6 2 4 **C** *Carbon* *12.0107*	1 1 **H** *Hydrogen* *1.00794*	99 2 8 18 32 29 8 2 **Es** *Einsteinium* *(252)*	12 2 8 18 18 7 **Mg** *Magnesium* *24.3050*	53 2 8 18 18 7 **I** *Iodine* *126.90447*	16 2 8 6 **S** *Sulfur* *32.066*
22 2 8 10 2 **Ti** *Titanium* *47.867*	88 2 8 18 32 18 8 2 **Ra** *Radium* *(226)*	39 2 8 18 9 2 **Y** *Yttrium* *88.90585*			

Chapter 2

Life's Chemical Basis

As Mr. Weitz used to say….you're doing the wrong kind of chemistry in here

So your grandpa says you're worthless?

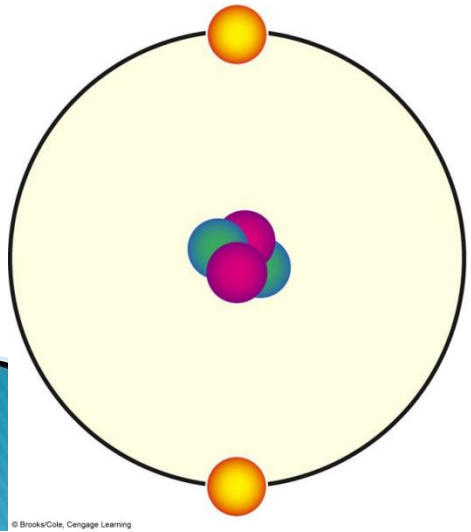
- Well, you aren't.
- 58 elements in the human body
- The average human cost = $118.63

Elements in a Human Body

Element	Number of Atoms (x 10^{15})	Retail Cost
Hydrogen	41,808,044,129,611	$ 0.028315
Oxygen	16,179,356,725,877	0.021739
Carbon	8,019,515,931,628	6.400000
Nitrogen	773,627,553,592	9.706929
Phosphorus	151,599,284,310	68.198594
Calcium	150,207,096,162	15.500000
Sulfur	26,283,290,713	0.011623
Sodium	26,185,559,925	2.287748
Potassium	21,555,924,426	4.098737
Chlorine	16,301,156,188	1.409496
Magnesium	4,706,027,566	0.444909
Fluorine	823,858,713	7.917263
Iron	452,753,156	0.054600
Silicon	214,345,481	0.370000
Zinc	211,744,915	0.088090
Rubidium	47,896,401	1.087153
Strontium	21,985,848	0.177237
Bromine	19,588,506	0.012858
Boron	10,023,125	0.002172
Copper	6,820,886	0.012961
Lithium	6,071,171	0.024233
Lead	3,486,486	0.003960
Cadmium	2,677,674	0.010136
Titanium	2,515,303	0.010920
Cerium	1,718,576	0.043120
Chromium	1,620,894	0.003402
Nickel	1,538,503	0.031320
Manganese	1,314,936	0.001526
Selenium	1,143,617	0.037949
Tin	1,014,236	0.005387
Iodine	948,745	0.094184
Arsenic	562,455	0.023576
Germanium	414,543	0.130435
Molybdenum	313,738	0.001260
Cobalt	306,449	0.001509
Cesium	271,772	0.000016
Mercury	180,069	0.004718
Silver	111,618	0.013600
Antimony	98,883	0.000243
Niobium	97,195	0.000624
Barium	96,441	0.028776
Gallium	60,439	0.003367
Yttrium	40,627	0.005232
Lanthanum	34,671	0.000566
Tellurium	33,025	0.000722
Scandium	26,782	0.058160
Beryllium	24,047	0.000218
Indium	20,972	0.000600
Thallium	14,727	0.000894
Bismuth	14,403	0.000119
Vanadium	12,999	0.000322
Tantalum	6,654	0.001631
Zirconium	6,599	0.000830
Gold	6,113	0.001975
Samarium	2,002	0.000118
Tungsten	655	0.000007
Thorium	3	0.004948
Uranium	3	0.000103
Total	67,179,218,505,055 x 10^{15}	**$118.63**

2.1 Start with atoms (this should be review for you!!!!)

- **Atoms** = the building blocks of all substances
  - Made up of electrons, protons and neutrons
- **Electrons (e^-)** have a negative charge
  - Move around the nucleus
- The **nucleus** contains protons and neutrons
  - **Protons (p^+)** have a positive charge
  - **Neutrons** have no charge



proton

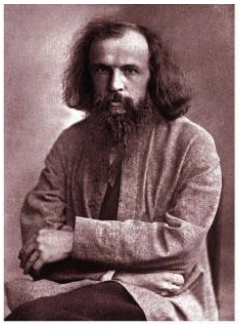
neutron

electron

Elements and the Periodic Table

- Atoms differ in number of subatomic particles
  - **Atomic number** = **number of protons** – determines the element
  - **Elements** consist only of atoms with the same atomic number

- Periodic Table
  - Dmitry Mendeleev
  - Arranged based on chemical properties
  - First 94 found in nature



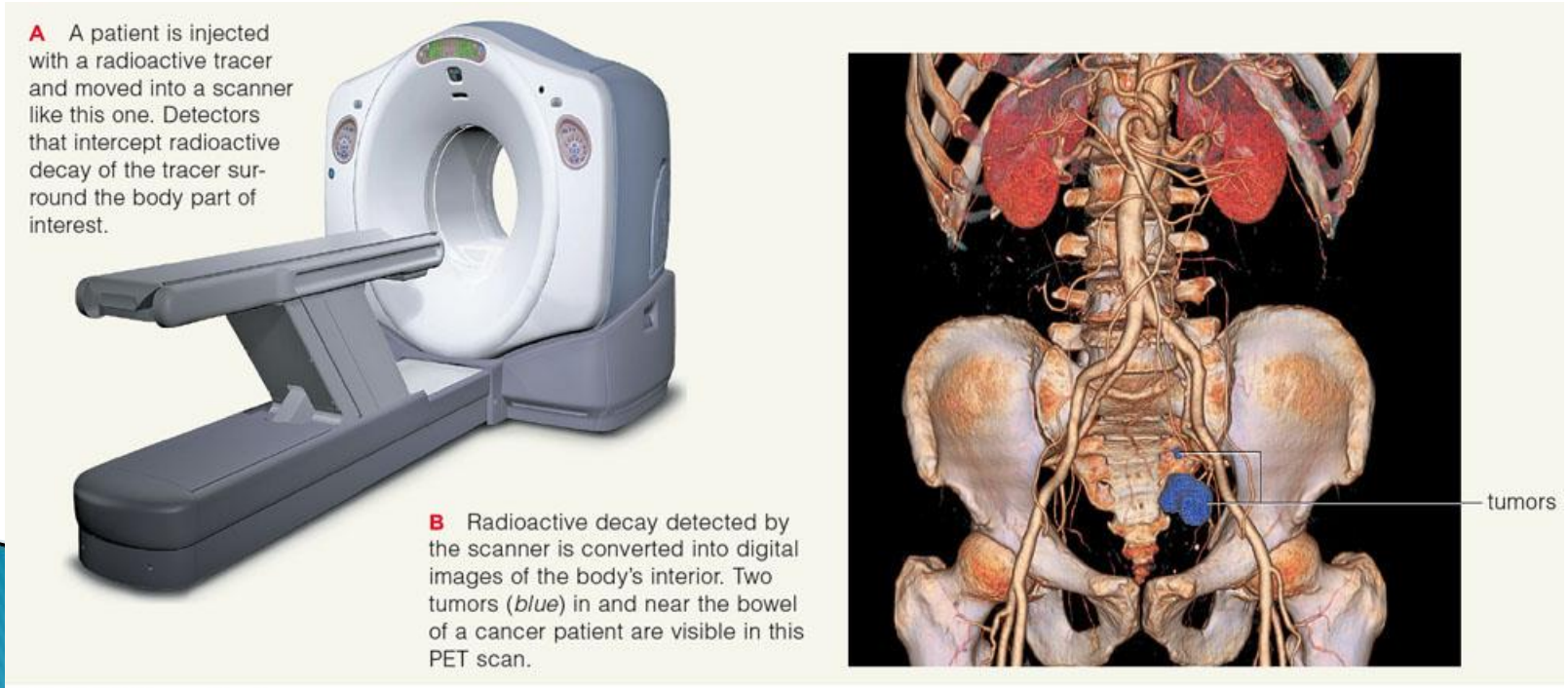
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	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
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh		118 Uuo
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

2.1 Radioisotopes

- Radioactive decay
  - Radioisotopes emit subatomic particles of energy when their nucleus breaks down, transforming one element into another at a constant rate
  - *Example:* $^{14}C \longrightarrow {}^{14}N$ – One of Carbon's neutrons spontaneously decays into a proton and electron (Carbon has 6 protons, Nitrogen has 7)
    - 14C's half life = 5,730 years – can date fossils
  - Is independent on temperature, pressure, or molecular structure

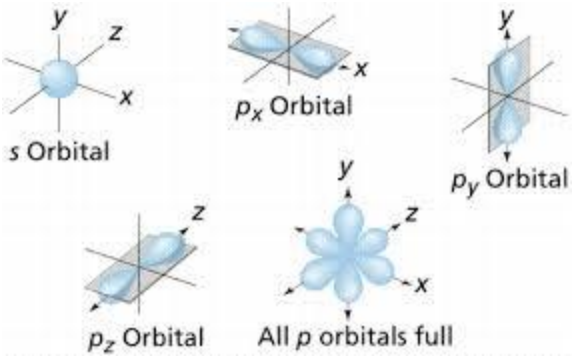
Tracers

- Tracer
  - Any molecule with a detectable substance attached
- *Examples:*
  - CO_2 tagged with ^{14}C used to track carbon through photosynthesis
  - Radioactive tracers used in medical PET scans



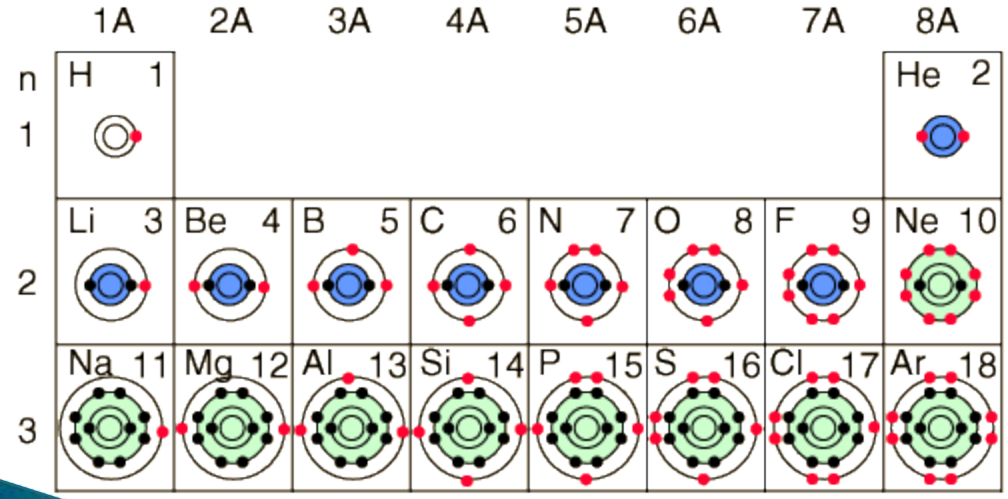
2.3 Why do electrons matter?

- Atoms acquire, share, and donate electrons
- Whether an atom will interact with other atoms depends on how many electrons it has
- Electrons move around nuclei in orbitals
  - Each orbital holds two electrons
  - Each orbital corresponds to an energy level
  - An electron can move in only if there is a vacancy



Shell Model

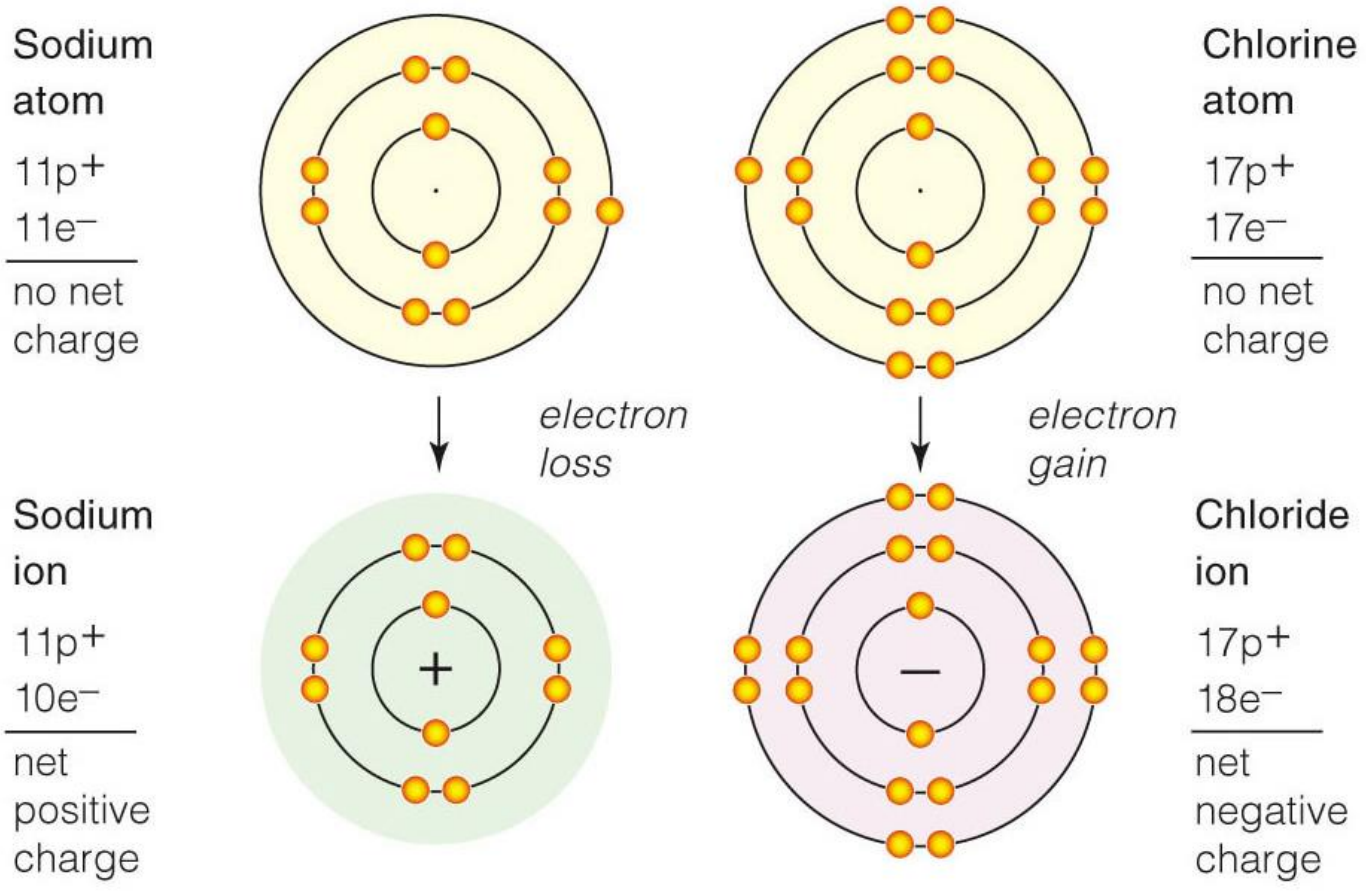
- The **shell model** of electron orbitals diagrams electron vacancies; filled from inside out
  - First shell: one orbital (2 electrons)
  - Second shell: four orbitals (8 electrons)
  - Third shell: four orbitals (book says 8 electrons – actually 18)



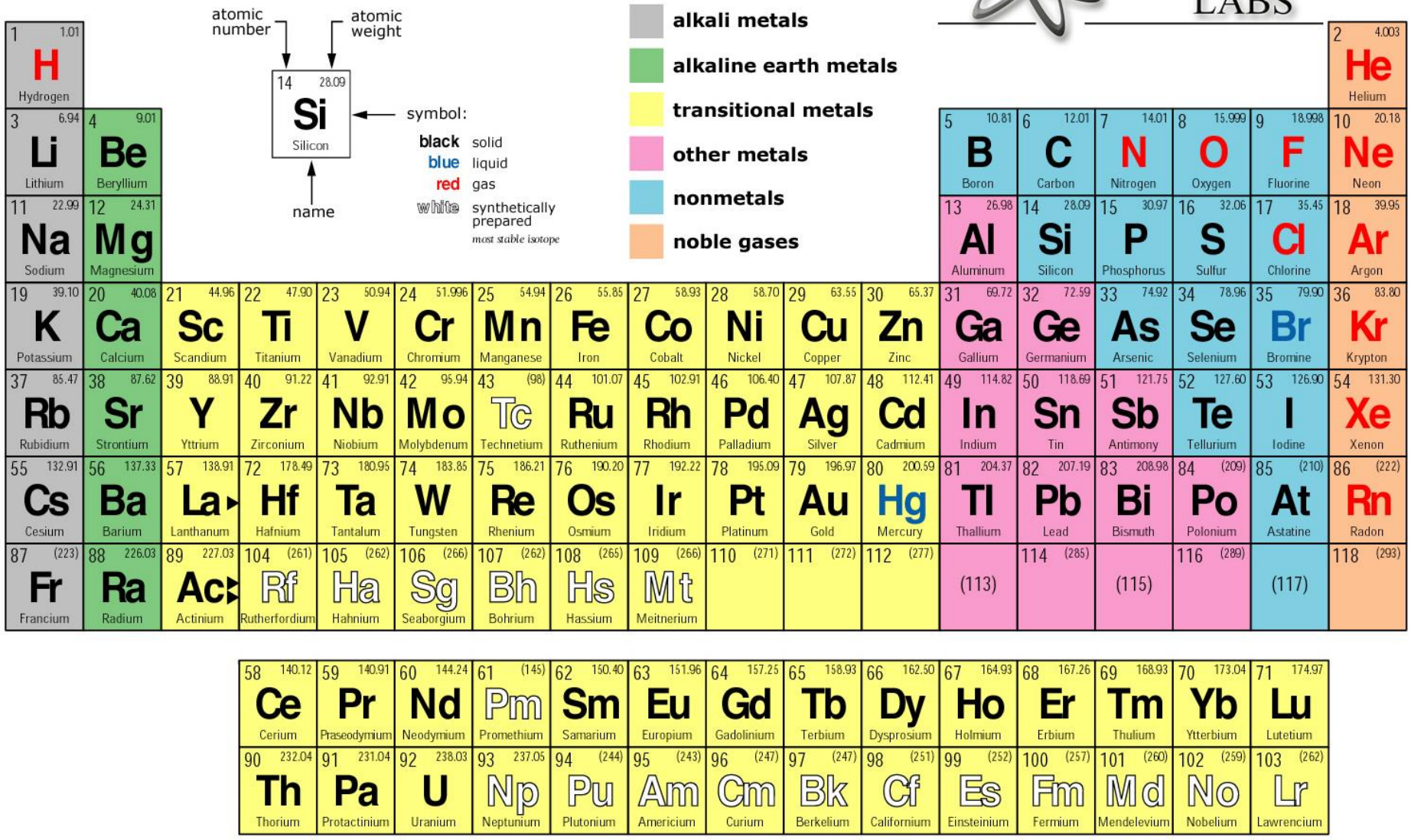
Atomic Number	Element Symbol	Electron Configuration	Number of Valence Electrons
1	H	$1s^1$	1
2	He	$1s^2$	2
3	Li	$1s^2 2s^1$	1
4	Be	$1s^2 2s^2$	2
5	B	$1s^2 2s^2 2p^1$	3
6	C	$1s^2 2s^2 2p^2$	4
7	N	$1s^2 2s^2 2p^3$	5
8	O	$1s^2 2s^2 2p^4$	6
9	F	$1s^2 2s^2 2p^5$	7
10	Ne	$1s^2 2s^2 2p^6$	8

Atoms and Ions

- **Ion**
  - An atom with a positive or negative charge due to loss or gain of electrons in its outer shell
  - *Examples:* Na^+, Cl^-

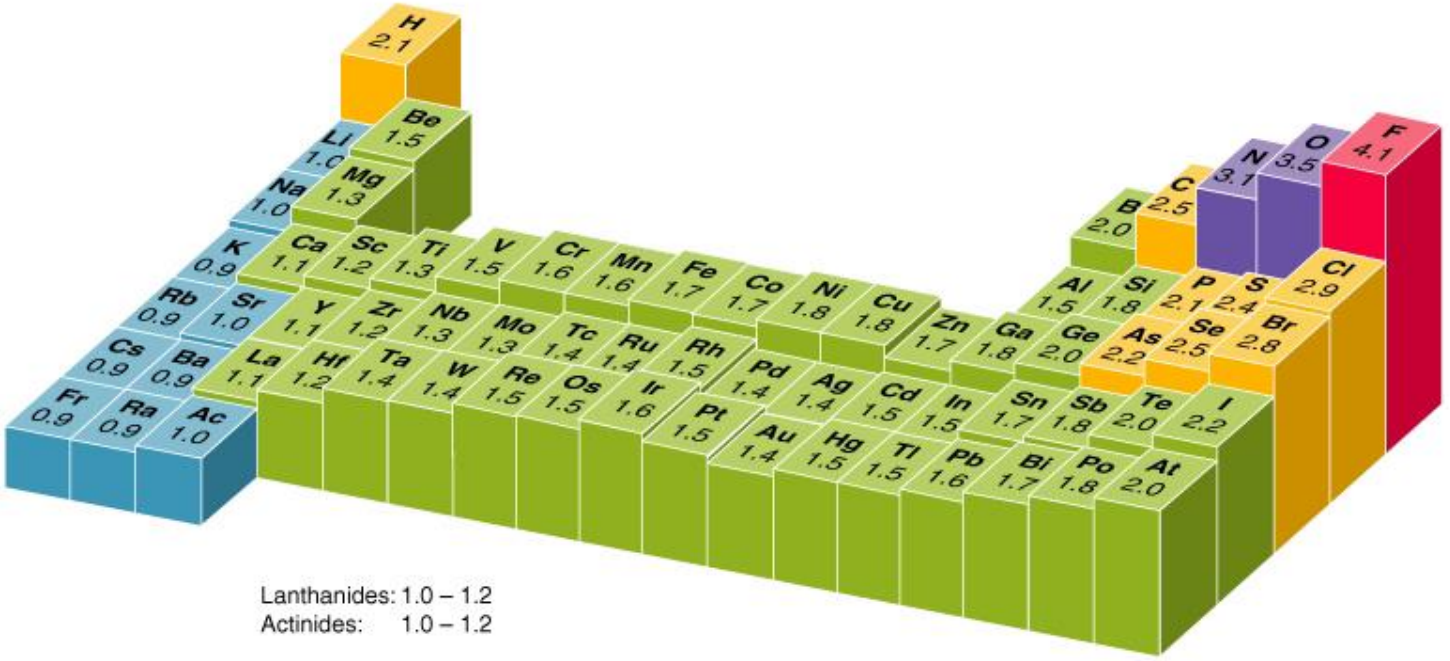


Periodic Table of the Elements

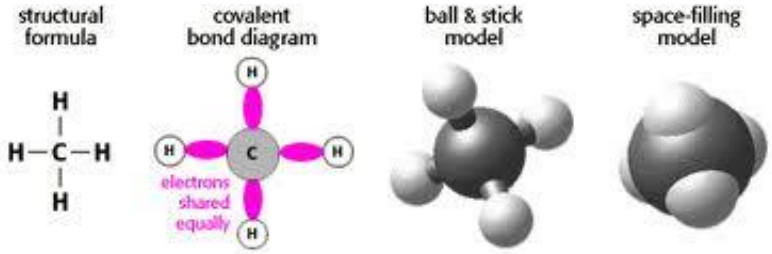


Electronegativity

- **Electronegativity**
  - A measure of an atom's ability to pull electrons from another atom (depends on size and # of vacancies)



How atoms interact



- **Chemical bond**
  - An attractive force existing between two atoms when their electrons interact
- **Molecule**
  - Two or more atoms joined in chemical bonds
- **Compounds**
  - Molecules consisting of two or more elements whose proportions do not vary
  - *Example:* Water (H_2O)
- **Mixture**
  - Two or more substances that
  - intermingle but do not bond;
  - proportions of each
  - can vary

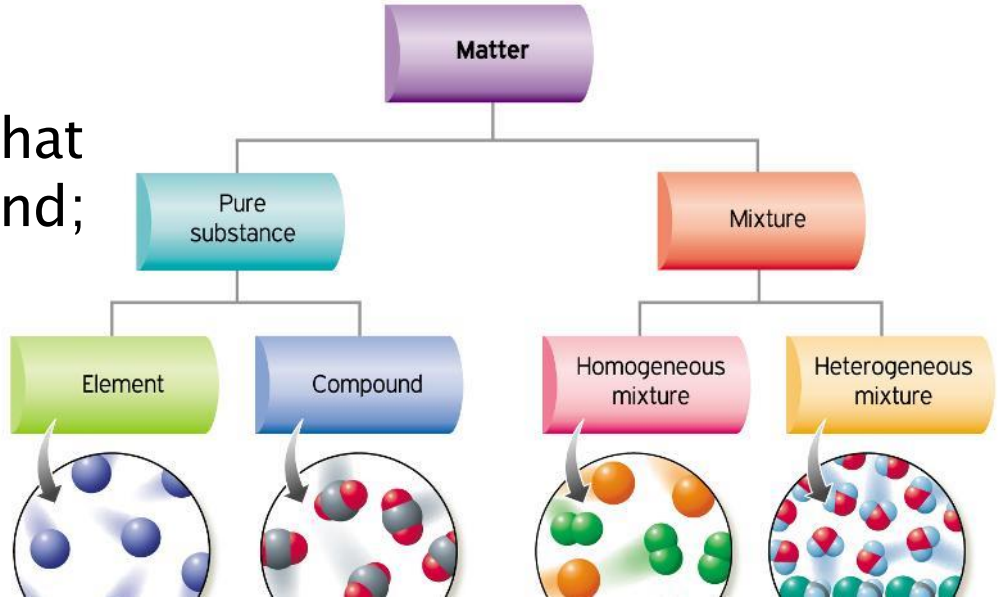
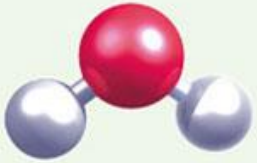
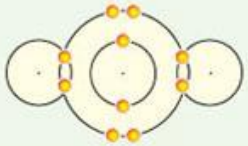


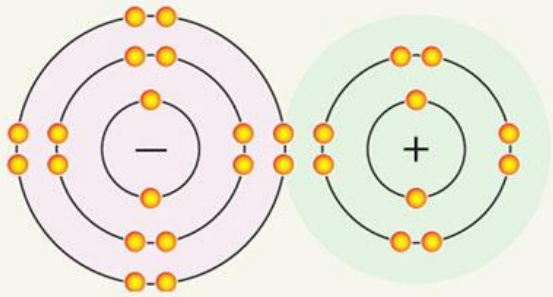
Table 2.1 Different Ways To Represent the Same Molecule

Common name	Water	Familiar term.
Chemical name	Hydrogen oxide	Systematically describes elemental composition.
Chemical formula	H_2O	Indicates unvarying proportions of elements. Subscripts show number of atoms of an element per molecule. The absence of a subscript means one atom.
Structural formula	H—O—H H–O–H	Represents each covalent bond as a single line between atoms. The bond angles may also be represented.
Structural model		Shows the positions and relative sizes of atoms.
Shell model		Shows how pairs of electrons are shared in covalent bonds.

Types of Bonding

- Ionic Bonding
  - A strong mutual attraction between two oppositely charges ions with a large difference in electronegativity (an electron is not usually transferred)
  - *Example:* NaCl (table salt)

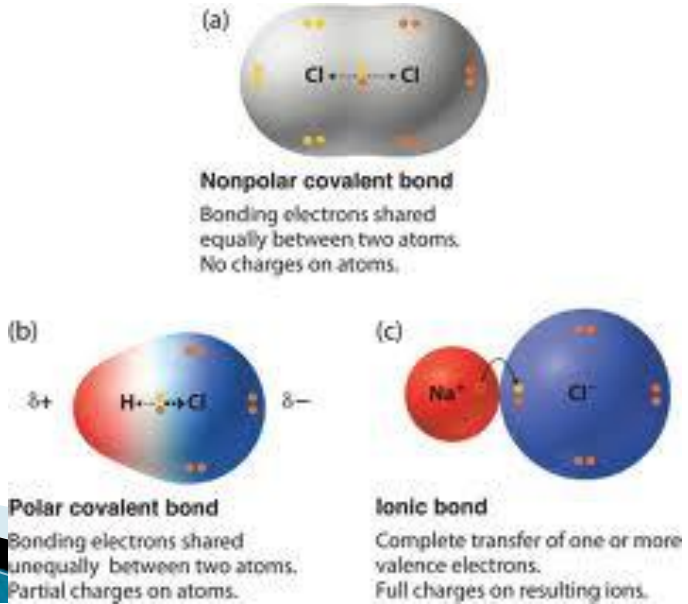
A A crystal of table salt is a cubic lattice of many sodium and chloride ions.



B The mutual attraction of opposite charges holds the two kinds of ions together in a lattice.

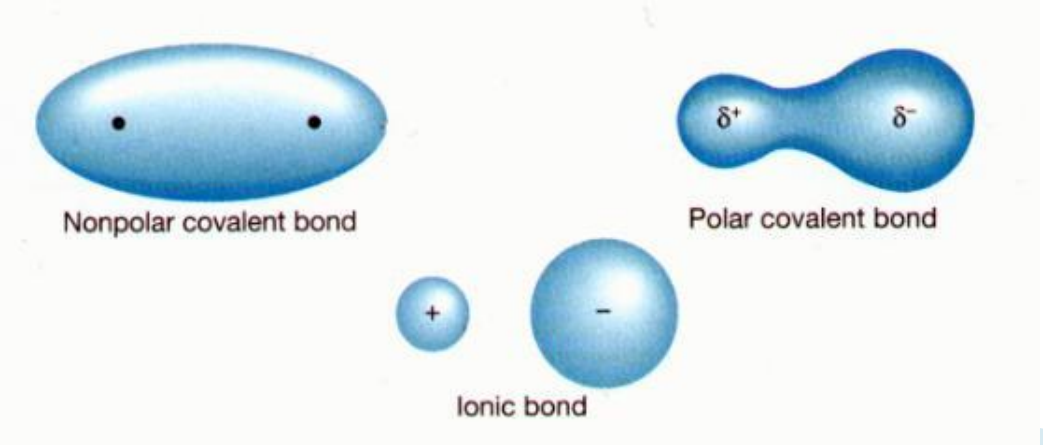
Covalent Bonding

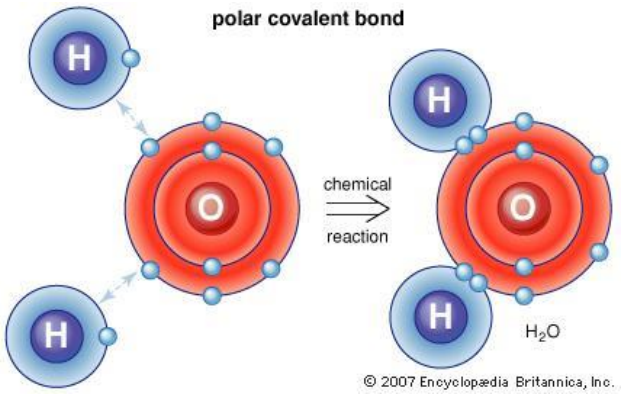
- **Covalent bond**
  - Two atoms with similar electronegativity and unpaired electrons sharing a pair of electrons
  - Can be **stronger** than ionic bonds
  - Atoms can share one, two, or three pairs of electrons (single, double, or triple covalent bonds)



Polar vs. Nonpolar covalent bond

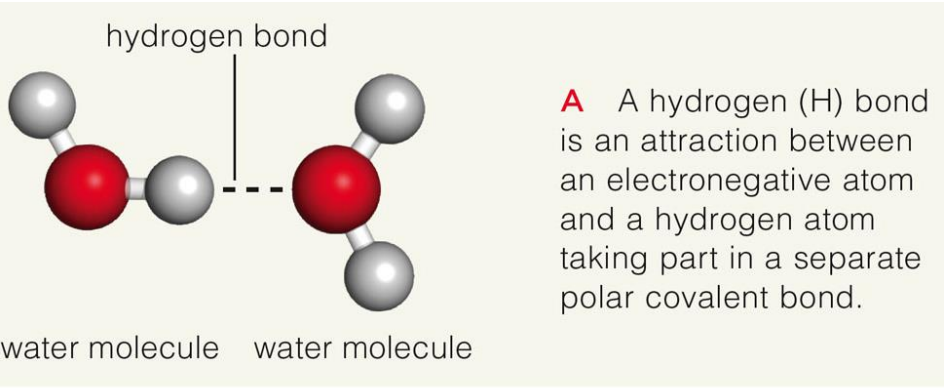
- **Nonpolar covalent bond**
  - Atoms sharing electrons equally; formed between atoms with identical electronegativity
- **Polar covalent bond**
  - Atoms with different electronegativity do not share electrons equally; one atom has a more negative charge, the other is more positive
- Bonding TedEd video



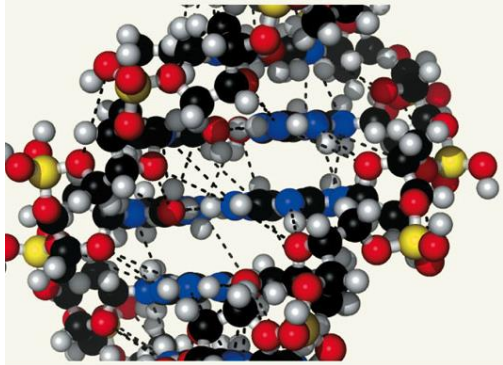


Hydrogen Bonds

- **Hydrogen bond**
  - A **weak** attraction between a highly electronegative atom and a hydrogen atom taking part in a separate polar covalent bond
  - Hydrogen bonds do not form molecules and are not "chemical bonds"
  - Hydrogen bonds stabilize the structures of large biological molecules



A A hydrogen (H) bond is an attraction between an electronegative atom and a hydrogen atom taking part in a separate polar covalent bond.



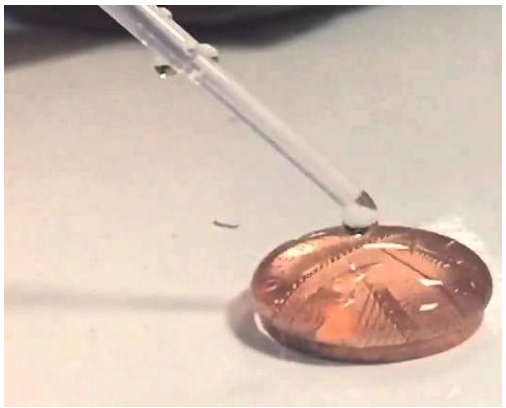
B Hydrogen bonds are individually weak, but many of them form. Collectively, they are strong enough to stabilize the structures of large biological molecules such as DNA, shown here.

2.5 Water's Life Giving Properties

- Living organisms are mostly water
  - the chemical reactions of life are carried out in water
  - Water is essential to life because of its unique properties

Penny Lab

- Question: How do salt, sugar and soap impact the number of drops of water that can be dropped on a penny?
  - Independent Variable:
  - Dependent Variable:
  - Control Group:
  - Constants:
  - Hypothesis:



- Brainstorm ideas for an experimental design:
- At the end, we will do a CER (Claim, evidence, reasoning)

SCIENTIFIC EXPLANATIONS

CLAIM

Statement about the results of an investigation

- A one-sentence answer to the question you investigated.
- It answers, **what can you conclude?**
- It should not start with **yes** or **no.**
- It should describe the relationship between **dependent** and **independent** variables.

EVIDENCE

Scientific data used to support the claim

Evidence must be:

- **Sufficient** — Use enough evidence to support the claim.
- **Appropriate** — Use data that support your claim. Leave out information that doesn't support the claim.
- **Qualitative** — (Using the senses), or **Quantitative** (numerical), or a combination of both.

REASONING

Ties together the claim and the evidence

- Shows **how** or **why** the data count as evidence to support the claim.
- Provides the justification for why **this** evidence is important to **this** claim.
- Includes one or more **scientific principles** that are important to the claim and evidence.

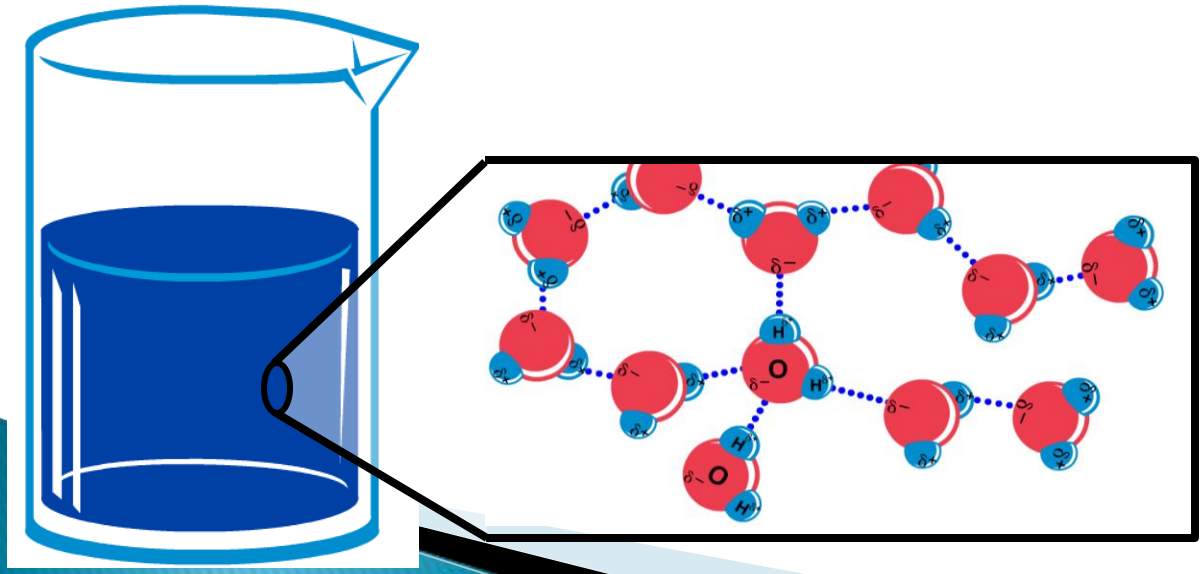
***Remember:** Read what you've written to be sure it makes sense as a whole explanation.

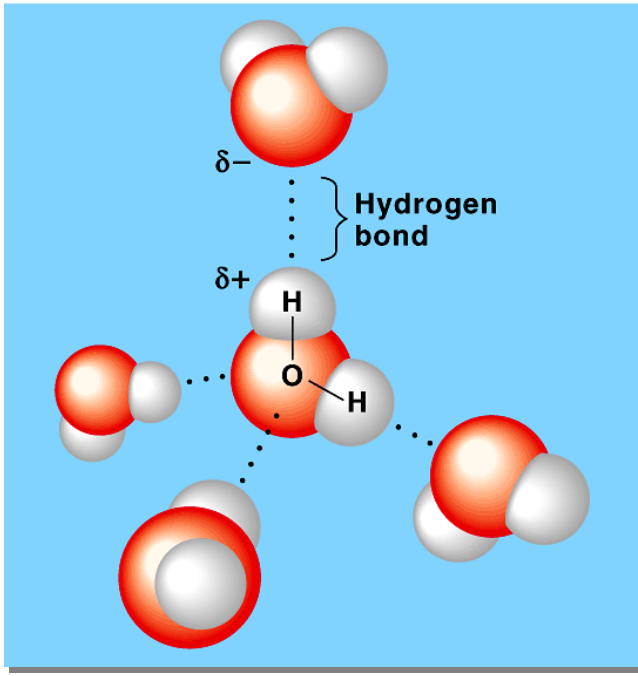
CER (Taken from activelearning.com)

- **Claim** – Statement about the results
  - A one-sentence answer to the question you investigated
  - In answers, what can you conclude?
  - Describes the relationship between the dependent and independent variables
- **Evidence** – Scientific data used to support your claim
  - Use enough evidence to support the claim
  - Use qualitative and quantitative data
- **Reasoning** – Ties together the claim and evidence
  - Shows HOW or WHY the data count as evidence to support THIS claim
  - Provides justification for why THIS evidence is important to THIS claim
  - Includes one or more SCIENTIFIC PRINCIPLE that are important to the claim and evidence

Properties of Water

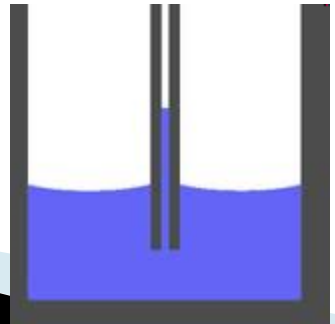
- The properties of water are a result of extensive hydrogen bonding with each other
  - Overall, water (H_2O) has no charge
  - slightly positive H attracted to slightly negative O end
  - Creates a “sticky” molecule

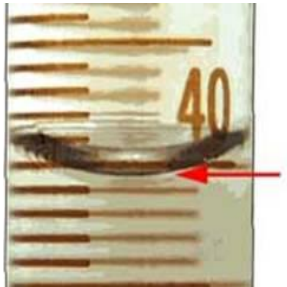


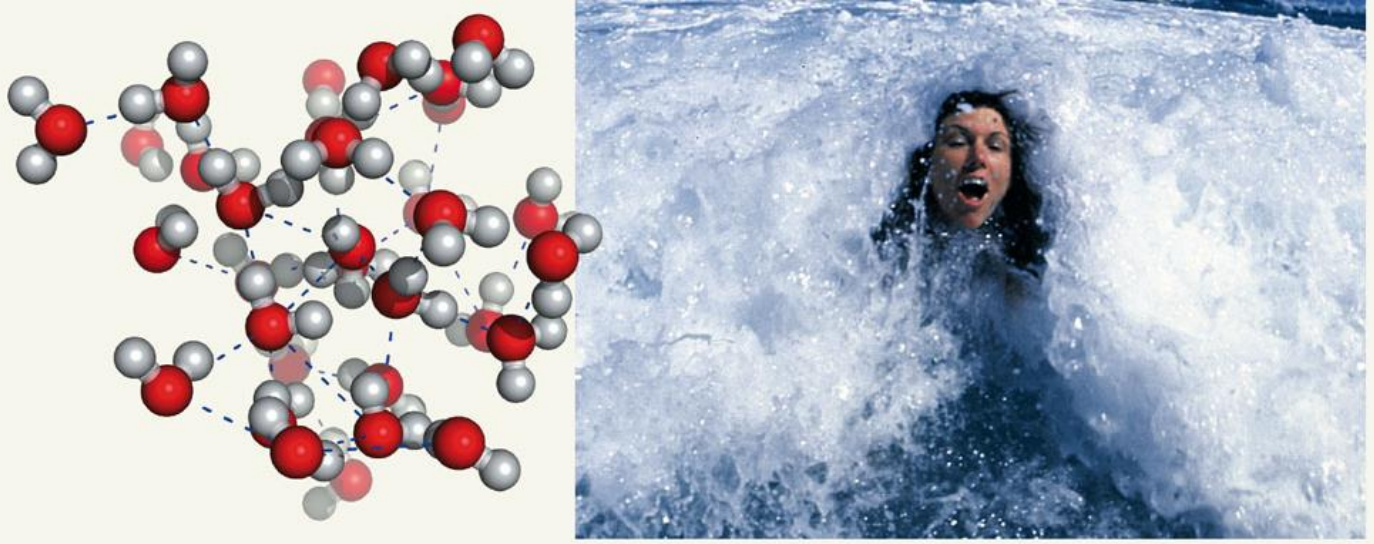


Adhesion and Cohesion

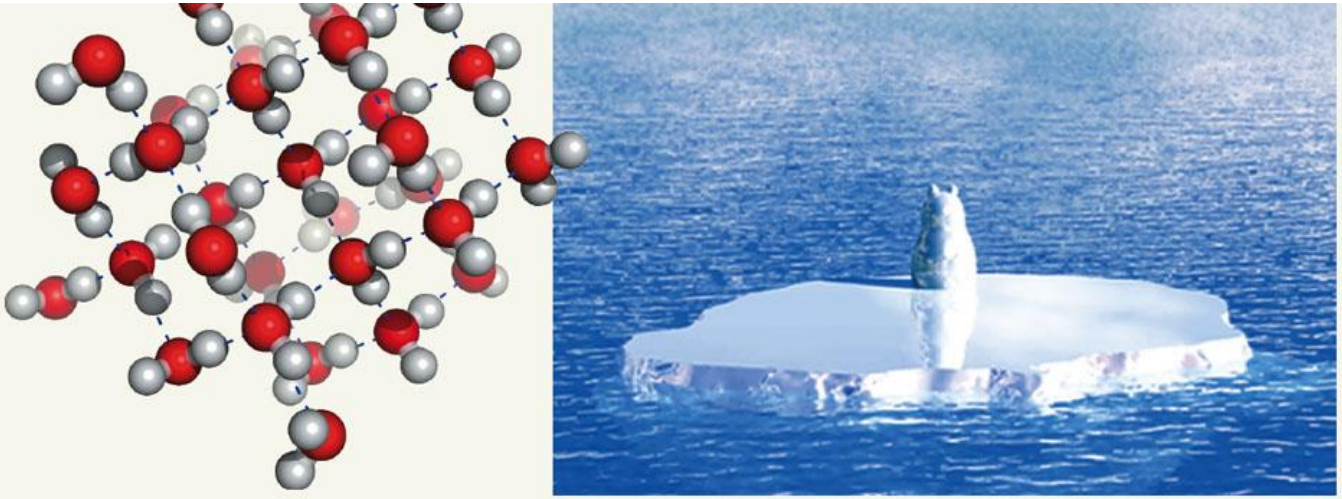
- **Cohesion** = hydrogen bonding between like molecules
  - Provides surface tension
  - Draws water up from roots of plants
- **Adhesion** = hydrogen bonding between water and other molecules
  - Capillary action
  - Meniscus







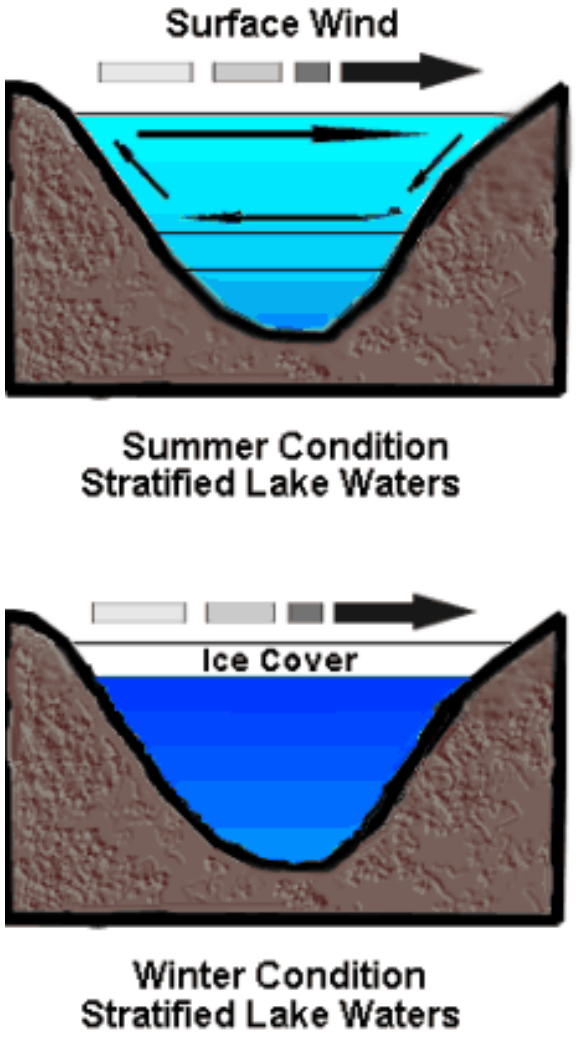
B Many hydrogen bonds (dashed lines) that form and break rapidly keep water molecules clustered together in liquid water.



C Below 0°C (32°F), the hydrogen bonds hold water molecules rigidly in the three-dimensional lattice of ice. The molecules are less densely packed in ice than in liquid water, so ice floats on water.

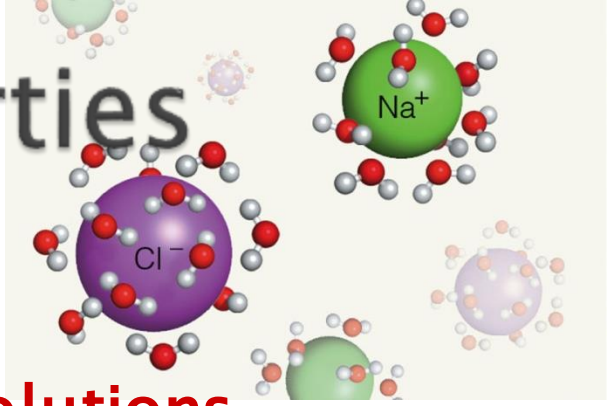
Why is “ice floats” important?

- Oceans & lakes don’t freeze solid
  - surface ice insulates water below
    - allowing life to survive the winter
  - seasonal turnover of lakes
    - sinking cold H_2O cycles nutrients in autumn

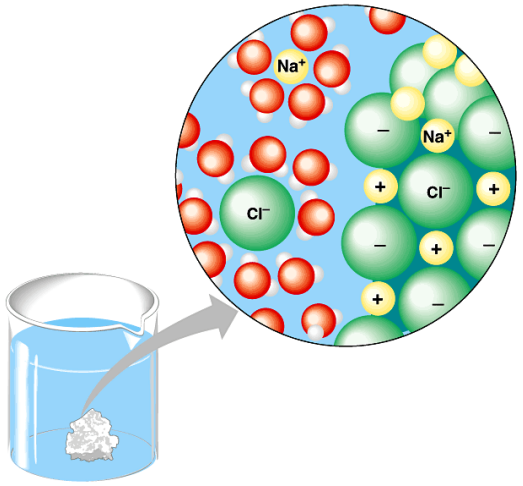


- H_2O resists changes in temperature –
  - takes a lot to heat it up
  - takes a lot to cool it down
- H_2O moderates temperatures on Earth

Water's solvent properties

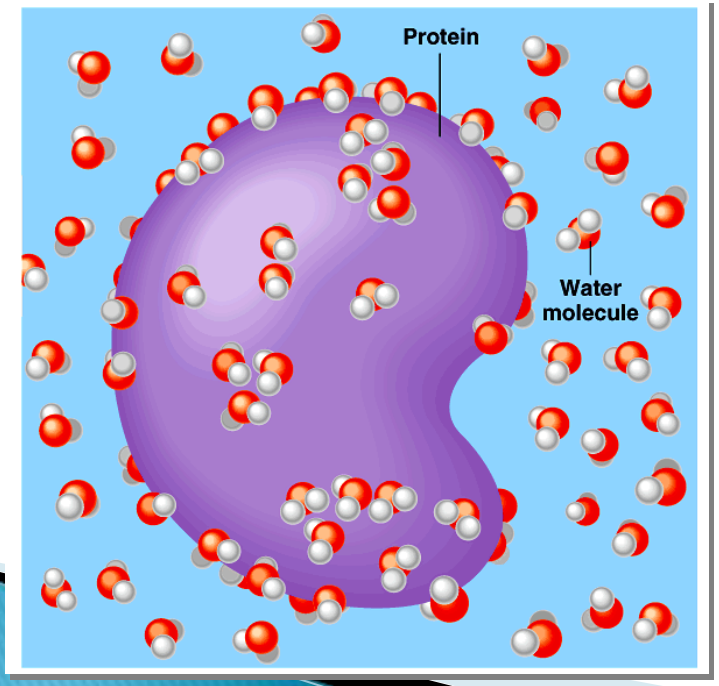


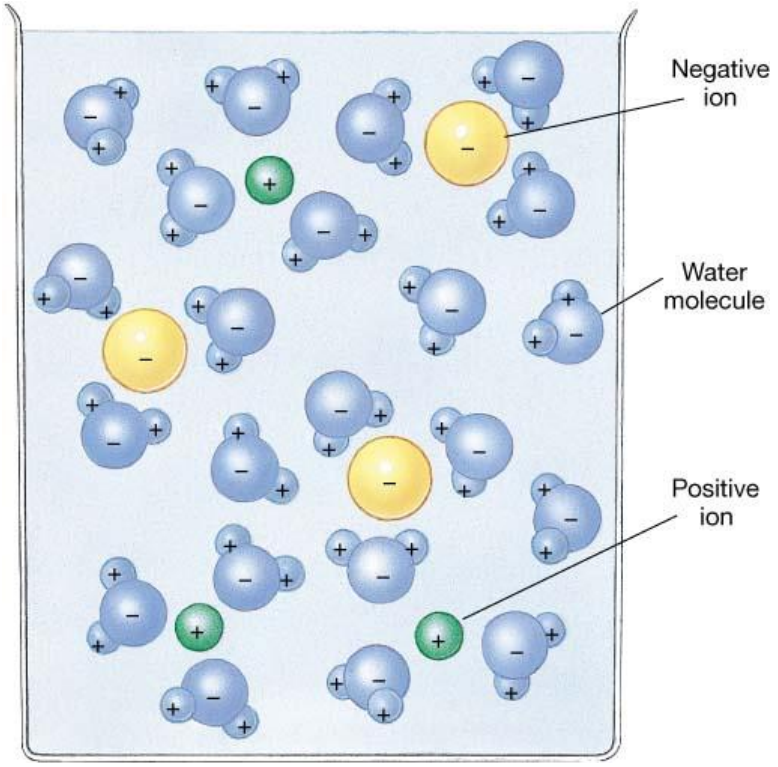
- **Solvents dissolve solutes creating solutions**
- Water dissolves polar molecules
  - H-bonds form between water molecules and polar molecules
  - Polar molecules dissolved by water are **hydrophilic** (water-loving)
  - Nonpolar **(hydrophobic)** molecules are not dissolved by water



What dissolves in water?

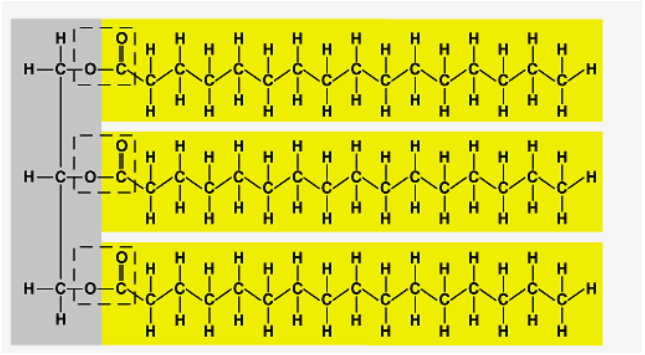
- substances have attraction to H_2O
- polar or non-polar?





What doesn't dissolve in water?

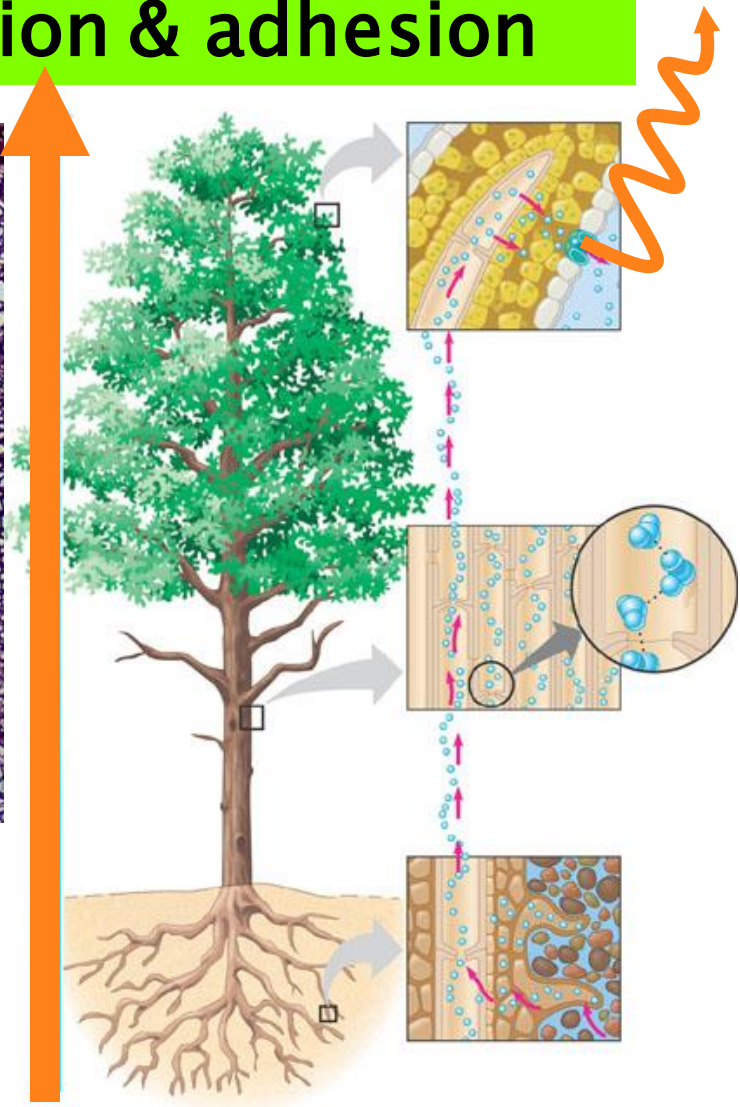
- substances that don't have an attraction to H_2O
  - polar or non-polar?



fat (triglycerol)

How does H_2O get to top of trees?

Transpiration is built on cohesion & adhesion



CLICKER QUIZ ON CHEMISTRY
1. Which statement is true?

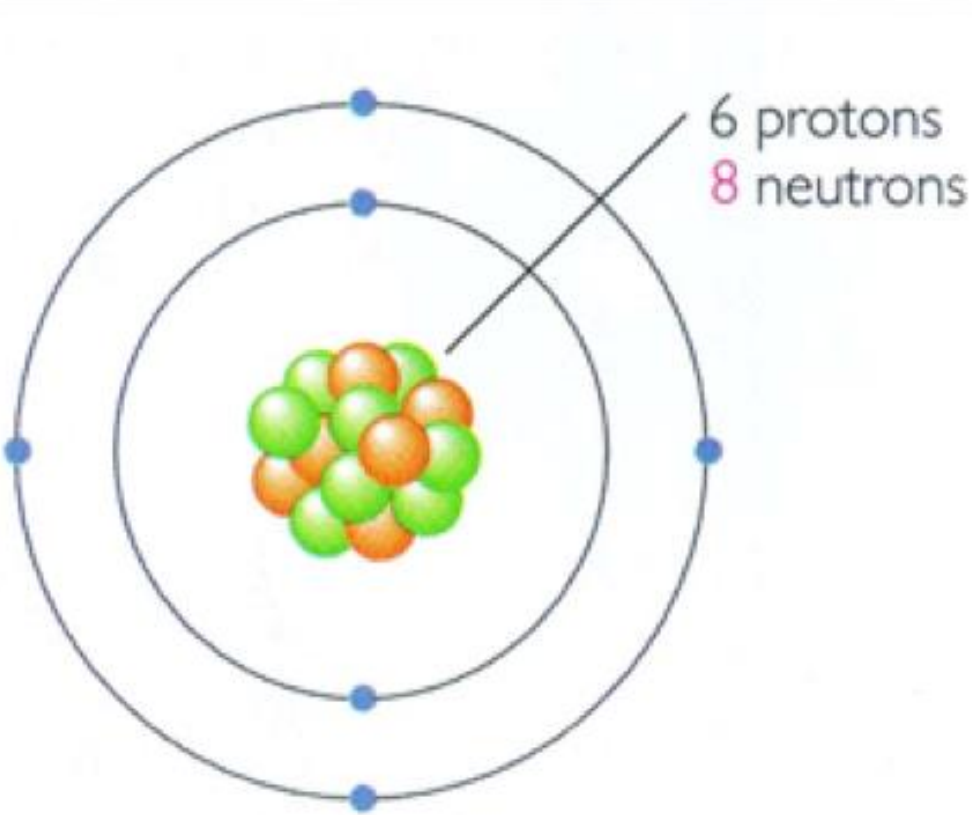
- A. Protons and neutrons have a positive charge and are found in the nucleus.
- B. Protons have a positive charge, electrons have a negative charge, and they are both found in the nucleus.
- C. Neutrons have no charge, electrons have a negative charge and are both found in the nucleus.
- D. Protons have a positive charge, neutrons have no charge and are both found in the nucleus.
- E. None of the above.

2. Which type of bond involves attraction between atoms that have gained or lost electrons (there is no sharing involved!)?

- A. Ionic
- B. Polar Covalent
- C. Nonpolar Covalent
- D. Hydrogen
- E. None of the above.

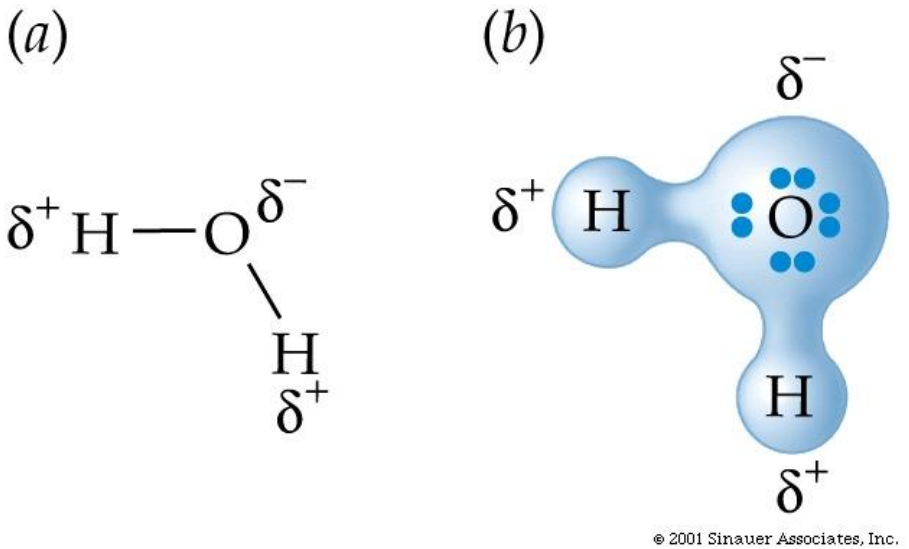
3. The atomic number in the atom is _____, the mass number is _____ and the atom has a ____ charge.

- A. 8, 14, negative
- B. 8, 8, neutral
- C. 8, 8, positive
- D. 6, 14, negative
- E. 6, 8, positive
- F. 6, 14, neutral
- G. 14, 14, neutral



4. What type of bond is shown between the oxygen and hydrogen atoms in a single water molecule?

- A. Ionic
- B. Polar Covalent
- C. Nonpolar Covalent
- D. Hydrogen Bond
- E. None of the above



5. Which of the following are a result of the hydrogen bonding in water?

- A. a “sticky molecule”
- B. surface tension.
- C. a solid form that is less dense than the liquid
- D. adhesion and cohesion
- E. All of the above

6. Complete the table

Substance	pH	Color change with cabbage juice	Acid or base
A	3		
B	7		
C	1		
D	11		

A – What substance has the most hydrogen ions?
B – How many times more acidic is substance C than A?
C – How many times more basic is substance D than B?

Acids and Bases

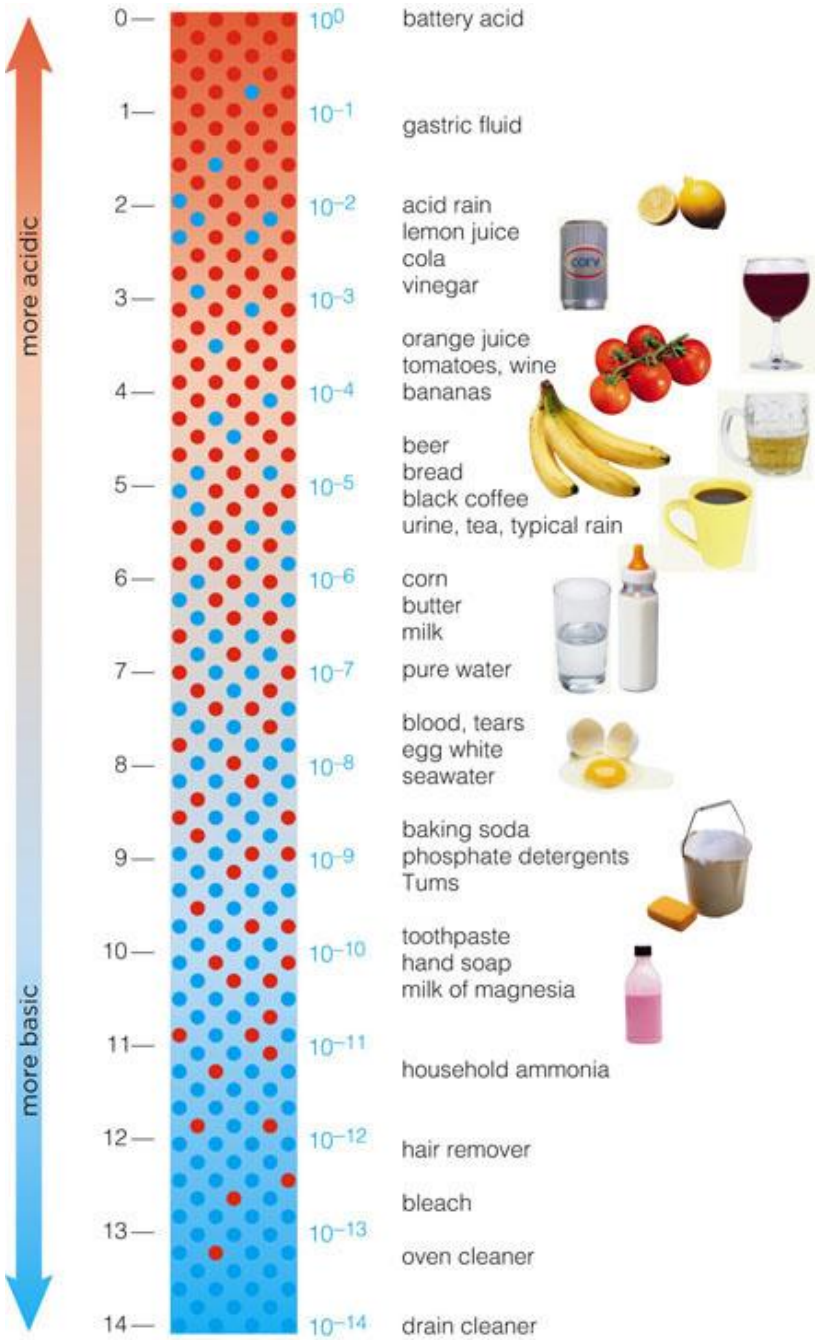
- Hydrogen ions have far-reaching effects because they are chemically active, and because there are so many of them

- Molecules in water (H_2O) can separate into hydrogen ions (H^+) and hydroxide ions (OH^-)

$$H_20 \longleftrightarrow H^+ + OH^-$$

pH Scale

- **pH** is a measure of the number of hydrogen ions in a solution
  - The more hydrogen ions, the lower the pH
  - pH 7 is neutral (pure water)
  - Most life chemistry occurs around pH 7
  - Each number is a 10x increase in H+



Acids and Bases

- Acids donate hydrogen ions in a water solution
  - pH below 7
- Bases accept hydrogen ions in a water solution
  - pH above 7
- Chemical reactions involving acids and bases are important to homeostasis

Strong and weak acids/bases

- Acids and bases can be weak (less H+) or strong (more H+)
  - Gastric fluid, pH 2-3
  - Acid rain

- *Example:* Hydrochloric acid is a strong acid

$$HCl \longleftrightarrow H^+ + Cl^-$$

Salts and Water

- **Salt**
  - A compound that dissolves easily in water and releases ions other than H^+ and OH^-

HCl (acid) + NaOH (base) → NaCl (salt) + H_20

Buffers Against Shifts in pH

- **Buffer system**
  - A set of chemicals (a weak acid or base and its salt) that can keep the pH of a solution stable

OH^- + H_2CO_3 (carbonic acid) →
HCO_3^- (bicarbonate) + H_20

H^+ + HCO_3^- (bicarbonate) →
H_2CO_3 (carbonic acid)