Molecular Literacy for All

a new lens to see the everyday molecules that fill our lives every day

As long as you live, keep learning how to live.
— Seneca

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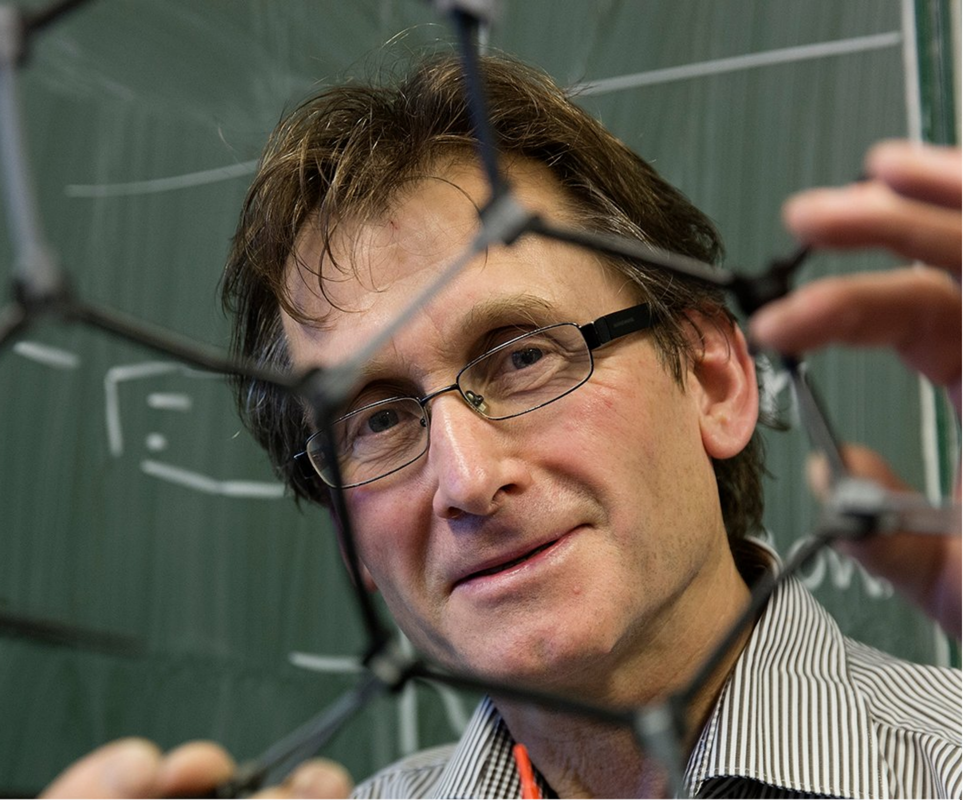
Today's Outline

- About the course
- The periodic table of elements and their atoms
  - Composition of humans
  - Nutritional elements
  - Earth abundance
- Atomic structure
  - Subatomic particles
  - Atomic number
- Isotopes
  - Atomic mass
  - Atomic weight
    - Variation on earth
    - Variation in space
- The mole
- Electrons in atoms
  - Shells and subshells
  - Valency
- Ions



"When I draw a molecule in China or in Argentina, it is the same molecule. People understand immediately without knowing Spanish or Chinese. That is beautiful. Our common goal is not about power or borders of the country, it is about bringing forward human knowledge."
-Ben Feringa (2016 Nobel Prize in Chemistry)

ABOUT THE COURSE

Expectations and prerequisites

Why study the language of molecules?

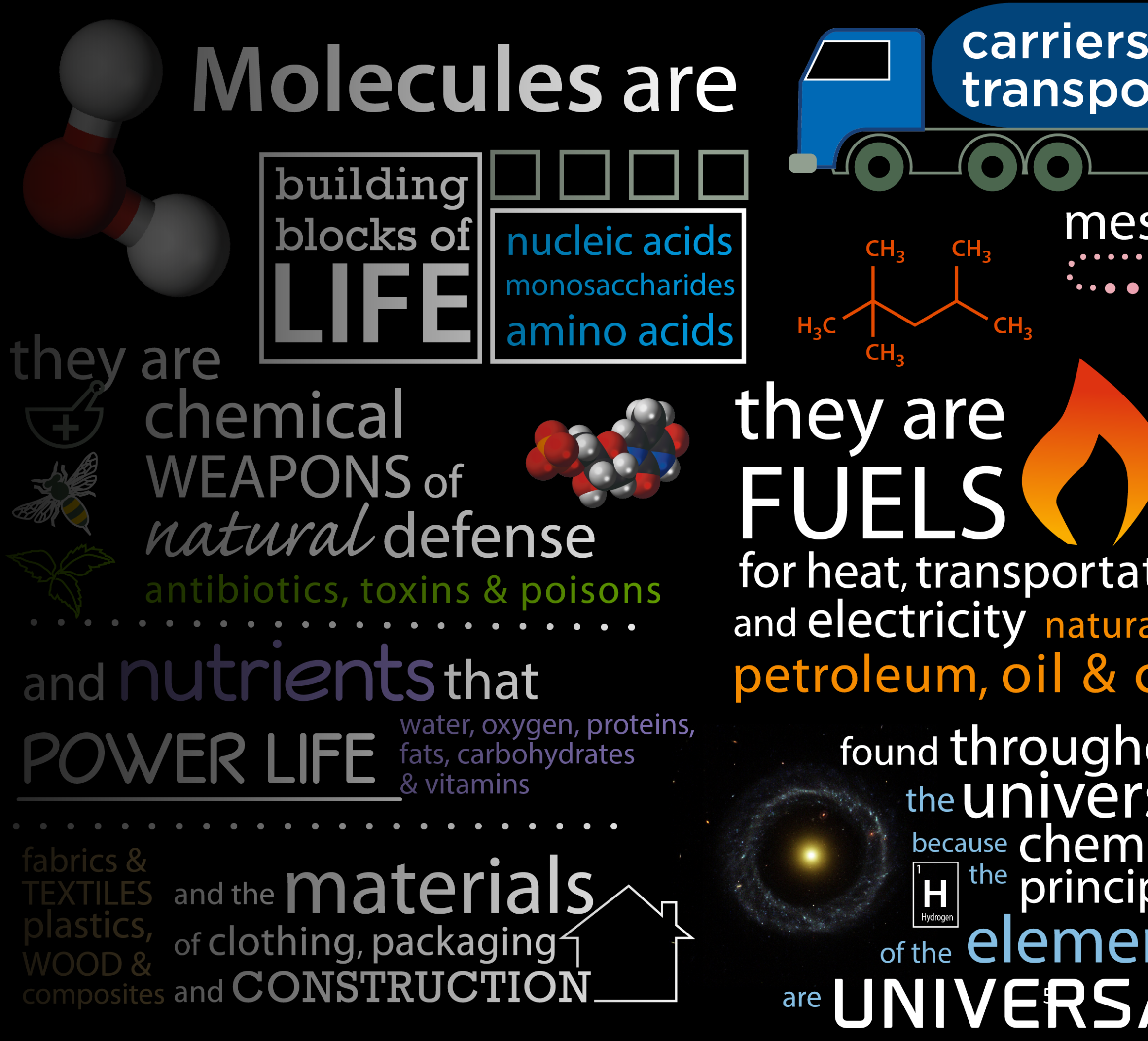
What makes the language of molecules difficult?

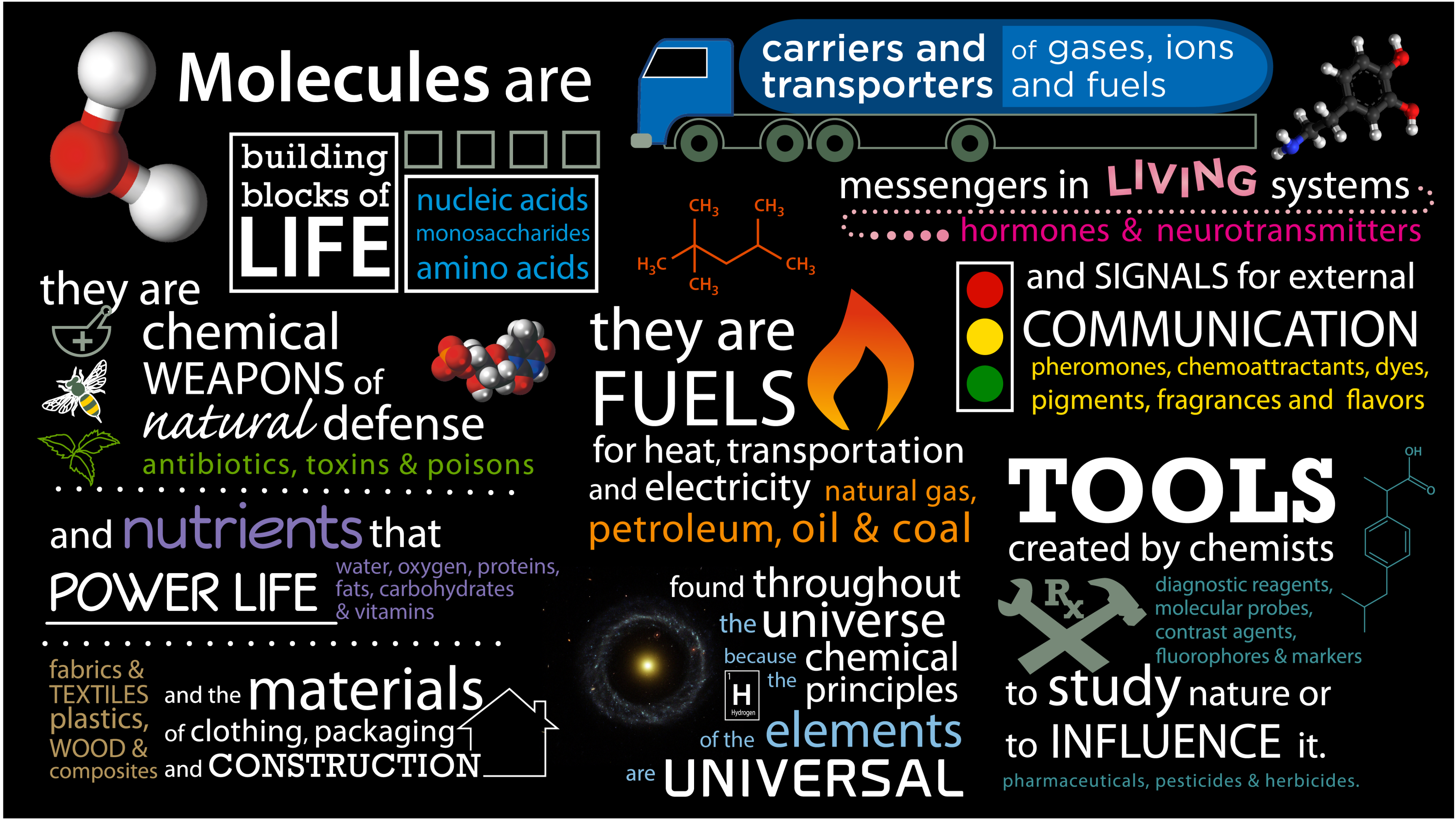
What’s required? What’s expected?

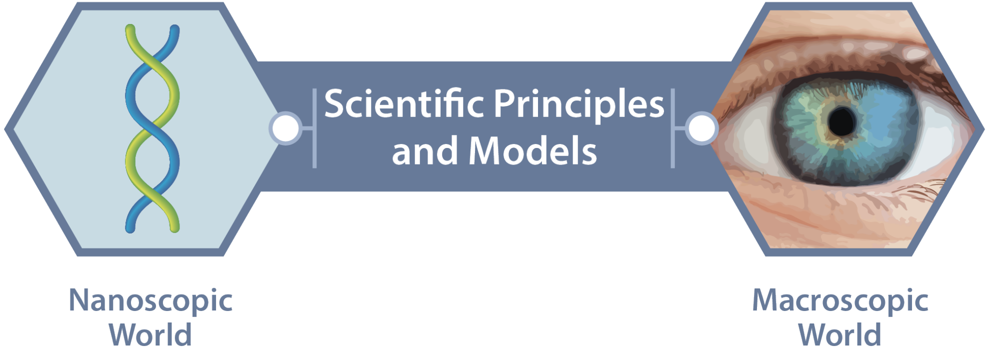
But as I learned more about science, I realized that it doesn’t require genius at all. It requires dedication, curiosity, and comfort in going against the grain of society. What all great scientists have in common is not some common innate ability, but the ability to identify what they don’t understand and to respond by learning the information already available or by doing the work to uncover the unknown.

Why study the language of molecules?

Molecules are invisible objects behind many **FUNCTIONS** we encounter in our everyday world.




Molecules are
building blocks of LIFE
nucleic acids
monosaccharides
amino acids
carriers and transporters of gases, ions and fuels
messengers in LIVING systems
hormones & neurotransmitters
and SIGNALS for external COMMUNICATION
pheromones, chemoattractants, dyes, pigments, fragrances and flavors
they are chemical WEAPONS of natural defense
antibiotics, toxins & poisons
they are FUELS for heat, transportation and electricity
natural gas, petroleum, oil & coal
CH3
CH3
H3C
CH3
CH3
TOOLS created by chemists
diagnostic reagents, molecular probes, contrast agents, fluorophores & markers
Rx
OH
O
to study nature or to INFLUENCE it.
pharmaceuticals, pesticides & herbicides.
and nutrients that POWER LIFE
water, oxygen, proteins, fats, carbohydrates & vitamins
found throughout the universe because the chemical principles of the elements are UNIVERSAL
1
H
Hydrogen
fabrics & TEXTILES
plastics, WOOD & composites
and the materials of clothing, packaging and CONSTRUCTION



Why study the language of molecules?

To help us think!

"No mind is better than the precision of its concepts"
-Ayn Rand

- Scientific principles and models from physics, chemistry and biology are a bridge to understand how observations relate to the invisible nanoscopic world.
- The language of molecules helps us to construct concepts about the nanoscopic world.

- words of a language help to form our mental concepts
- sentences are combinations of concepts (i.e., our thoughts)
- thoughts are representations that help us make sense of the world

https://inference-review.com/article/fodors-legacy

Why study the language of molecules?

To recognize ignorance

The word, *Ignorant,* shares a root with the word *ignore*

paul tyrrell
@PBTyrrell

Replying to @Plant_proof @DabianDina and 6 others

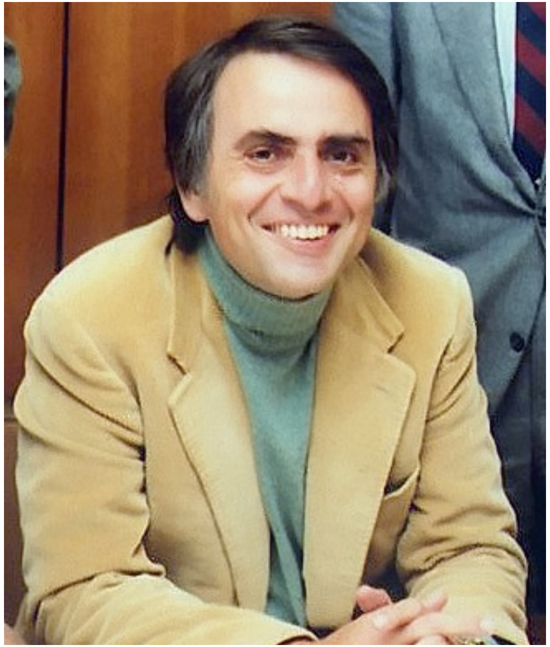
Sugar in fruit is the same sugar in table sugar. It's the same molecule. The sugar spikes the insulin. Over 10years if spiking a bodies insulin. The pancreas starts to fail. Leading to type 2 diabetes and metabolic disorder. Simple facts.

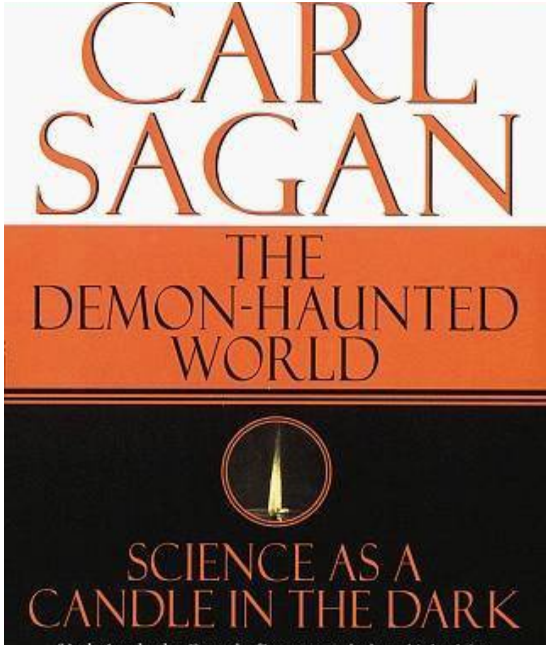
5:33 PM · May 21, 2020 · Twitter for iPhone

"Be aware of the ignorance without judging the ignorance."

Guru Singh

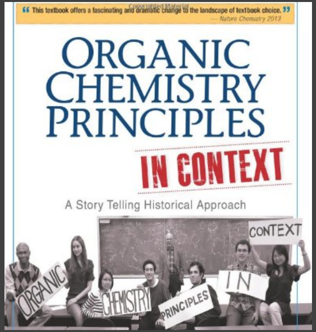
Ignorance and power

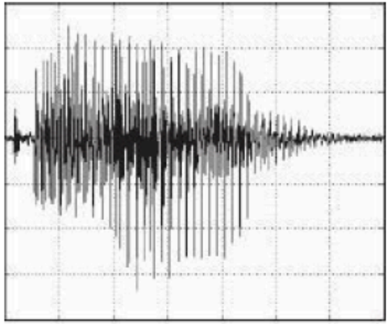




"We've arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces."

Learning in the Wild

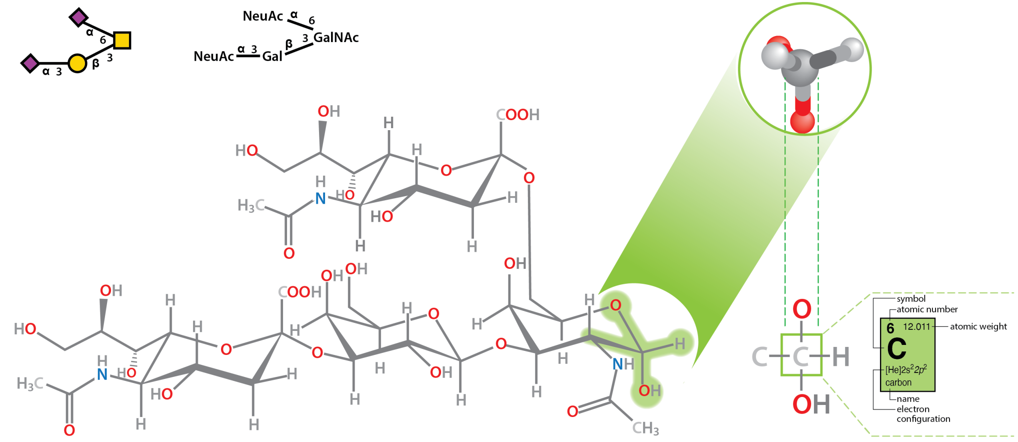




"We don't learn the alphabet before we hear people speaking."

What makes the language of molecules difficult?

SNFG	Abbr.	Systematic name
■	GalNAc	2-Acetamido-2-deoxy-D-galactopyranose
●	Gal	D-Galactopyranose
◆	NeuAc	5-Acetamido-3,5-dideoxy-D-glycero-D-galacto-non-2-ulopyranosonic acid



https://www.ncbi.nlm.nih.gov/glycans/snfg.html

The language of molecules represents invisible objects. These representations come in several dialects:

- Textual
- Symbolic
- Graphical
- 3D
- Implicit

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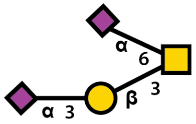
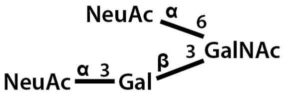
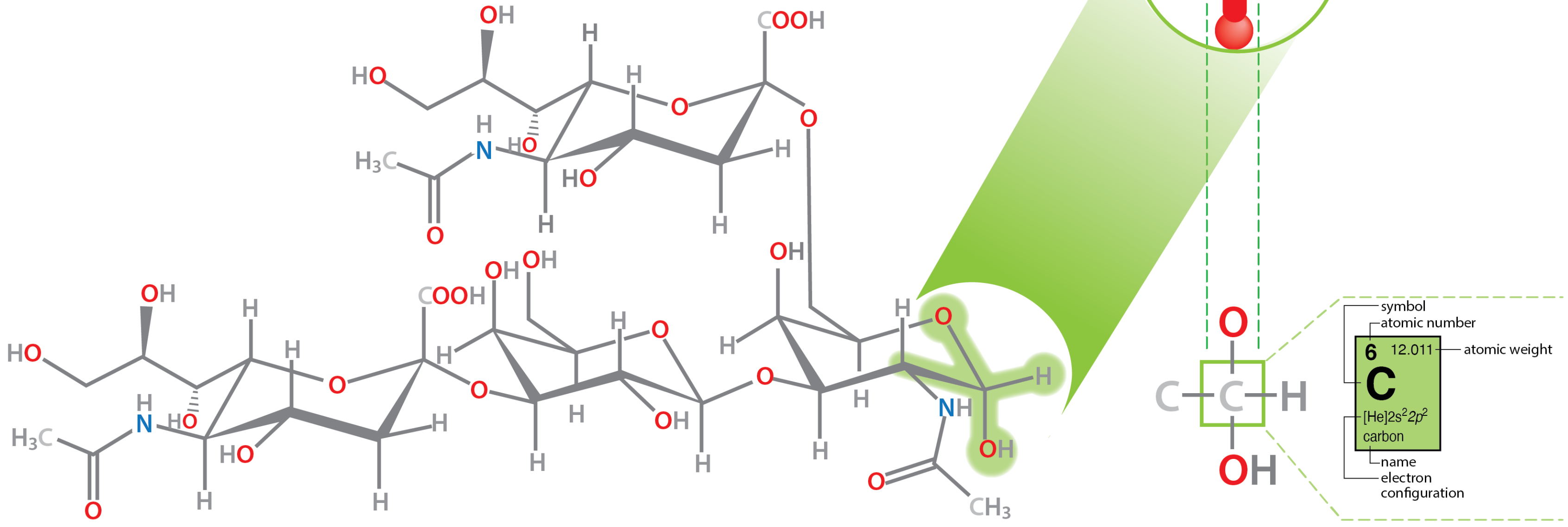
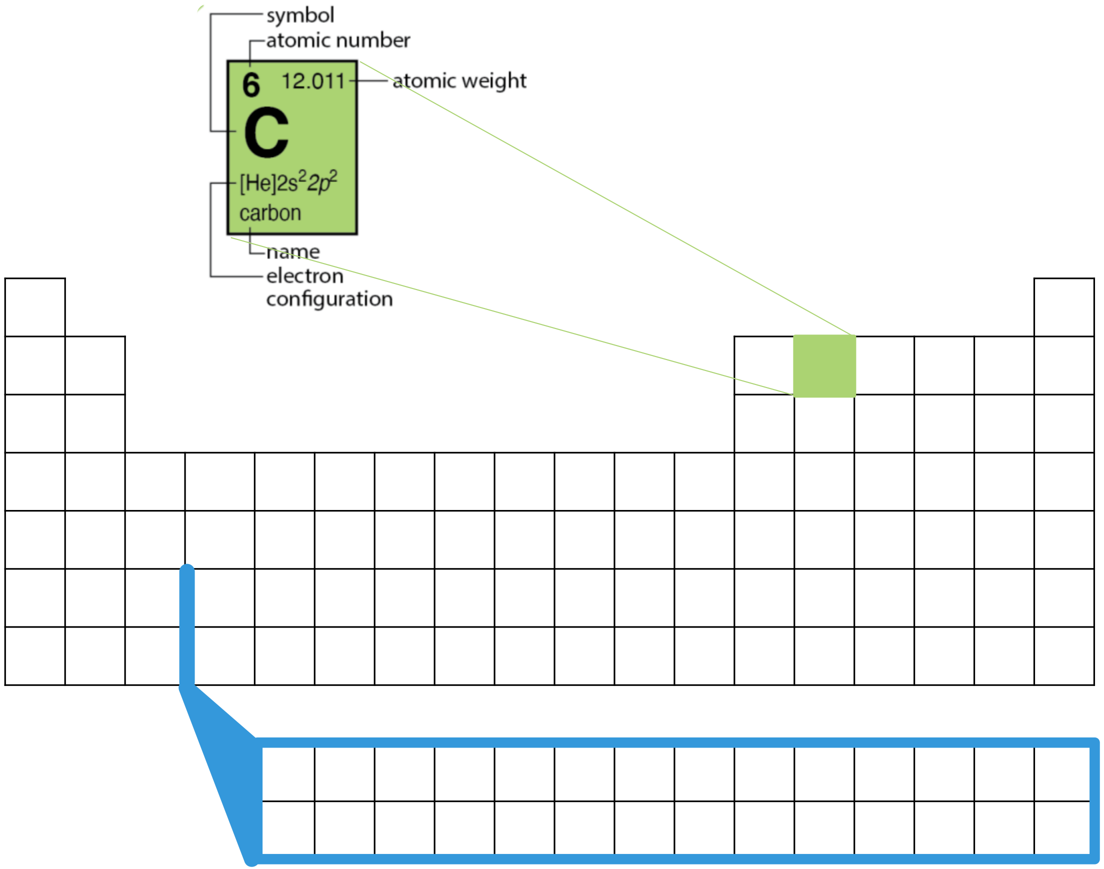




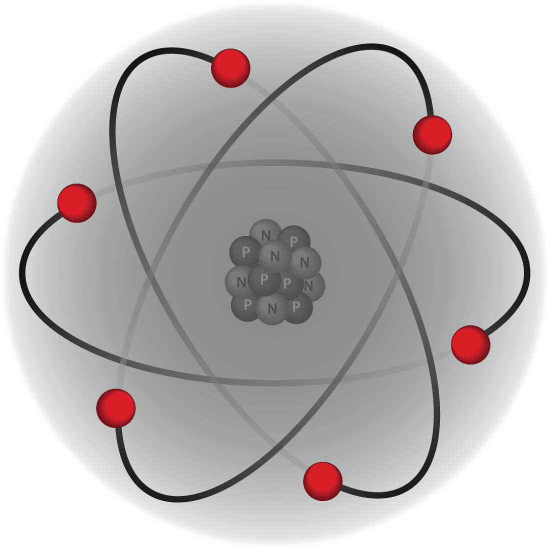


https://www.ncbi.nlm.nih.gov/glycans/snfg.html

The Periodic Table of the Elements:
The Alphabet of the Molecular Language



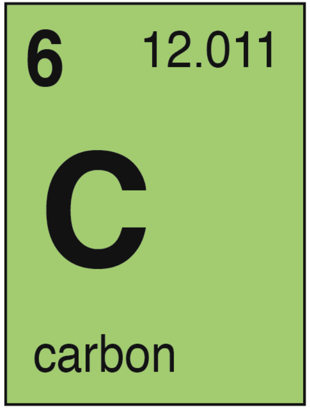
The atom and its subatomic particles



Subatomic Particle	Location	Charge	Mass	Change subatomic particle	
				What changes?	What stays the same?
proton	nucleus	+	1,836	element	
electron	cloud	-	1	charge	mass
neutron	nucleus	none	1,839	mass	charge

Atomic Number

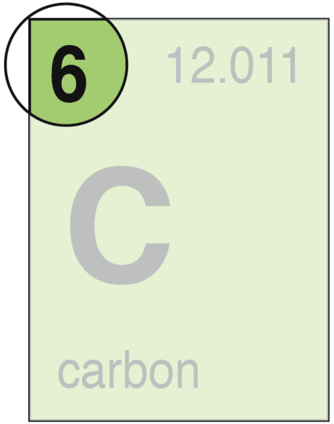
Every element has a unique number of protons.



Atomic Number

Every element has a unique number of protons.

The number of protons is the element's atomic number.



Atomic Number

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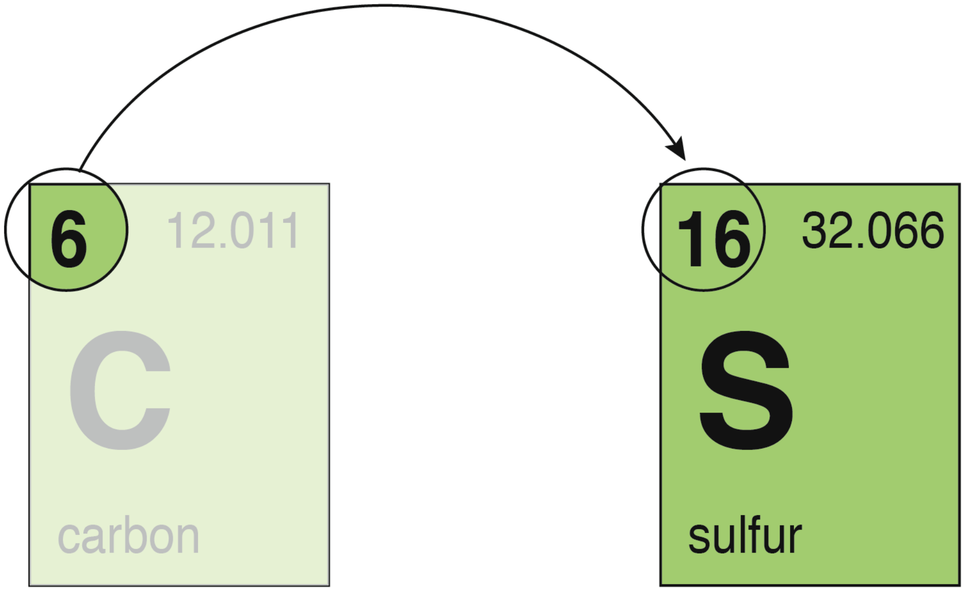
Any change in the number of protons changes the element.



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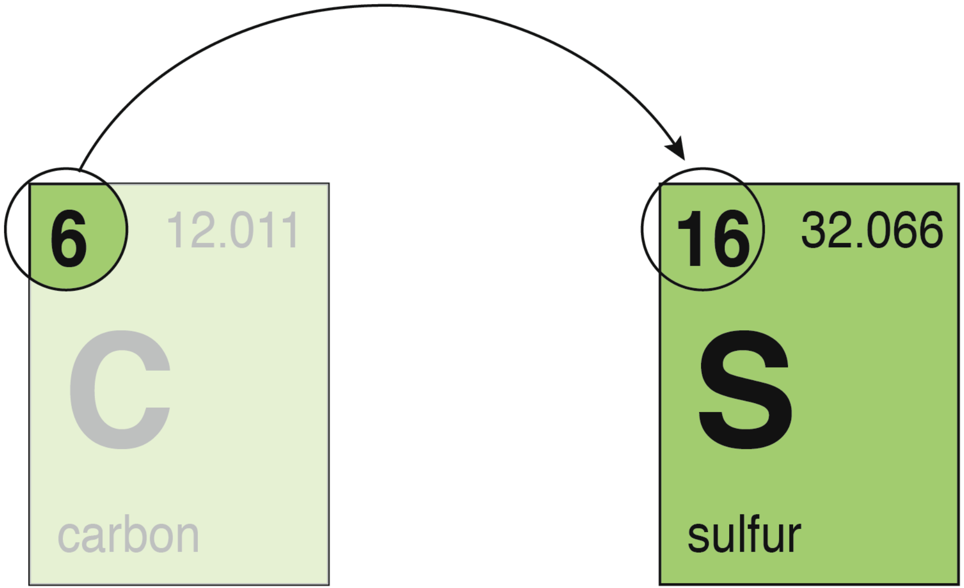
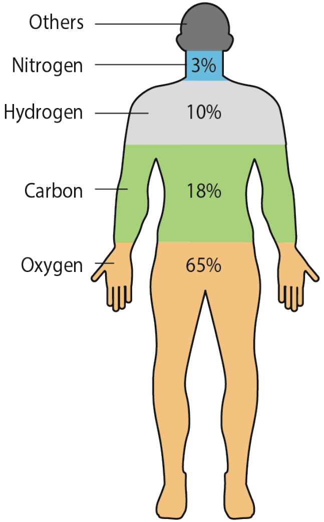


The elements of the periodic table begin with atomic number 1 and increase by 1 proton from left to right.

Chemical reactions conserve the elemental identity of every atom.

Nuclear reactions involve changes in the number of protons in an atom, and thus change the element.

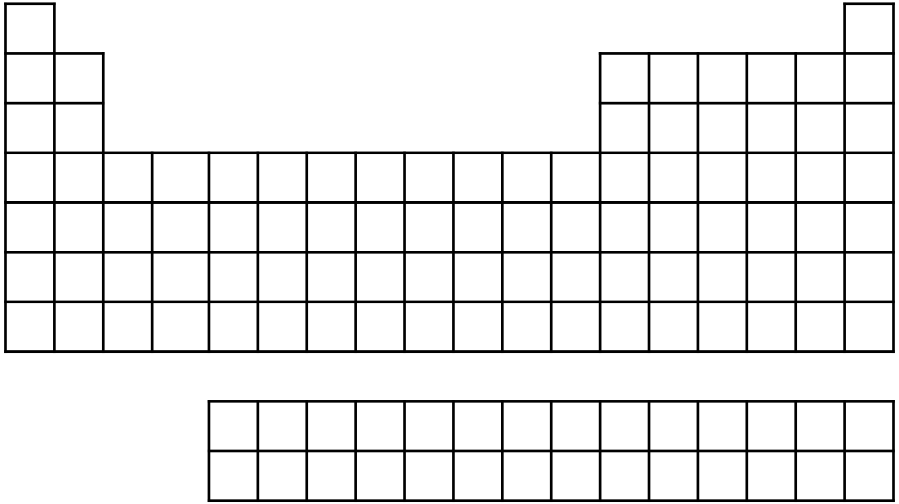
Everyday elements every day



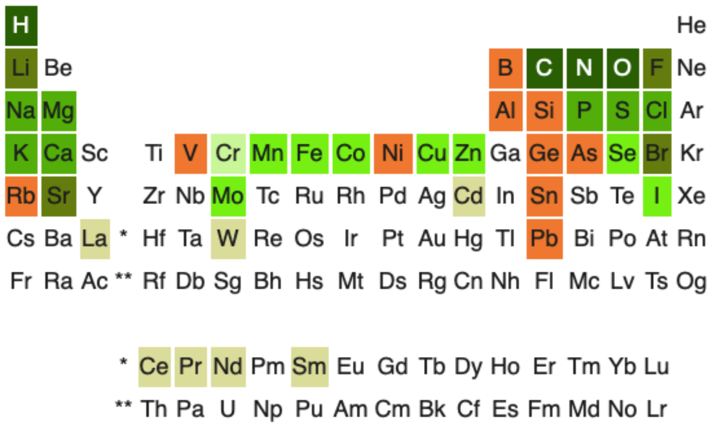
Element	Symbol	Atomic #	% mass	% atoms
Oxygen	O	8	65.0	24.0
Carbon	C	6	18.5	12.0
Hydrogen	H	1	9.5	52.0
Nitrogen	N	7	3.2	1.1
Calcium	Ca	20	1.5	0.22
Phosphorus	P	15	1.0	0.22
Potassium	K	19	0.4	0.03
Sulfur	S	16	0.3	0.038
Sodium	Na	11	0.2	0.037
Chlorine	Cl	17	0.2	0.024
Magnesium	Mg	12	0.1	0.015
All others			<1.0	<0.3

The main elements that compose the human body (including water).

Find the locations of the main elements of the body



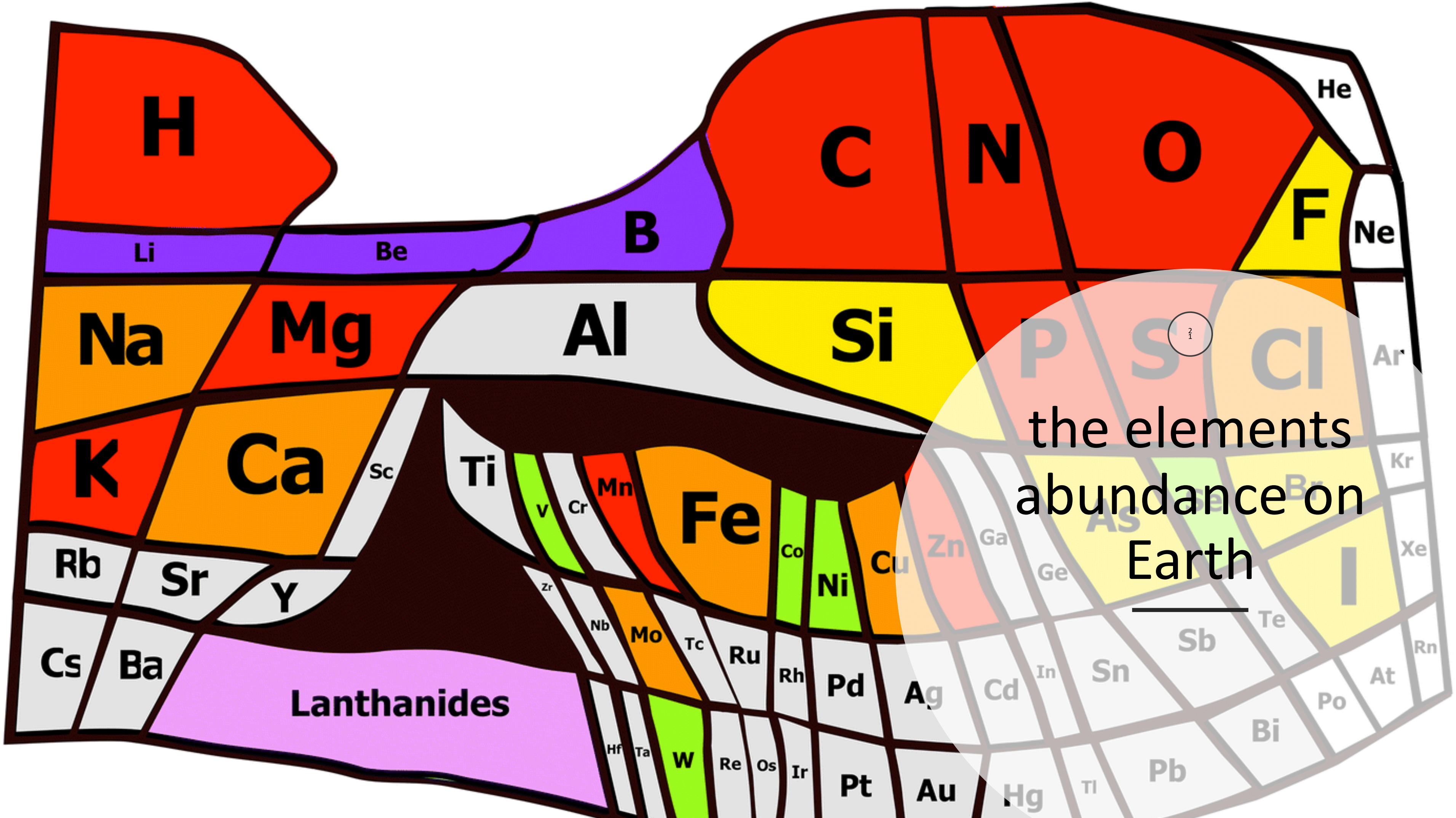
Nutritional elements in the periodic table



Legend:

- The four basic organic elements
- Quantity elements
- Essential trace elements
- Deemed essential trace element by U.S., not by European Union
- Suggested function from deprivation effects or active metabolic handling, but no clearly-identified biochemical function in humans
- Limited circumstantial evidence for trace benefits or biological action in mammals
- No evidence for biological action in mammals, but essential in some lower organisms.
(In the case of lanthanum, the definition of an essential nutrient as being indispensable and irreplaceable is not completely applicable due to the extreme similarity of the lanthanides. The stable early lanthanides up to Sm are known to stimulate the growth of various lanthanide-using organisms.)[19]

the elements abundance on Earth



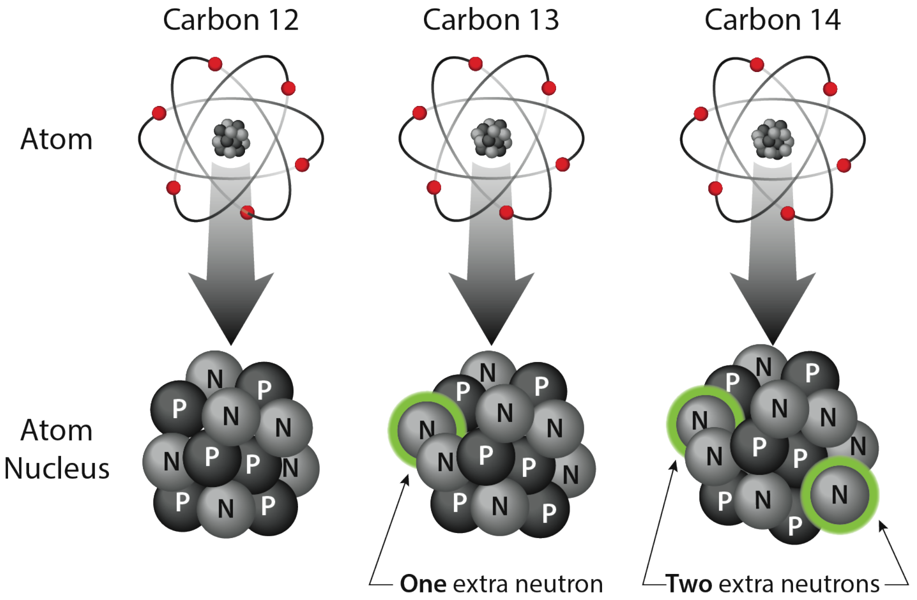
Isotopes

atomic variants of a chemical element

Isotopes are variants of a particular chemical element which differ in neutron number.

Each atomic number identifies a specific element, but not the isotope.

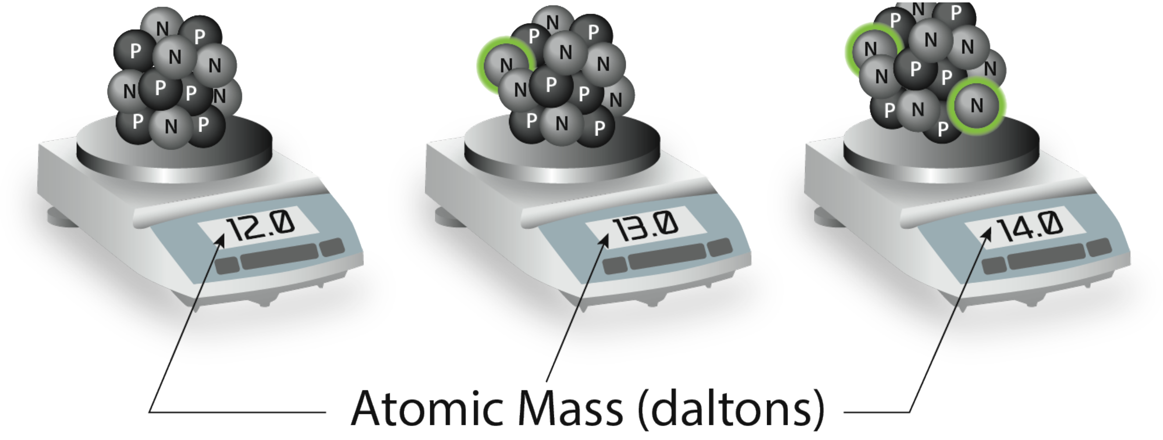
An atom of a given element may have a wide range in its number of <u>neutrons</u>.



^{12}C	^{13}C	^{14}C
Carbon-12	Carbon-13	Carbon-14
98.9%	1.1%	<0.1%
6 protons	__ protons	__ protons
6 neutrons	__ neutrons	__ neutrons

Explore: <u>The isotopes of hydrogen</u>

Isotope	Common name	Abundance	Decay?
^{1}H			
^{2}H			
^{3}H			



The atomic mass is defined as the mass of a single atom, which can only be one isotope at a time, and is not an abundance-weighted average, as in the case of atomic weight.

Atomic Mass

- The protons and neutrons of the nucleus account for nearly all of the total mass of atoms, with the electrons and nuclear binding energy making minor contributions.
- The atomic mass is often expressed in the unit dalton (symbol: Da, or u) where 1 dalton is defined as $^1/_{12}$ of the mass of a single carbon-12 atom, at rest.
- The **atomic mass** of a carbon-12 atom is exactly 12 Da.

Atomic Weight

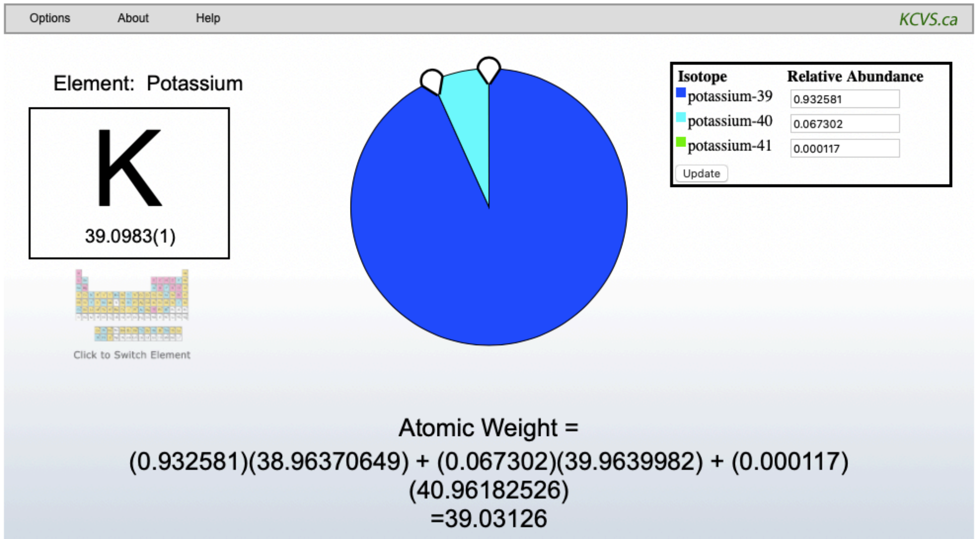
Why is atomic weight important?

➢ To count by weighing

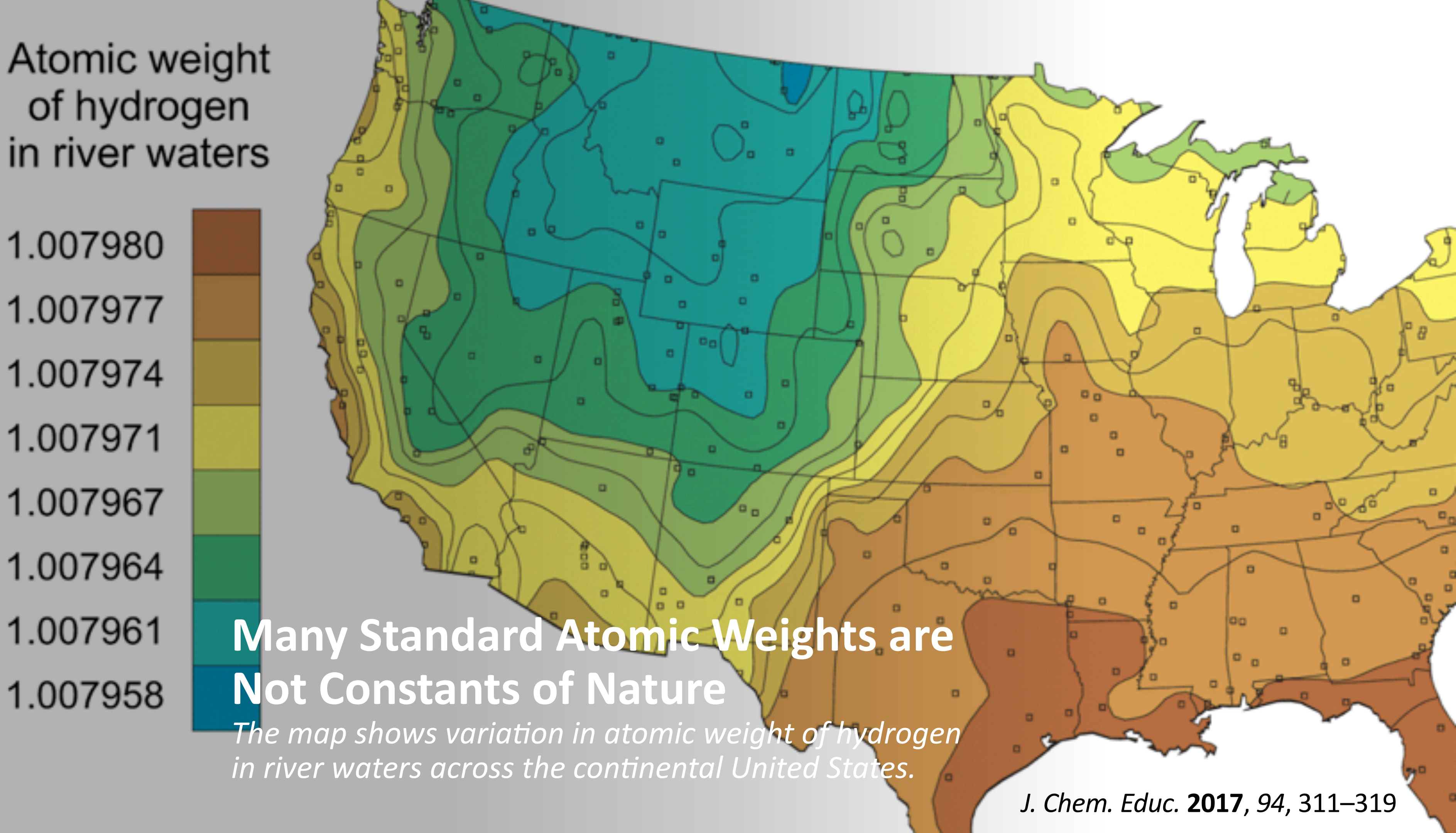
How are the **atomic weight** values on the periodic table calculated?

- Isotopes are atoms of the same element with different numbers of neutrons.

- **Atomic weight** of an element takes into account:
  - The **atomic mass** of each isotope in a sample of that element
  - The **relative abundance** of each contributing isotope in the sample



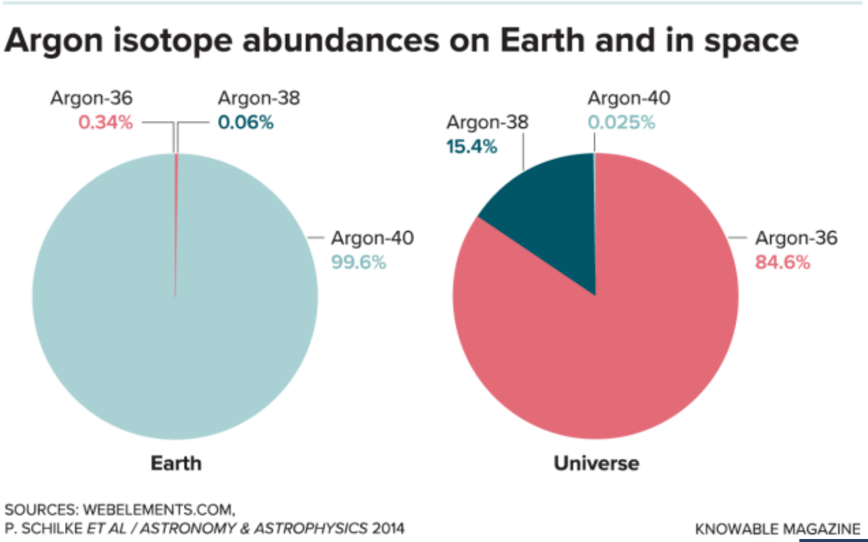
[Link to the calculator]



Many Standard Atomic Weights are Not Constants of Nature

The map shows variation in atomic weight of hydrogen in river waters across the continental United States.

J. Chem. Educ. **2017**, *94*, 311–319



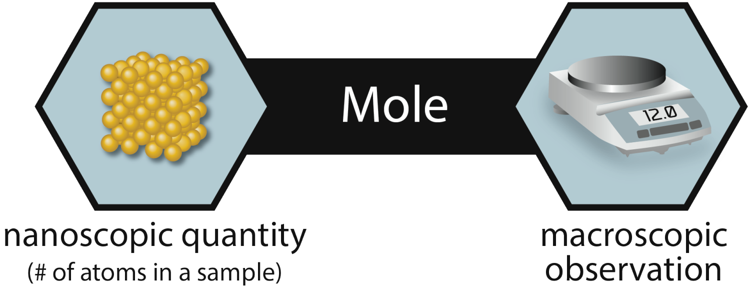
The argon in Earth's air is nearly all made up of the isotope argon-40, but in space a different isotope, argon-36, dominates.

On Earth, as it is not in the heavens

https://www.discovermagazine.com/the-sciences/the-impossible-molecules-that-only-appear-in-space

Count by Weighing – The Concept of the Mole

Count by weighing is a technique that's very useful in cases where the **counting** of substances is difficult because of their small size and a higher quantity. It applies to atoms. The mole is used to quantify concentration (e.g., moles per liter, or M).

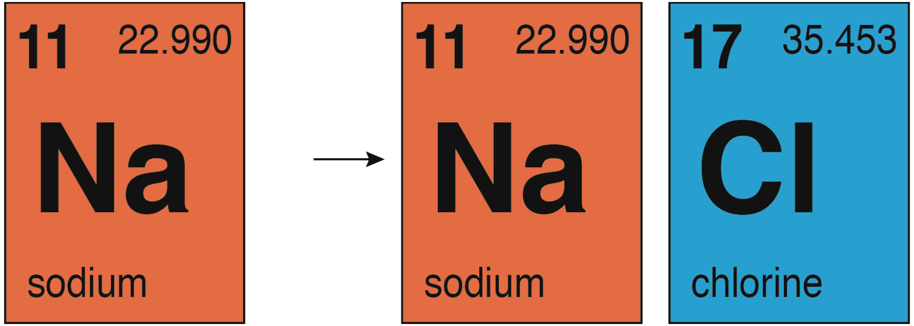


Know the average mass of an element, as that element occurs in nature, you can calculate the number of atoms in any given sample of that element by weighing the sample. The atomic weight of an element, as found in the periodic table, allow us to count by weighing.

Sodium

Salt is not the same as sodium.
The term “salt” refers to sodium chloride.
“Sodium” refers to dietary sodium. One gram of salt (sodium chloride) equals 390 milligrams of sodium.

Healthy eating patterns limit sodium to less than 2,300 mg per day for adults and children ages 14 years and older and to the age- and sex-appropriate Tolerable Upper Intake Levels (UL) of sodium for children younger than 14 years (see Appendix 7). Sodium is an essential nutrient and is needed by the body in relatively small quantities, provided that substantial sweating does not occur.



Sodium **Salt**

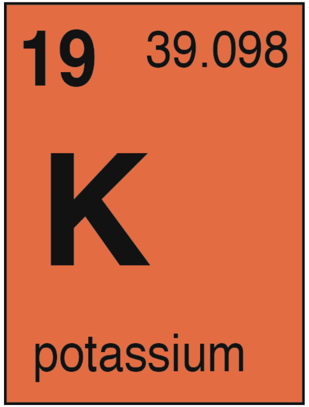
One teaspoon of table salt equals to 5.69 g of NaCl

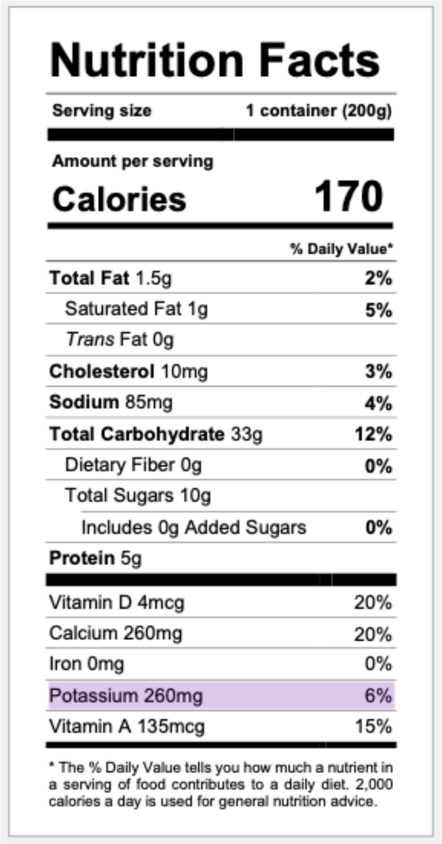
Potassium

Although the majority of Americans consume sufficient amounts of most nutrients, some nutrients are consumed by many individuals in amounts below the Estimated Average Requirement or Adequate Intake (AI) levels. These include potassium, dietary fiber, choline, magnesium, calcium, and vitamins A, D, E, and C.

Detrimental health issues may arise when potassium intake is insufficient and/ or when sodium intake is too high

RDA = Recommended Dietary Allowance
AI = Adequate Intake
UL = Tolerable Upper Intake Level





Nutrition Facts

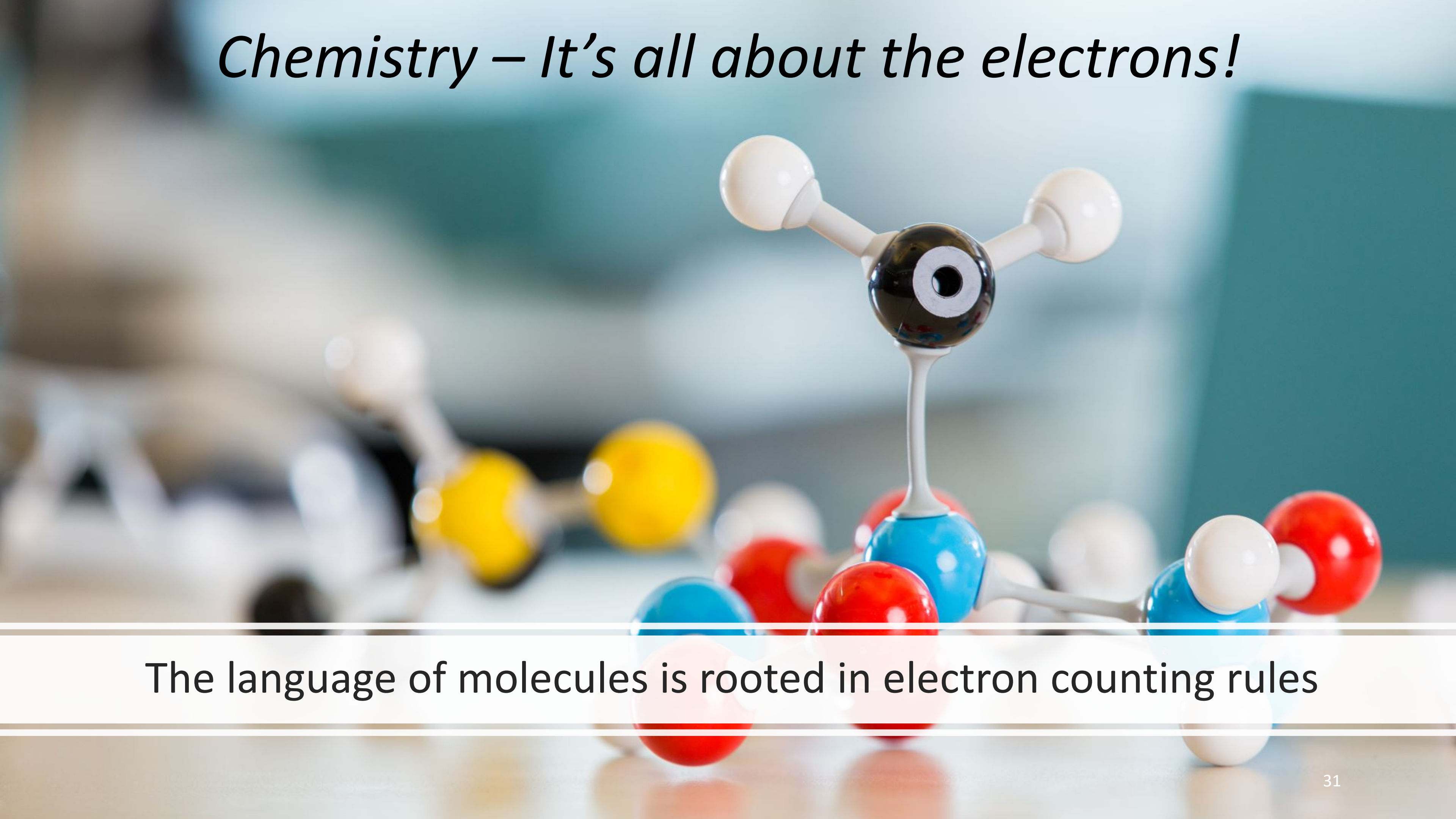
Serving size	**1 container (200g)**
Amount per serving	
Calories	**170**
	% Daily Value*
Total Fat 1.5g	**2%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 10mg	**3%**
Sodium 85mg	**4%**
Total Carbohydrate 33g	**12%**
Dietary Fiber 0g	**0%**
Total Sugars 10g	
Includes 0g Added Sugars	**0%**
Protein 5g	
Vitamin D 4mcg	20%
Calcium 260mg	20%
Iron 0mg	0%
Potassium 260mg	6%
Vitamin A 135mcg	15%

* The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Reading Food Labels

	Source of Goal[a]	Child 1-3	Female 4-8	Male 4-8	Female 9-13	Male 9-13	Female 14-18	Male 14-18	Female 19-30	Male 19-30	Female 31-50	Male 31-50	Female 51+	Male 51+
Calorie Level(s) Assessed		1,000	1,200	1,400, 1,600	1,600	1,800	1,800	2,200, 2,800, 3,200	2,000	2,400, 2,600, 3,000	1,800	2,200	1,600	2,000
Minerals														
Calcium, mg	RDA	700	1,000	1,000	1,300	1,300	1,300	1,300	1,000	1,000	1,000	1,000	1,200	1,000[b]
Iron, mg	RDA	7	10	10	8	8	15	11	18	8	18	8	8	8
Magnesium, mg	RDA	80	130	130	240	240	360	410	310	400	320	420	320	420
Phosphorus, mg	RDA	460	500	500	1,250	1,250	1,250	1,250	700	700	700	700	700	700
Potassium, mg	AI	3,000	3,800	3,800	4,500	4,500	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Sodium, mg	UL	1,500	1,900	1,900	2,200	2,200	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300
Zinc, mg	RDA	3	5	5	8	8	9	11	8	11	8	11	8	11
Copper, mcg	RDA	340	440	440	700	700	890	890	900	900	900	900	900	900
Manganese, mg	AI	1.2	1.5	1.5	1.6	1.9	1.6	2.2	1.8	2.3	1.8	2.3	1.8	2.3
Selenium, mcg	RDA	20	30	30	40	40	55	55	55	55	55	55	55	55

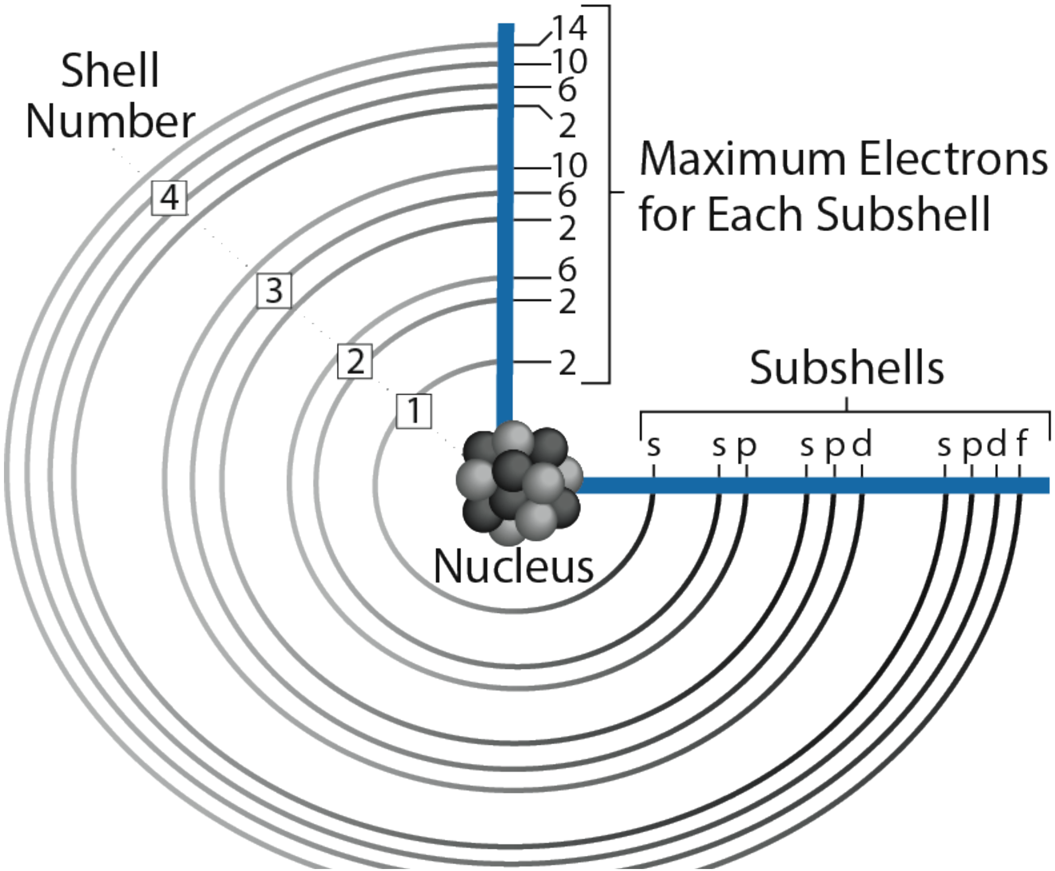
Chemistry – It’s all about the electrons!



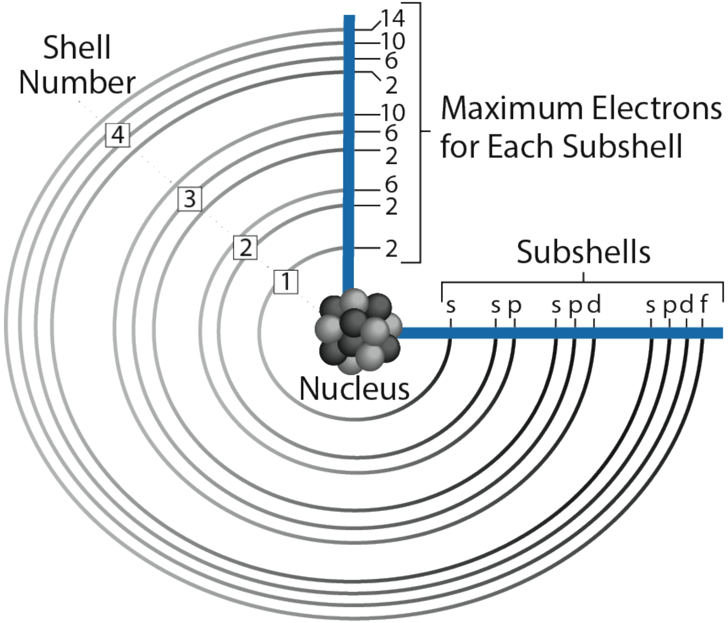
The language of molecules is rooted in electron counting rules

Given…

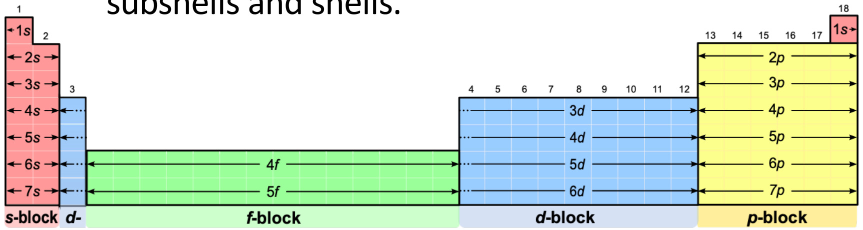
- The shells and their subshells are models to approximate the arrangement of electrons around the nucleus.
- Each subshell has a maximum capacity i.e., an upper limit, as to the number of electrons that it can accommodate.
- A shell's electron capacity is the sum of the maximum capacity of each of its subshell.
- The maximum electron capacity of a shell determines its chemical properties.
- The second shell, has a capacity of eight electrons giving rise to the **octet rule**.
- A shell at capacity is said to be **filled**.
- Electrons in the outermost shell are called **valence electrons**.
- Electrons in the inner shells are called **core electrons**.
- The chemistry of atoms and molecules is understood by the giving or receiving of electrons (electron sharing) to bring about filled shells.



The periodic table and electron count



The shape of the periodic table follows the order with which electrons are added to subshells and shells.

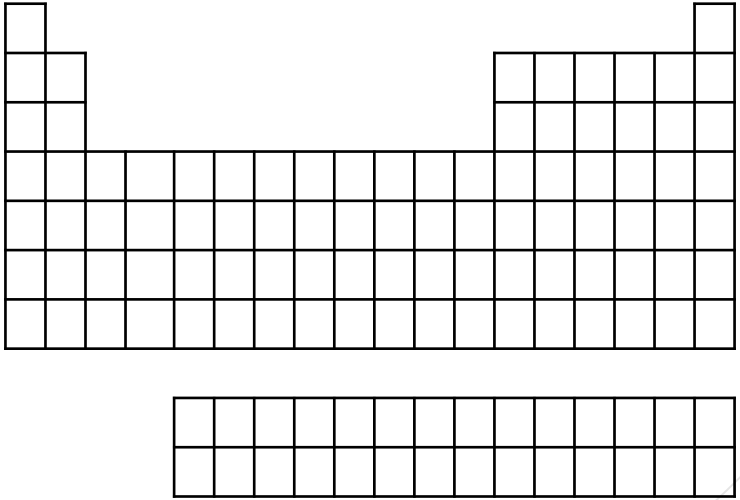


Valency is the combining power of an atom

- Consider an atom in isolation. The outermost electron shell of that atom is known as the valence shell, and the electrons in that shell are called valence electrons.
- The no. of valence electrons (i.e., electron count) determines the atom's ability to bond with other atoms.
- No. core electrons that carbon (C) has: ______
- No. valence electrons that carbon has: ______
- No. electrons to fill carbon's valence shell: _____
- We usually show the valence electrons and ignore the core electrons. Draw the valence electrons around (C).

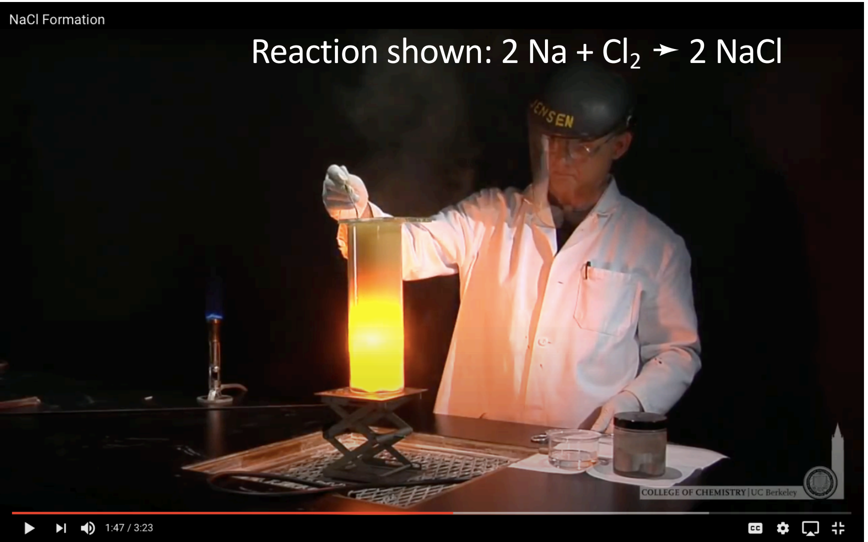
C

For hydrogen through chlorine, indicate the number of valence electrons in the atoms of each element



Transferring electrons to fill shells

Electrons transfer from one atom to another during chemical reactions. In the process, atoms may gain or lose electrons. Electron transfer is favorable when atoms, initially with incomplete shells, attain filled shells. A reaction that is favorable releases energy.



1. Show the valence electrons for sodium and chlorine atoms

2. Which atom is the electron donor, and which is the electron acceptor?

3. Use an arrow to show the electron transfer from the donor to the acceptor

$$\boxed{Na} + \boxed{Cl}$$

$$\downarrow$$

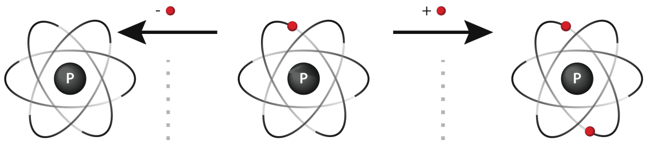
NaCl

4. Both atoms in NaCl now have filled shells

Chemical reactions are understood as the transfer of electrons from donor to acceptor atom

Ions

- Since the electric charge on a proton is equal to the charge on an electron, the net charge on an ion is equal to the number of protons in the ion minus the number of electrons.
- If the number of electrons is different from the nucleus' electrical charge, such an atom is called an [ion](ion).
- Ions are formed by the gain or loss of electrons to an atom’s valence shell.
- An anion (−), from the Greek word, meaning "up", is an ion with more electrons than protons, giving it a net negative charge
- A cation (+), from the Greek word, meaning "down", is an ion with fewer electrons than protons, giving it a positive charge.



# of protons (P)	1	1	1
# of electrons (●)	0	1	2
Charge	+1	0	-1
Notation	H^+	H	H^-
Classification	cation	neutral (not an ion)	anion

Optional Reading

- *The Same and Not the Same* by Roald Hoffmann
- *Organic Chemistry: Principles in Context* by Mark Green
- *Nature's Robots* by Tanford and Reynolds