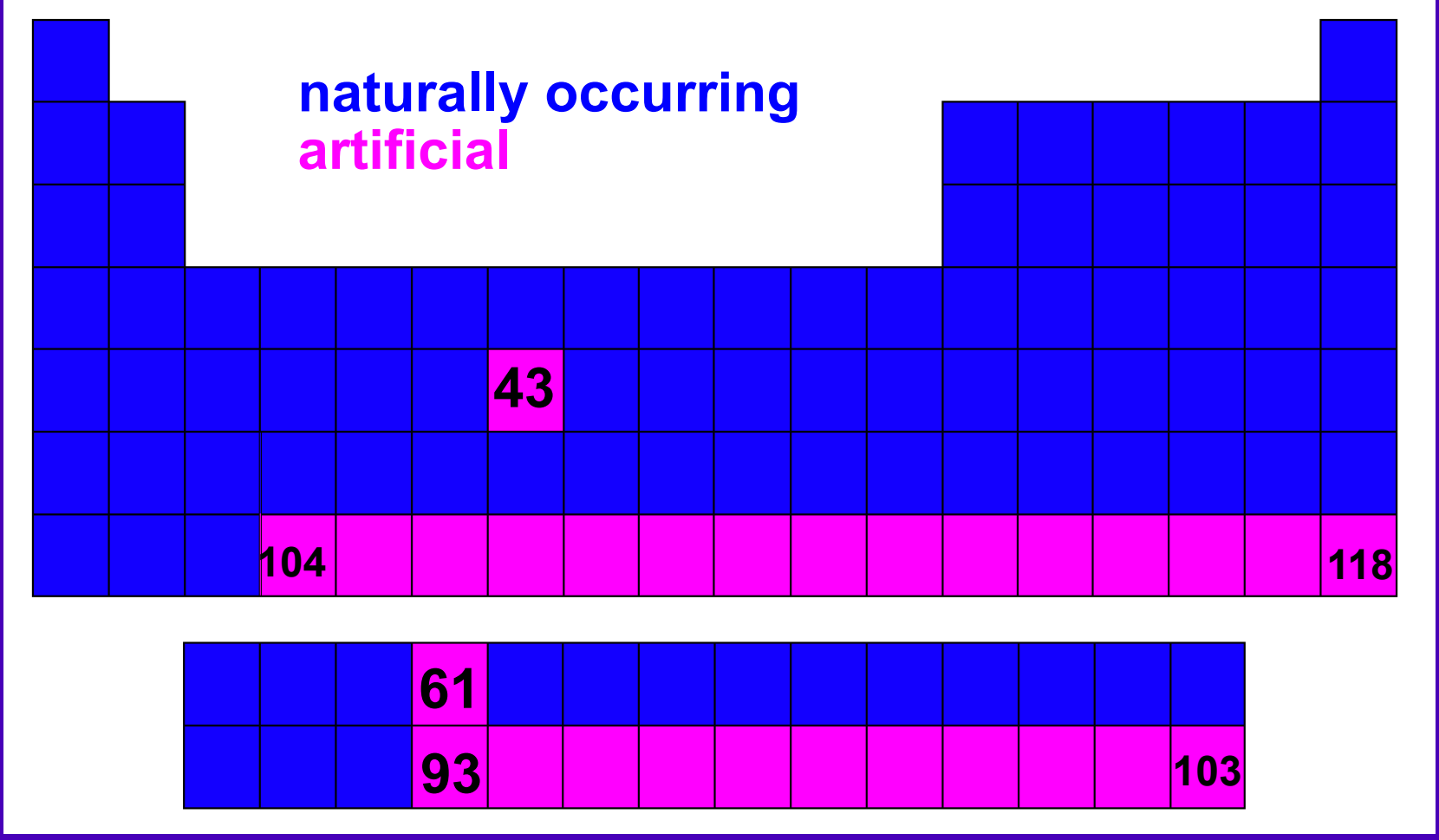
58 Ce cerium 140.1	59 Pr praseodymium 141.0	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 153.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
90 Th thorium 232.4	91 Pa protactinium 231.4	92 U uranium 238.0	93 Np neptunium (237)	94 Pu plutonium (240)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (248)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (257)	102 No nobelium (259)	103 Lr lawrencium (262)

What's missing?

- Sc, Ga, Ge, Re, hafnium (1923)
- noble gases (1894-1898)
- radioactive elements (1898-1900)
- rare earth elements (1878-1901)
- artificial elements (1939-present)

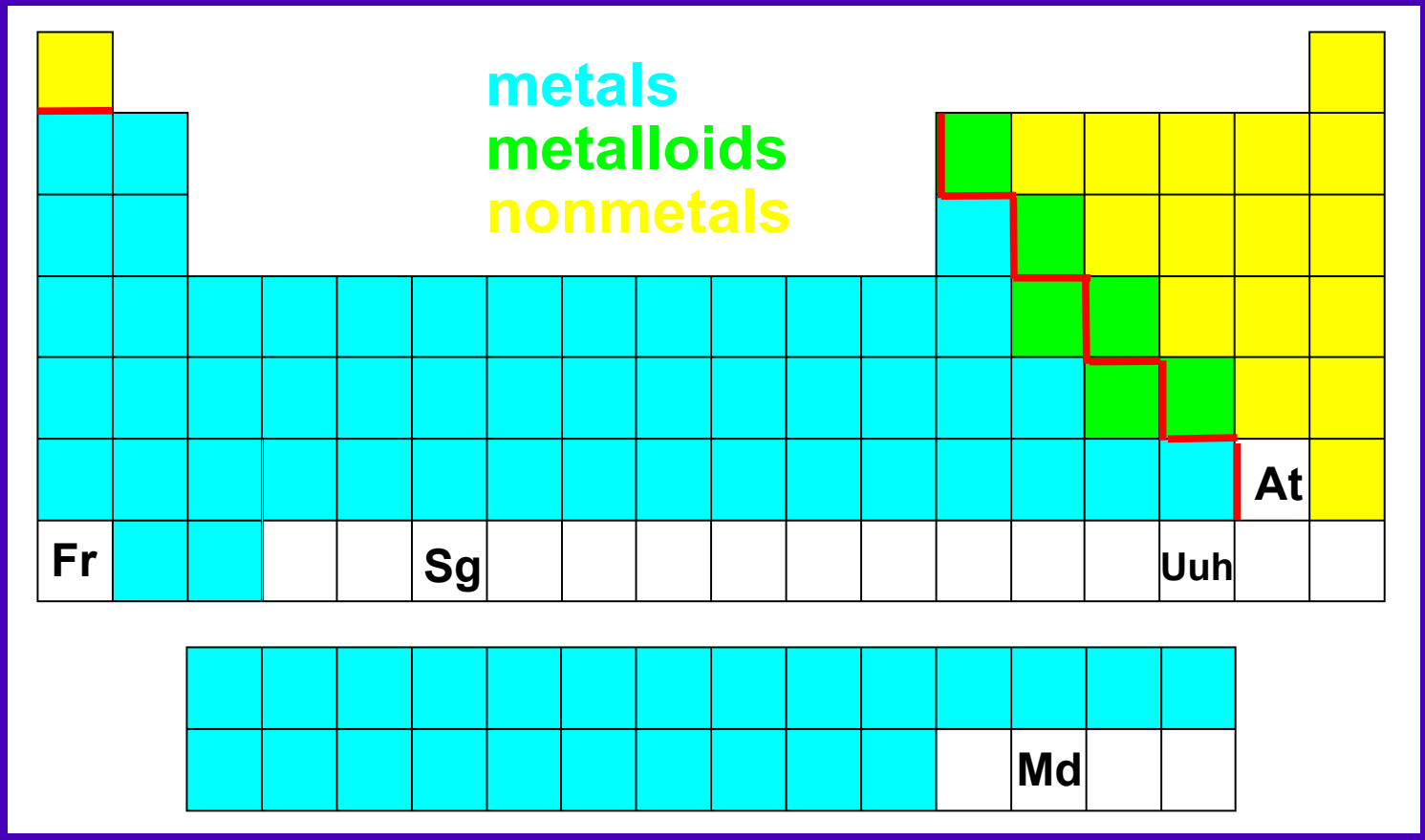
Let's look at some of the patterns the Periodic Table reveals.

Where are the naturally occurring and artificial elements?



artificial elements = 43, 61, 93-118

Where are the metals, nonmetals, and metalloids?



What would you guess about the appearance of the following elements?

francium metal

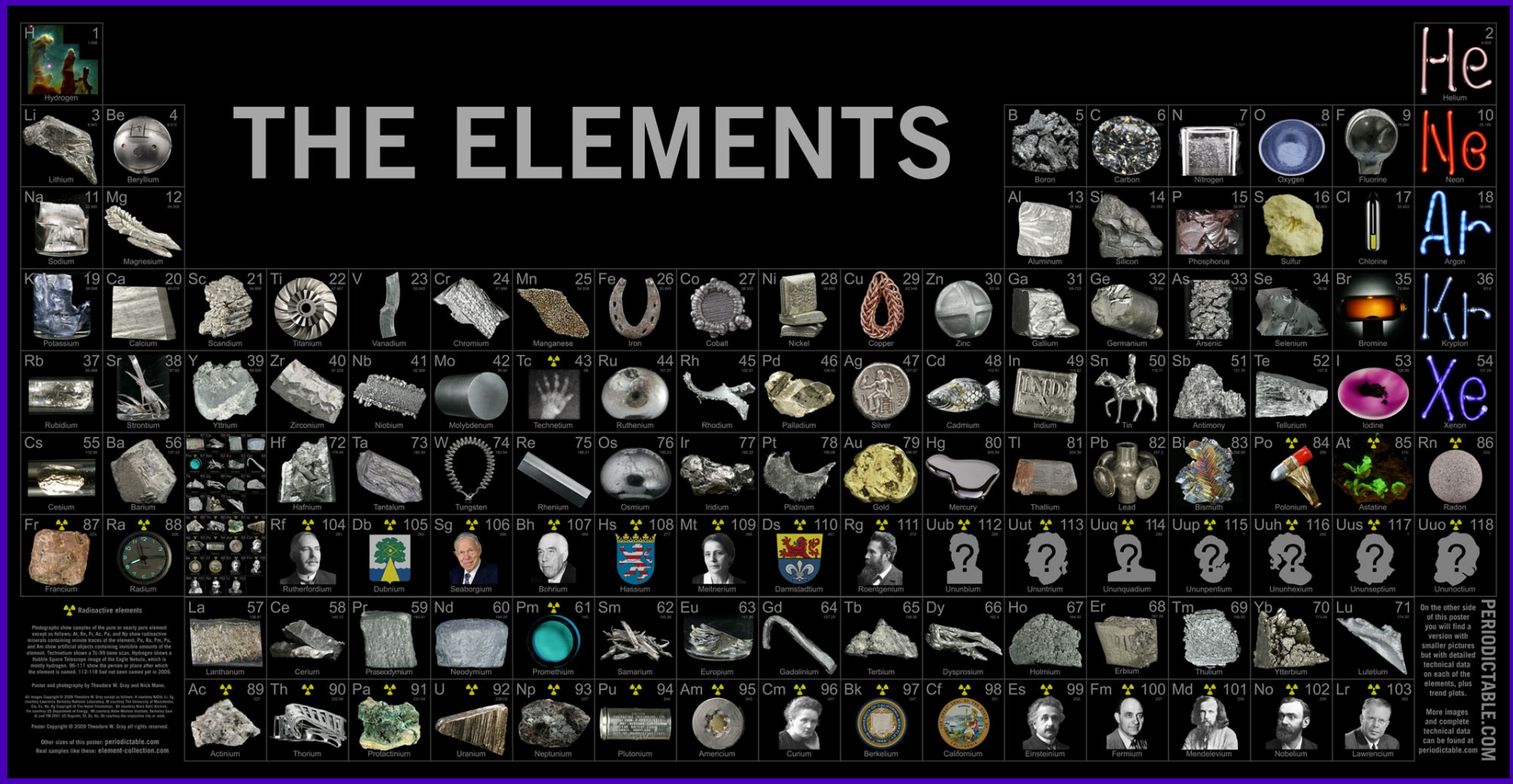
mendelevium metal

seaborgium metal

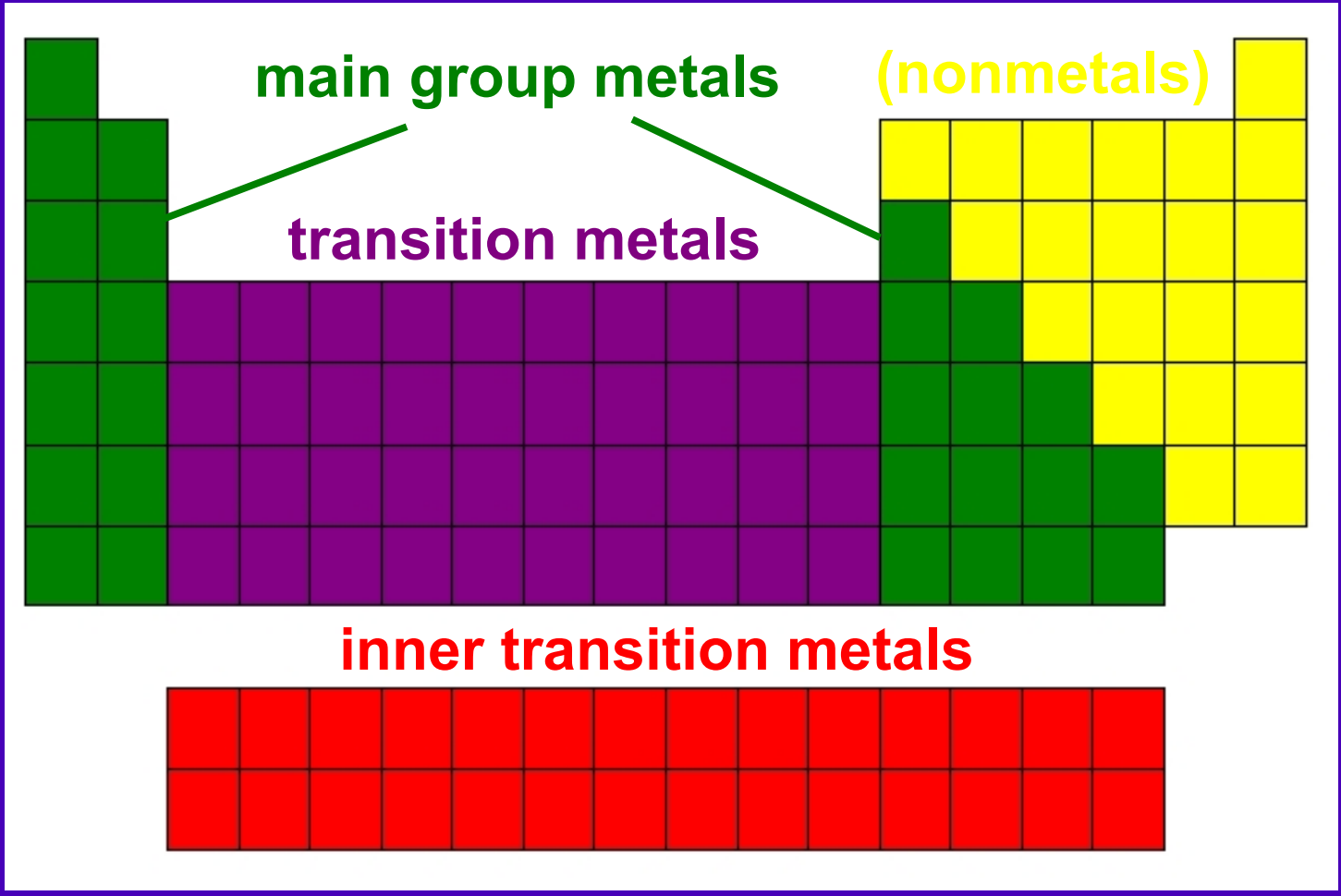
ununhexium metal

astatine nonmetal or metalloid

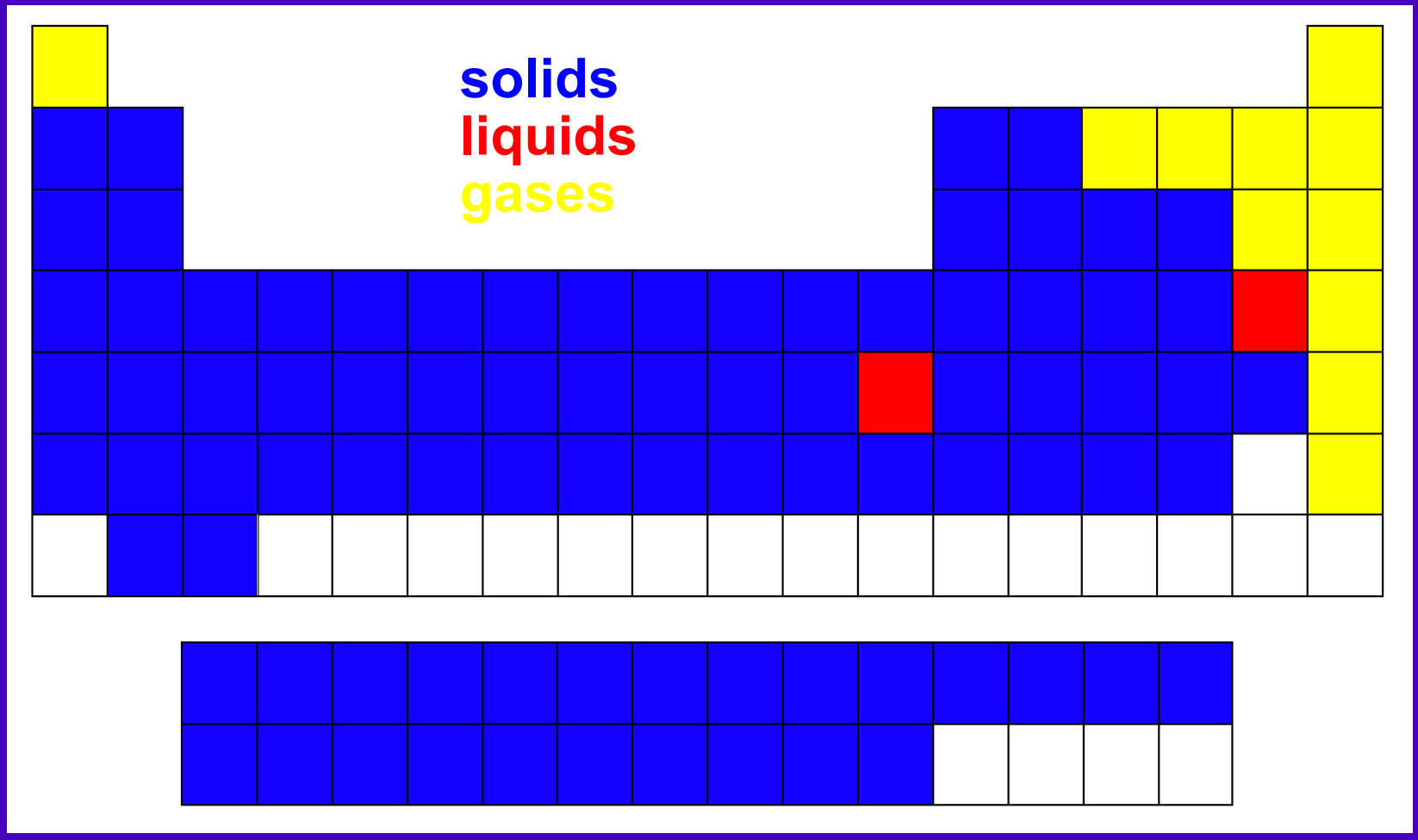
Here is a visually beautiful Periodic Table created by Theo Gray. You can order a 20” x 40” poster for $15 at his website.



How are the metals divided up?



Where are the solids, liquids, and gases?



Can you predict the physical state of the unknown elements?

all solids except Uuo, which is probably a gas