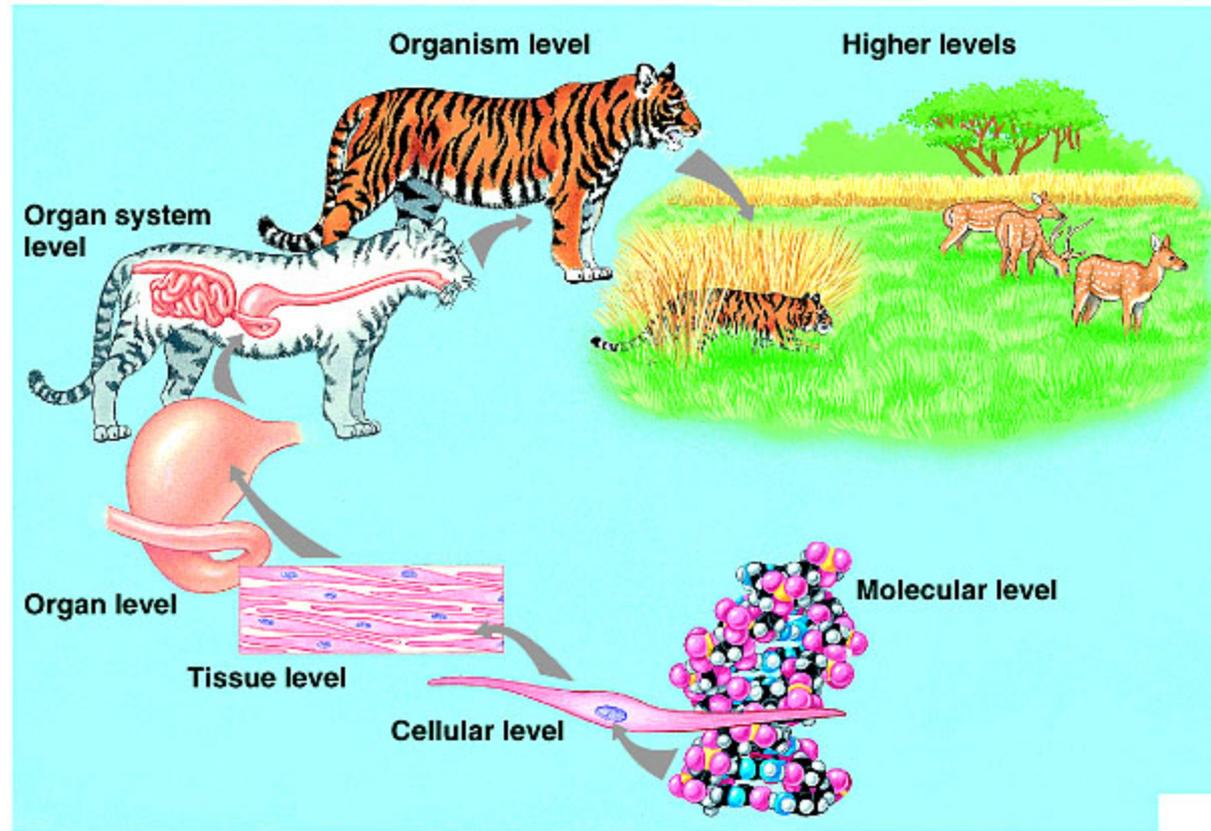


# CHEMICAL BASIS OF LIFE

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# Life is hierarchically organized

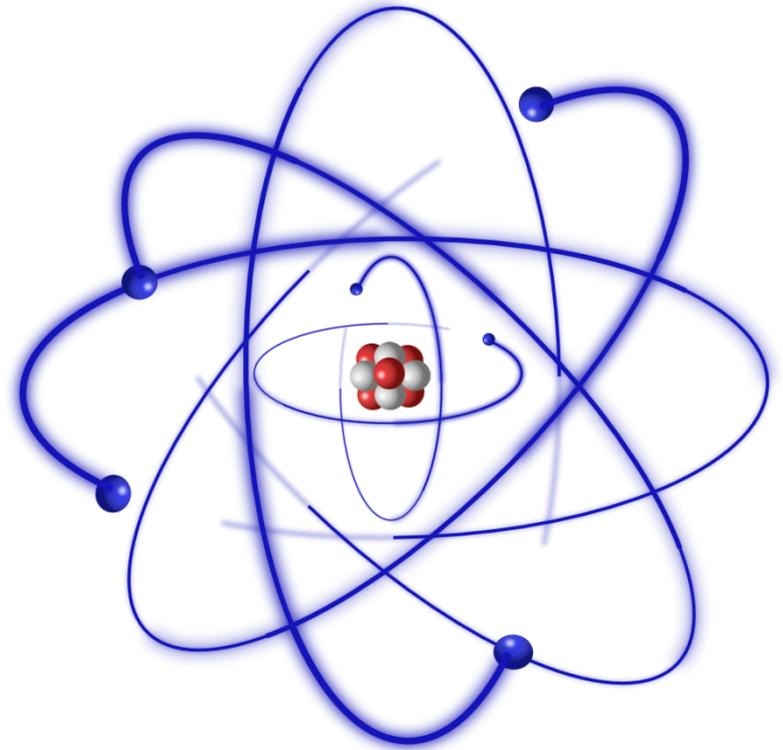
Figure 2.1 The hierarchy of biological order



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# What's the matter?

- All “stuff” is matter
  - ▣ Matter has mass
- Fundamental unit = atom
- Elements = different atoms
- Compounds
  - ▣ = combinations of elements
  - ▣ i.e. NaCl



# Elements essential to life

□ All life forms require 25 elements

□ The Big 4

□ CHON

■ Carbon

■ Hydrogen

■ Oxygen

■ Nitrogen

□ Makes up 96% of living matter

Elements Found in the Human Body

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|----|
| 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 | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At |  |  | Rn |
| Fr | Ra | Ac |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  |    |

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

|    |    |   |    |    |    |    |    |    |    |    |    |    |    |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|

■ Common Elements   ■ Trace Elements   ■ Remaining Elements

# Elements essential to life

- All life forms require 25 elements
- The Little 4
  - P-CaSK
  - Phosphorous
  - Calcium
  - Sulfur
  - Potassium (K)
- Makes up  $>3\%$

Elements Found in the Human Body

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|----|
| 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 | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At |  |  | Rn |
| Fr | Ra | Ac |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  |    |

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

|    |    |   |    |    |    |    |    |    |    |    |    |    |    |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|

 Common Elements  Trace Elements  Remaining Elements

# Elements essential to life

- All life forms require 25 elements
- Trace elements
  - ▣ Essential in small amounts
  - ▣ Make up  $< 1\%$

Elements Found in the Human Body

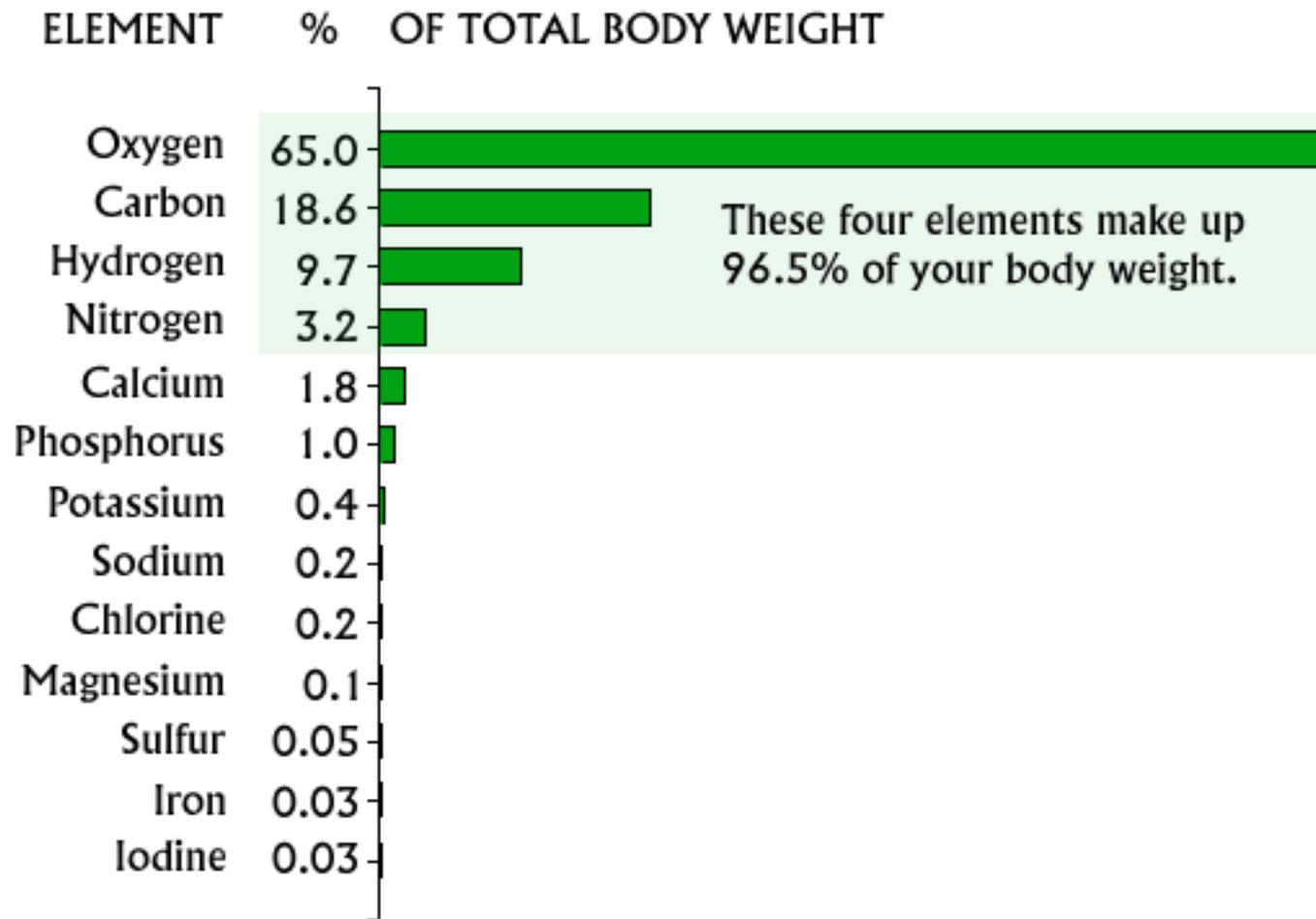
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|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|----|
| H  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  | He |
| Li | Be |    |    |    |    |    |    |    |    |    |    | 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 | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At |  |  | Rn |
| Fr | Ra | Ac |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |  |    |

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

|    |    |   |    |    |    |    |    |    |    |    |    |    |    |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
|----|----|---|----|----|----|----|----|----|----|----|----|----|----|

Common Elements
  Trace Elements
  Remaining Elements

# Elements essential to life

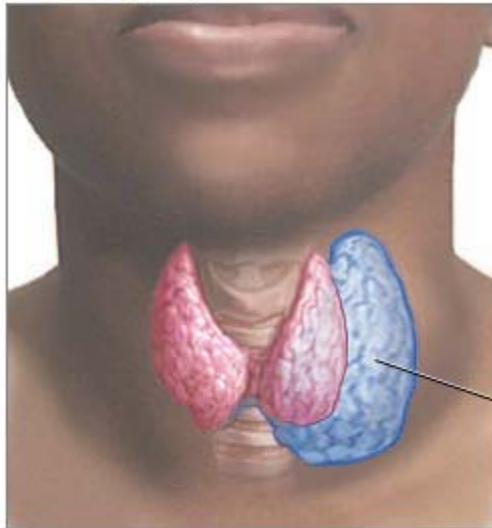


# Trace elements are important

## □ Iodine deficiency

## □ Iron deficiency

Hyperthyroidism caused  
by thyroid adenoma



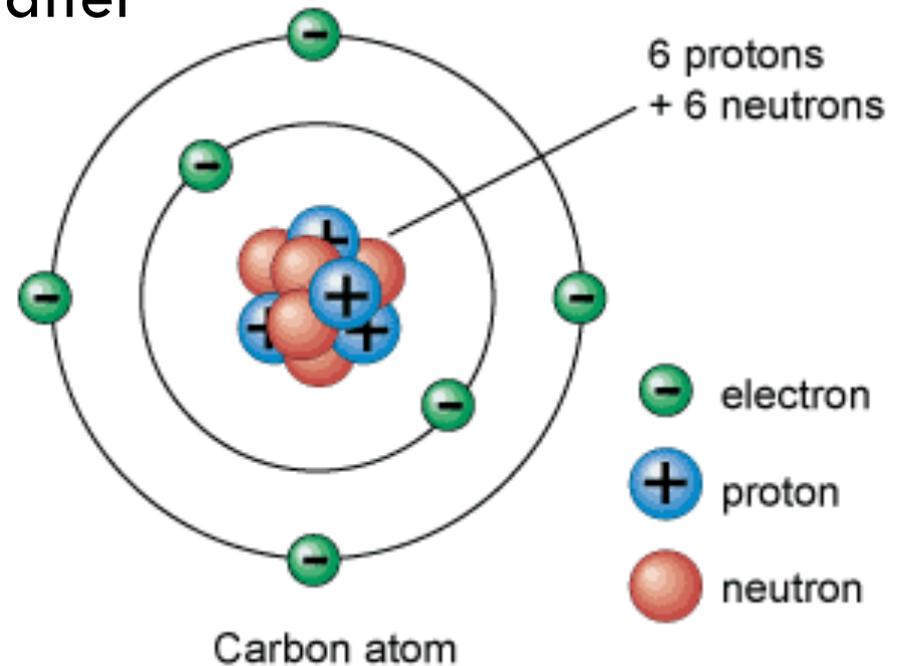
Hyperfunctioning  
thyroid (goiter)

ADAM.



# The atom

- Atom
  - ▣ = fundamental unit of matter
- Subatomic particles
  - ▣ Proton, neutron, electron



# The atom

## □ Nucleus

- Has  $> 99.9\%$  mass

- Proton

  - Positively charged

- Neutron

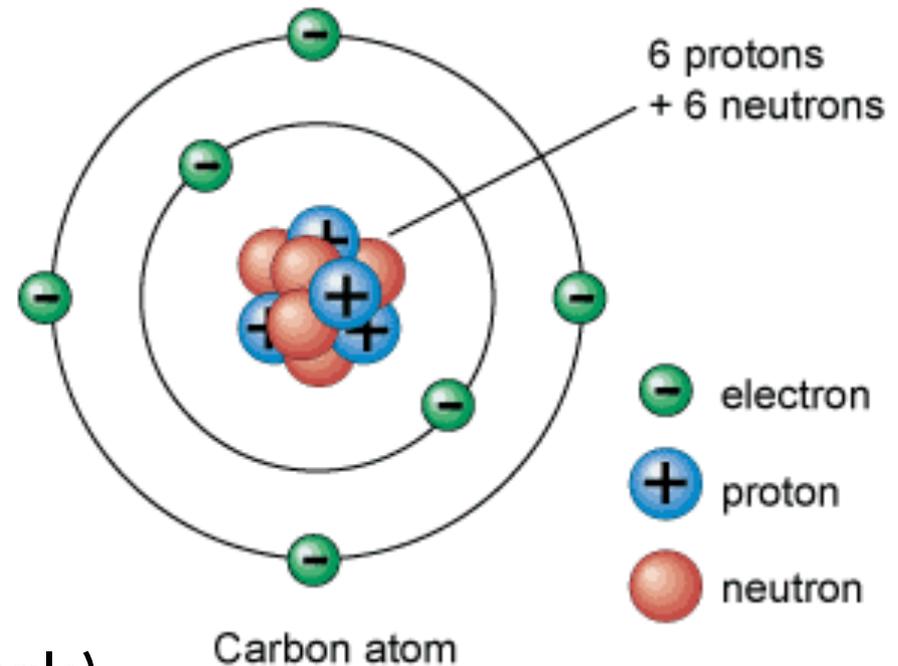
  - No charge

## □ Electron cloud

- Electron

  - Negatively charged

- Electron shells (aka orbitals)



# Calculating subatomic particles

## □ Atomic number

□ = protons

□ = electrons

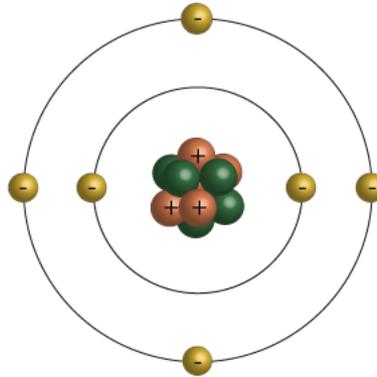
## □ Atomic mass

□ Mass of all subatomic particle

## □ Neutrons = AM (rounded) – AN

□ i.e. C neutrons =  $12 - 6 = 6$

□ Calculate neutrons in Lithium



|                         |                   |
|-------------------------|-------------------|
| Group: 14/IVA/IVB       |                   |
| <b>6</b>                | <b>12.011</b>     |
| Electron Configuration: | Oxidation States: |
| $1s^2$                  | +2                |
| $2s^2p^2$               | +4                |
|                         | -4                |
| <b>C</b>                |                   |
| Carbon                  |                   |

|    |    |    |    |    |    |    |    |    |    |     |     |     |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|----|----|----|----|----|
| 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 | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au  | Hg  | Tl  | Pb | Bi | Po | At | Rn |
| Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Uut | Uub | Uuq |    |    |    |    |    |
|    |    | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy  | Ho  | Er  | Tm | Yb | Lu |    |    |
|    |    | Th | Pa | U  | Np | Pu | Am | Cm | Bk | Cf  | Es  | Fm  | Md | No | Lr |    |    |

# Calculating subatomic particles

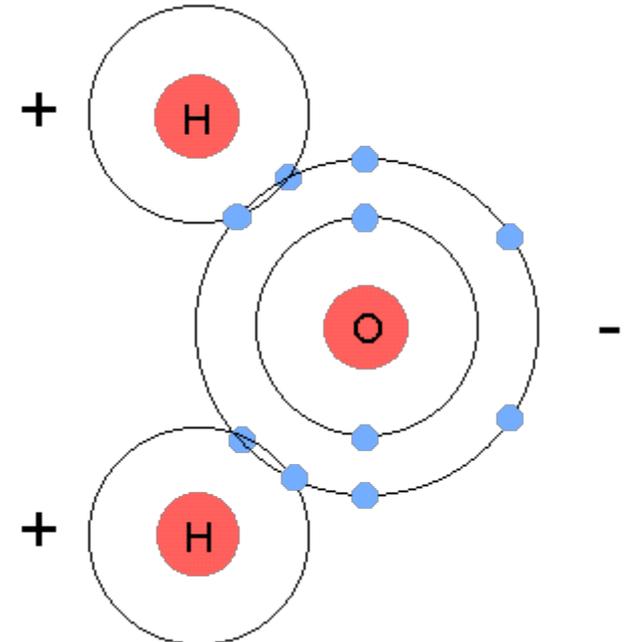
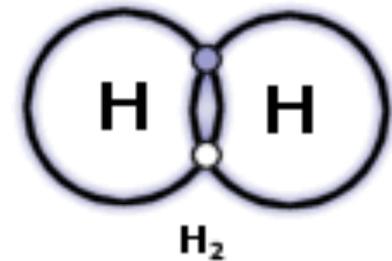
- Electron levels (= orbitals)
  - 1<sup>st</sup> level: up to 2 electrons
  - 2<sup>nd</sup> level: up to 8 electrons
  - 3<sup>rd</sup> level: up to 8 electrons
- The rule:
  - Fill one level before the next
- Draw
  - Hydrogen
  - Carbon
  - Oxygen

|   |                   |
|---|-------------------|
| Group: 14/IVA/IVB   |                   |
| <b>6</b>  | <b>12.011</b>     |
| Electron Configuration:   | Oxidation States: |
| 1s <sup>2</sup>   | +2                |
| 2s <sup>2</sup> p <sup>2</sup>  | +4                |
|   | -4                |
|  |                   |
| Carbon  |                   |

|    |    |    |    |    |    |    |    |    |    |     |     |     |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|----|----|----|----|----|
| 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 | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au  | Hg  | Tl  | Pb | Bi | Po | At | Rn |
| Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Uut | Uub | Uuq |    |    |    |    |    |
|    |    |    |    |    |    |    |    |    |    |     |     |     |    |    |    |    |    |
|    |    | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy  | Ho  | Er  | Tm | Yb | Lu |    |    |
|    |    | Th | Pa | U  | Np | Pu | Am | Cm | Bk | Cf  | Es  | Fm  | Md | No | Lr |    |    |

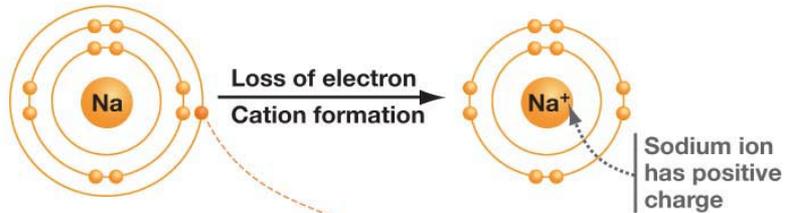
# Atomic Bonds

- Molecules
  - ▣ More than one atom bonded together
- Covalent bond
  - ▣ Atoms share electrons
  - ▣ Non-polar covalent bonds
    - Equal attraction
    - i.e.  $H_2$
  - ▣ Polar covalent bonds
    - Asymmetric attraction
    - i.e.  $H_2O$

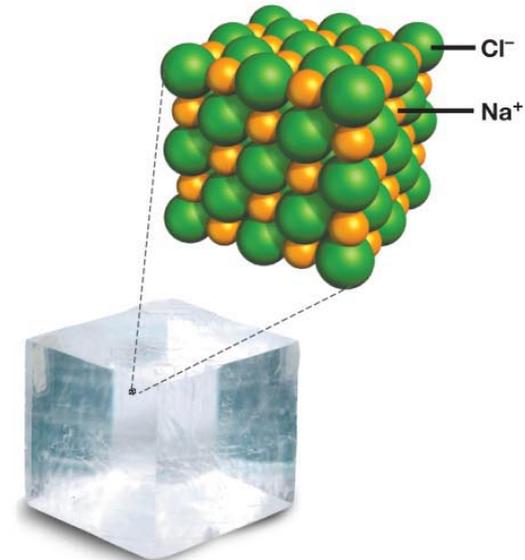
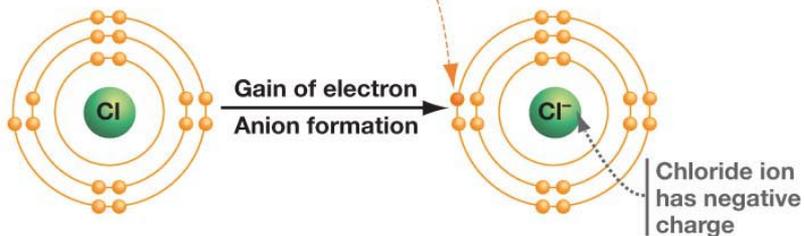


# Atomic Bonds

- Ionic bonds
  - One atoms “steals” another  $e^-$
  - Unequal attraction
  - i.e. NaCl

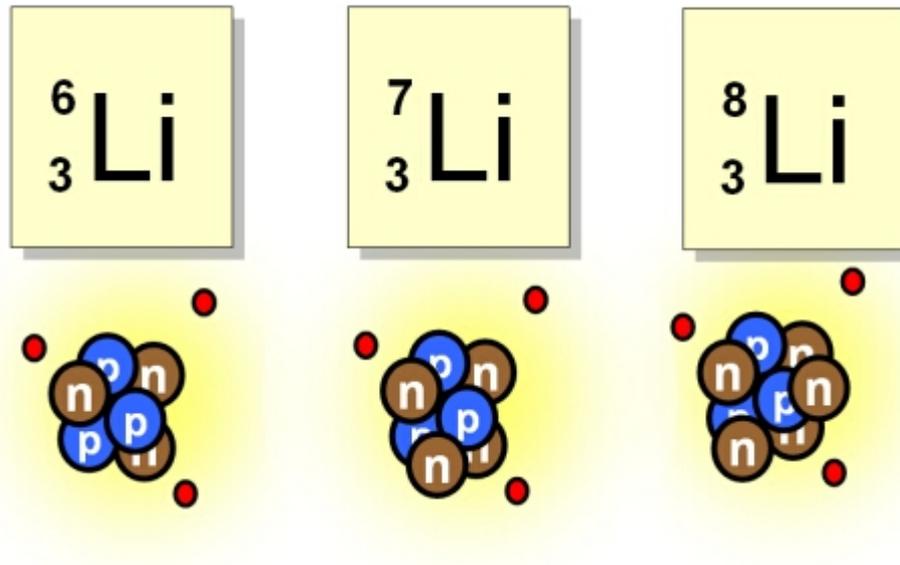


(b) A chloride ion being formed



# Isotopes

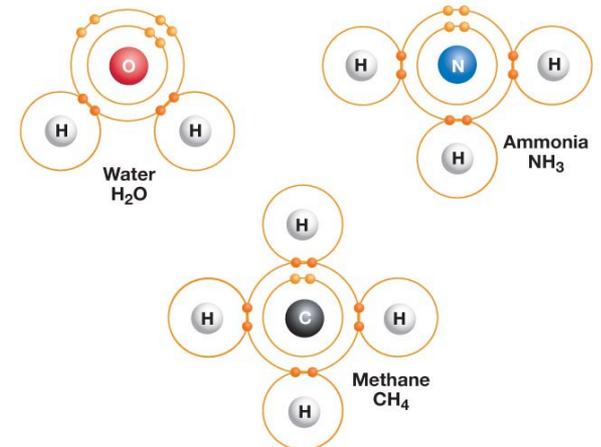
- = atoms with more or less neutrons than protons
- Atomic mass
  - ▣ Average of all existing isotopes
  - ▣ Lithium (AM) = 6.9



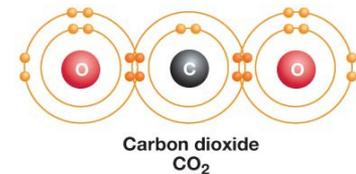
# Numbers of bonds

- Depends on number of unpaired electrons
  - If more than one an atom can form
    - Multiple single bonds
    - Double bonds
    - Triple bonds

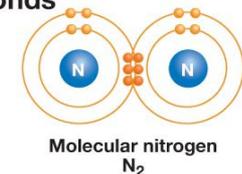
(a) Single bonds



(b) Double bonds



(c) Triple bonds



# Chemical reactions

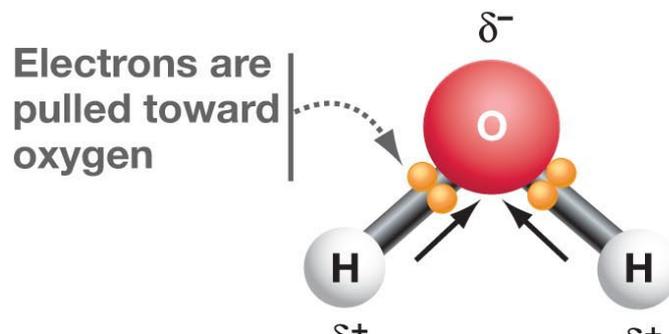
- Occurs when

1. One substance combines with another
2. One substance is broken down into another
3. Chemical bonds are broken and other bonds form

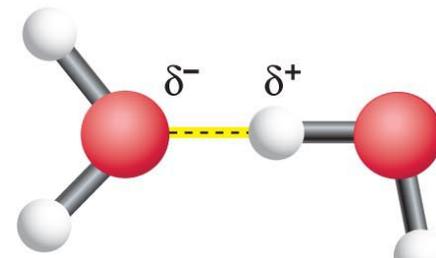
# Water as a solvent

- Life is based on water b/c it is a great solvent
  - ▣ Dissolves other substances
- Why?
  - ▣ Connected by hydrogen bonds
    - Weak attractions b/n partially negative O and partially positive H of another polar molecule (i.e. H<sub>2</sub>O)

**(a) Water is polar.**

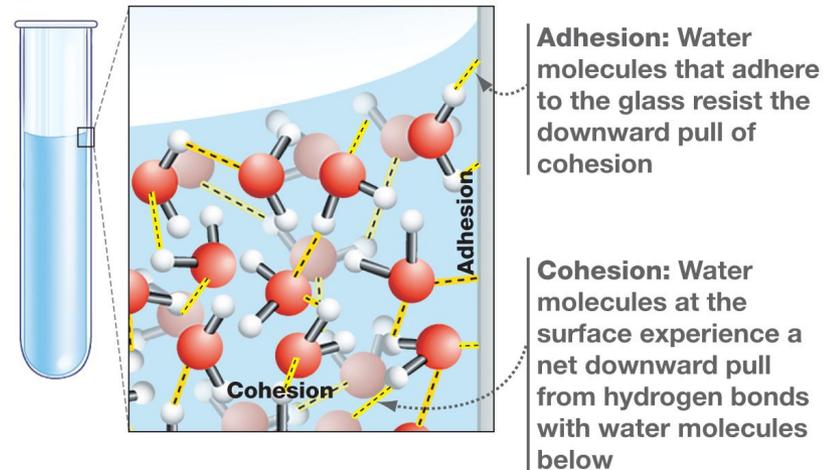


**(b) Hydrogen bonds form between water molecules.**



# Other properties of water

- b/c of small size, bent shape, and polarity
- It is:
  - ▣ Cohesive
    - Binding b/n like molecules
    - Resulting in surface tension
  - ▣ Adhesive
    - Binding b/n unlike molecules
  - ▣ Denser as liquid than solid
  - ▣ Absorb large amounts of E



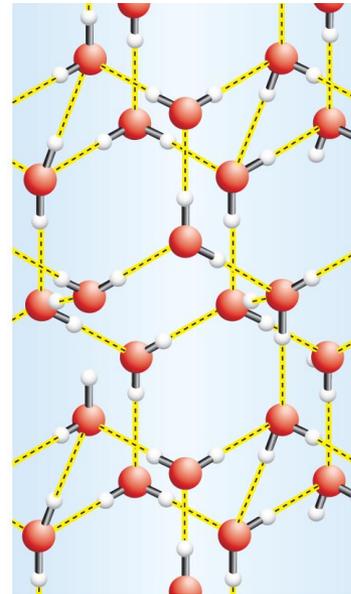
# Other properties of water

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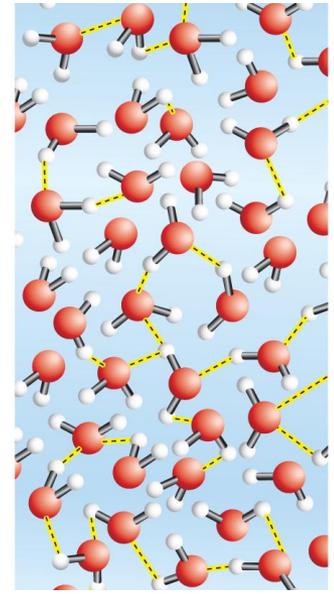


# Other properties of water

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- It is:
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    - Resulting in surface tension
  - Adhesive
    - Binding b/n unlike molecules
  - Denser as liquid than solid
  - Absorb large amounts of E



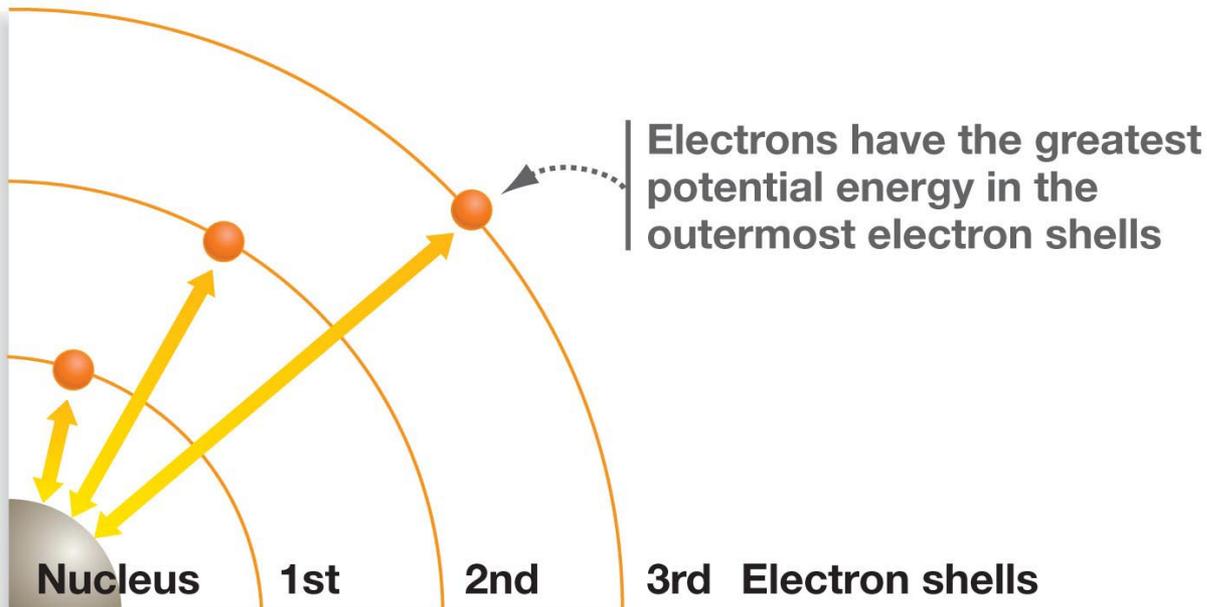
Solid water



Liquid water

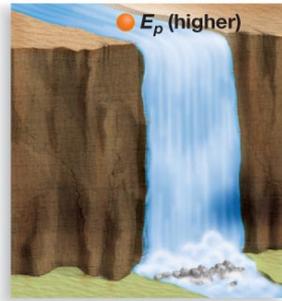
# Energy

- Is the capacity to do work
- Potential E
  - ▣ Stored E
  - ▣  $e^-$  in outer shell have more PE
- Kinetic E
  - ▣ Energy of movement
  - ▣ Measured as temperature
  - ▣ Low temp. objects = slower



# Energy

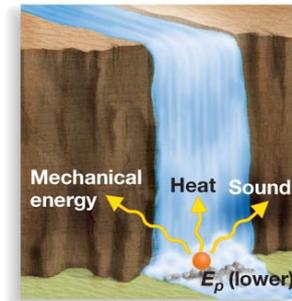
## (a) PROCESS: ENERGY TRANSFORMATION IN A WATERFALL



1. Potential energy



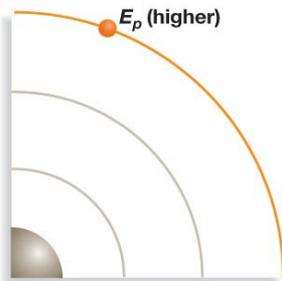
2. Kinetic energy



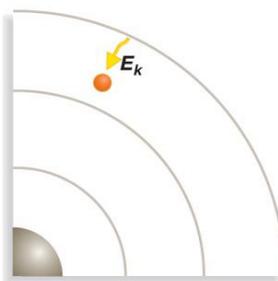
3. Other forms of energy

**Conclusion: Energy is neither created nor destroyed; it simply changes form.**

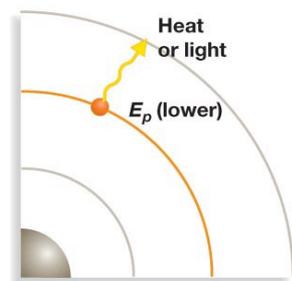
## (b) PROCESS: ENERGY TRANSFORMATION IN AN ATOM



1. Potential energy



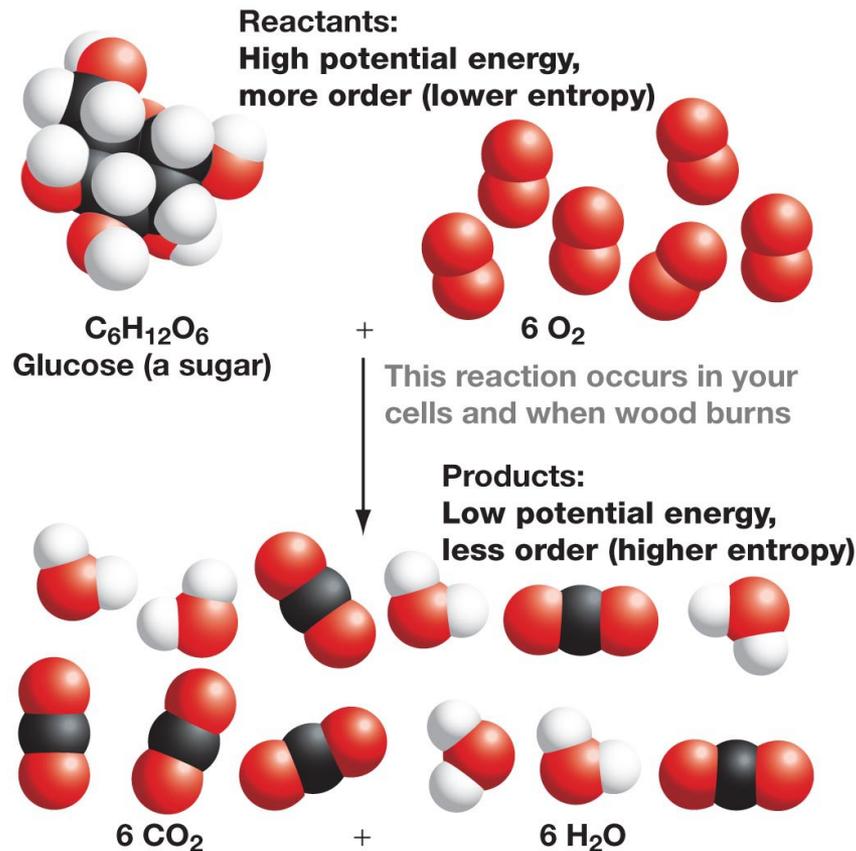
2. Kinetic energy



3. Other forms of energy

**Conclusion: Energy is neither created nor destroyed; it simply changes form.**

# Laws of thermodynamics



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## □ First

- Energy is conserved (not created nor destroyed)

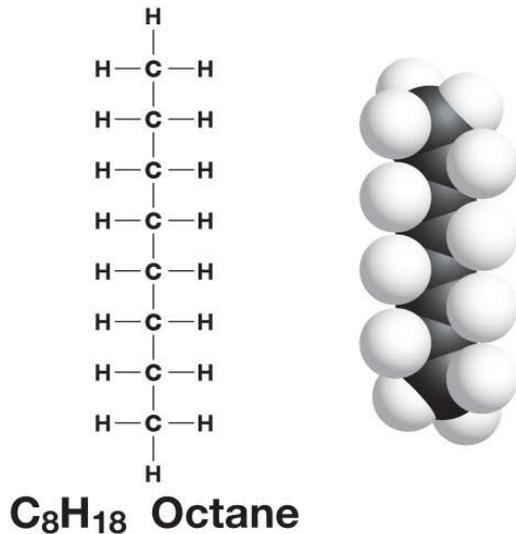
## □ Second

- Chemical reactions result in less usable E

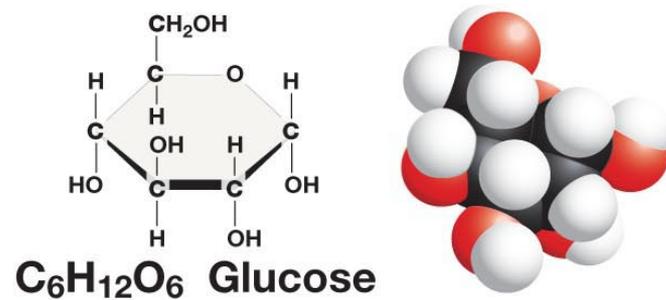
# Carbon

- Most versatile atom
  - 4 valence e<sup>-</sup>
  - Can form any version of covalent bonds

(a) Carbons linked in a linear molecule



(b) Carbons linked in a ring

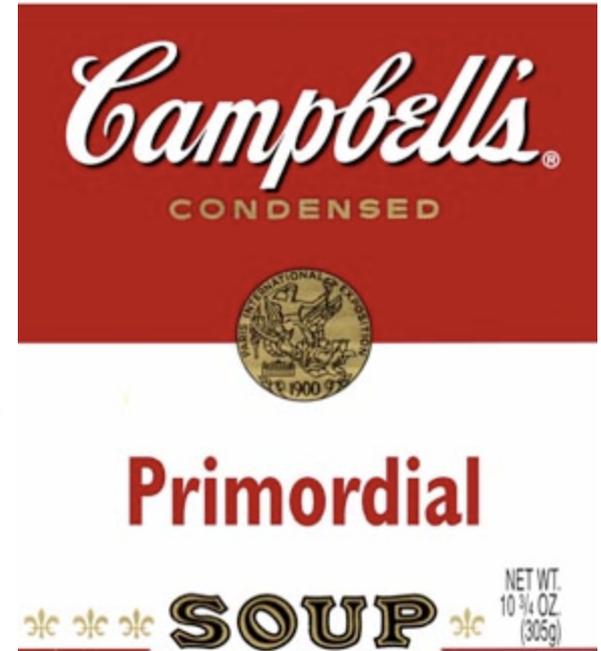


# Beginning of Life?

- Science does not rely on faith
  - ▣ It relies on hypothetico-deductive reasoning
- Take home message:
  - ▣ No one REALLY knows how we came to be
  - ▣ We never will
    - Can't be certain of early Earth environment where life is thought to come into being
- Origin of life is philosophy, not science

# Theory of abiogenesis

- Life spontaneously generated
  - ▣ from a “primordial soup”
- Chemical processes naturally produced amino acids
  - ▣ AA = building blocks of life
- Miller-Urey experiment
  - ▣ Reproduced hypothetical environment of early Earth
  - ▣ Produced amino acids
- Many problems producing more complex molecules spontaneously
  - ▣ i.e. DNA



# Life from asteroids

## □ Pros

- Amino acids found on asteroids
- Bacteria persist on outside of space station
- New missions to Mars take extra steps not to contaminate

## □ Cons

- Hard to imagine

# Hydrothermal origins

- Life came from deep-sea vents
- Pros
  - ▣ Vents are energy-rich source
  - ▣ Amino-acid synthesis is possible
    - Raw ingredients
- Cons
  - ▣ Lack of stability of organic molecules due to heat