General Biology

Course No: BNG2003
Credits: 3.00

2. The Chemical Context of Life

2a. Chemical Foundations of Biology

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Elements and Compounds

- Matter is made up of elements, substances that cannot be broken down to other substances by chemical reactions

- Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of matter, which is anything that takes up space and has mass

- **A compound**
  - is a substance consisting of two or more elements combined in a fixed ratio
  - has characteristics different from those of its elements

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+


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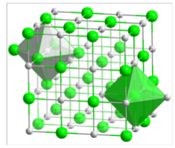
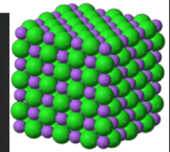



Sodium
+

Chloride
→

Sodium Chloride

food preservative
table salt
Ocean

Essential Elements of Life

- Essential elements
  - Include Carbon, Hydrogen, Oxygen, and Nitrogen
  - make up 96% of living matter

- A few other elements
  - make up the remaining 4% of living matter

Symbol	Element	Atomic Number	Percentage of Human Body Weight
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

- The effects of essential element deficiencies

(a) Nitrogen deficiency

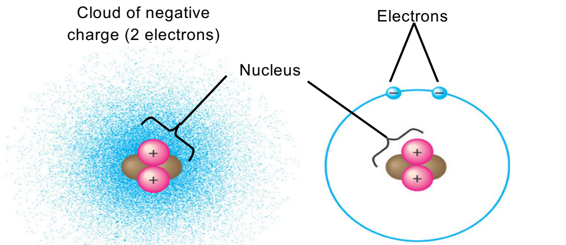
(b) Iodine deficiency (---> hypertrophy)
Disturbed thyroid function; thyroid synthesizes Iodine-containing hormones such as thyroxine (T4) and T3 ((Tetrajodthyronine, T4) und Trijodthyronine (T3)).

- Trace elements
  - are required by an organism in only minute (tiny, exiguous, diminutive) quantities

- An element's properties depend on the structure of its atoms
- Each **element**
  - **consists of a certain kind of atom** that is different from those of other elements
- An atom
  - is the smallest unit of matter that still retains the properties of an element
- Atoms of each element
  - Are composed of even smaller parts called subatomic particles

- Relevant subatomic particles include
  - Neutrons, which have no electrical charge
  - Protons, which are positively charged
  - Electrons, which are negatively charged
- Protons and neutrons
  - Are found in the atomic nucleus
- Electrons
  - Surround the nucleus in a "cloud"

- Simplified models of an atom



(a) This model represents the electrons as a cloud of negative charge, as if we had taken many snapshots of the 2 electrons over time, with each dot representing an electron's position at one point in time.

(b) In this even more simplified model, the electrons are shown as two small blue spheres on a circle around the nucleus.

Atomic Number and Atomic Mass

- Atoms of the various elements
  - Differ in their number of subatomic particles
- The atomic number of an element
  - Is the number of protons
  - Is unique to each element
- The mass number of an element
  - Is the sum of protons plus neutrons in the nucleus of an atom
  - Is an approximation of the atomic mass of an atom
- Atoms of a given element
  - May occur in different forms
- Isotopes of a given element
  - Differ in the number of neutrons in the atomic nucleus
  - Have the same number of protons
- Radioactive isotopes
  - Spontaneously give off particles and energy

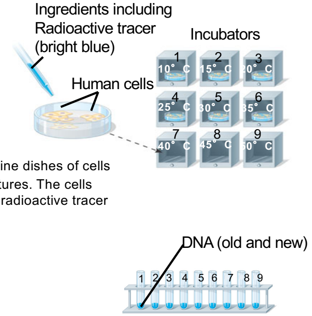
Radioactive isotopes can be used in biology

APPLICATION Scientists use radioactive isotopes to label certain chemical substances, creating tracers that can be used to follow a metabolic process or locate the substance within an organism. In this example, radioactive tracers are being used to determine the effect of temperature on the rate at which cells make copies of their DNA.

TECHNIQUE

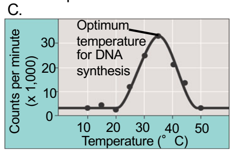
1 Ingredients for making DNA are added to human cells. One ingredient is labeled with 3H, a radioactive isotope of hydrogen. Nine dishes of cells are incubated at different temperatures. The cells make new DNA, incorporating the radioactive tracer with 3H.

2 The cells are placed in test tubes, their DNA is isolated, and unused ingredients are removed.



3 A solution called scintillation fluid is added to the test tubes and they are placed in a scintillation counter. As the 3H in the newly made DNA decays, it emits radiation that excites chemicals in the scintillation fluid, causing them to give off light. Flashes of light are recorded by the scintillation counter.

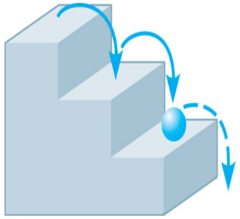
RESULTS The frequency of flashes, which is recorded as counts per minute, is proportional to the amount of the radioactive tracer present, indicating the amount of new DNA. In this experiment, when the counts per minute are plotted against temperature, it is clear that temperature affects the rate of DNA synthesis—the most DNA was made at 35° C.



The Energy Levels of Electrons

- An atom's electrons vary in the amount of energy they possess
- Energy is defined as the capacity to cause change
- Potential energy is the energy that matter possesses because of its location or structure

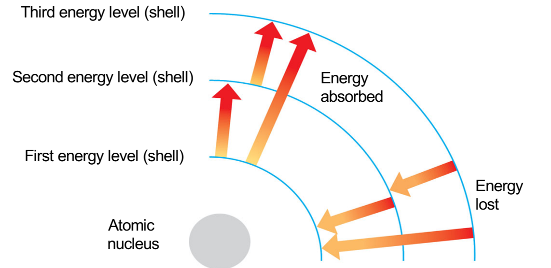
- The electrons of an atom
  - differ in the amounts of potential energy they possess



(a)

A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons, because the ball can only rest on each step, not between steps.

- Energy levels
  - are represented by electron shells

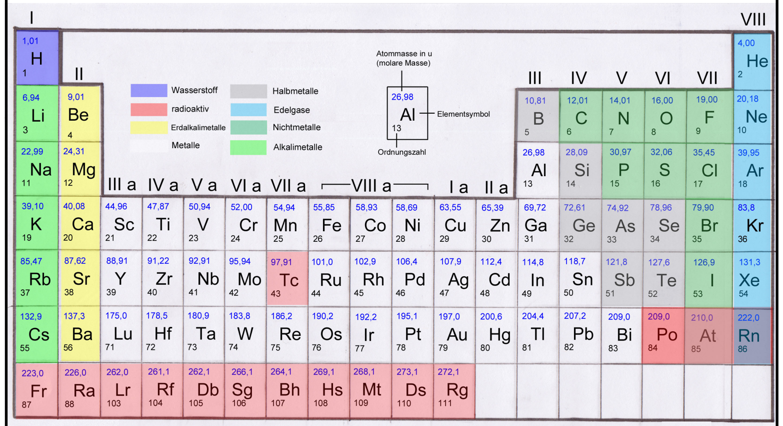


(b) An electron can move from one level to another only if the energy it gains or loses is exactly equal to the difference in energy between the two levels. Arrows indicate some of the step-wise changes in potential energy that are possible.

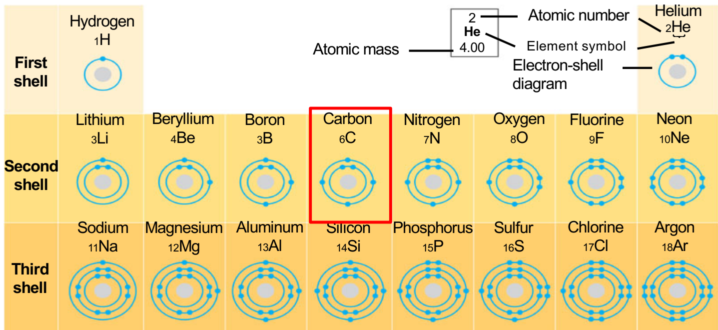
Electron Configuration and Chemical Properties

- The chemical behavior of an atom
  - is defined by its electron configuration and distribution
- Valence electrons
  - are those in the outermost, or valence shell
  - determine the chemical behavior of an atom
- An orbital
  - is the three-dimensional space where an electron is found 90% of the time

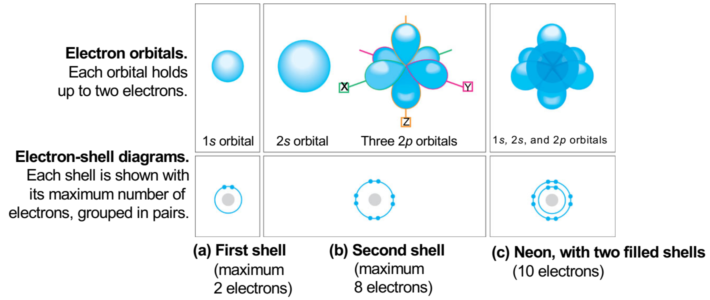
The periodic table of the elements



- The periodic table of the elements
  - shows the electron distribution for all the elements

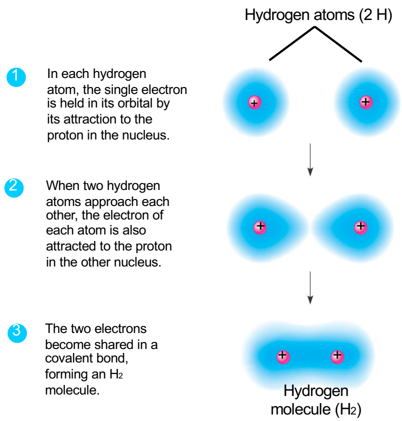


- Each electron shell consists of a specific number of orbitals



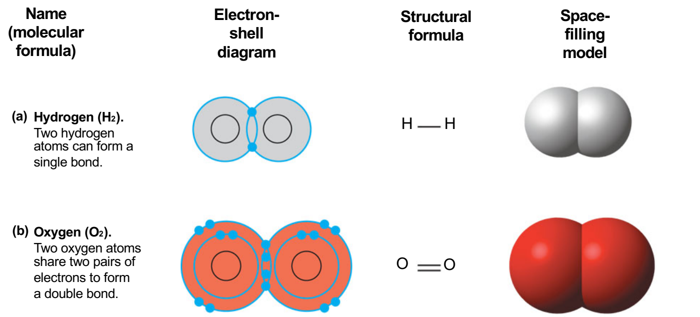
- The formation and function of **molecules** depend on **chemical bonding** between **atoms**
- A covalent bond is the sharing of a pair of valence electrons

- Formation of a covalent bond

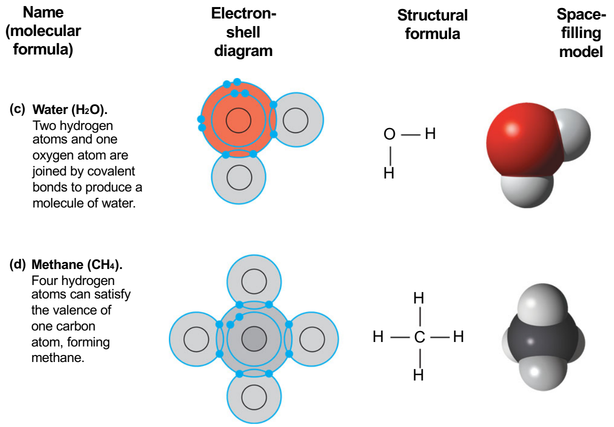


- A **molecule consists** of two or more atoms held together by **covalent bonds**
- A single bond is the sharing of one pair of valence electrons
- A double bond is the sharing of two pairs of valence electrons

- Single and double covalent bonds

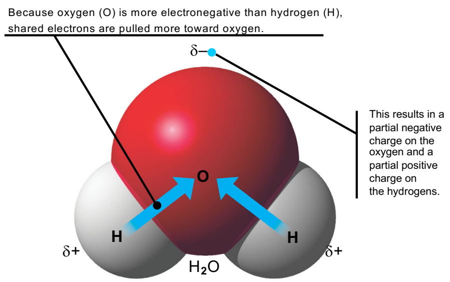


- Covalent bonding in compounds



- Electronegativity
  - Is the attraction of a particular kind of atom for the electrons in a covalent bond
- The more electronegative an atom
  - The more strongly it pulls shared electrons toward itself
- In a nonpolar covalent bond
  - The atoms have similar electronegativities
  - Share the electron equally

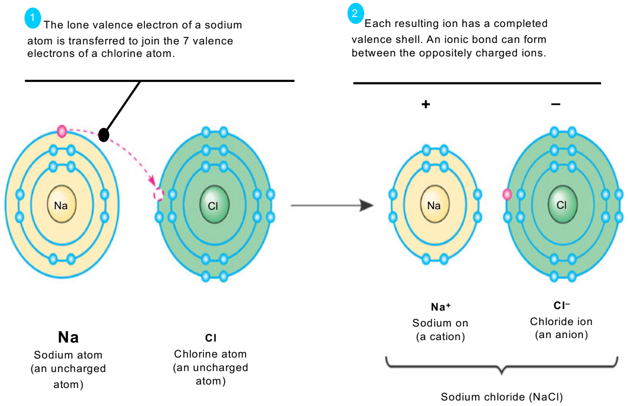
- In a polar covalent bond
  - The atoms have differing electronegativities
  - Share the electrons unequally



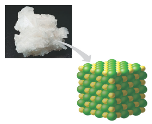
Ionic Bonds

- In some cases, atoms strip electrons away from their bonding partners
- Electron transfer between two atoms creates ions
- Ions
  - are atoms with more or fewer electrons than usual
  - are charged atoms
- An anion
  - is negatively charged ions
- A cation
  - is positively charged

- **An ionic** bond is an attraction between anions and cations



- Ionic compounds are often called salts, which may form crystals

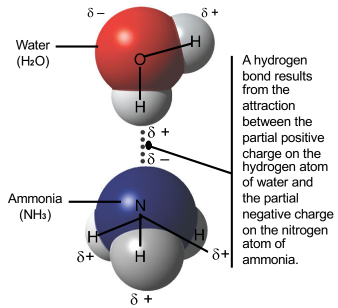


Weak Chemical Bonds

- several types of weak chemical bonds are important in living systems

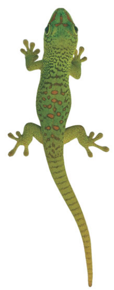
Hydrogen Bonds

- A hydrogen bond forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom



Van der Waals Interactions

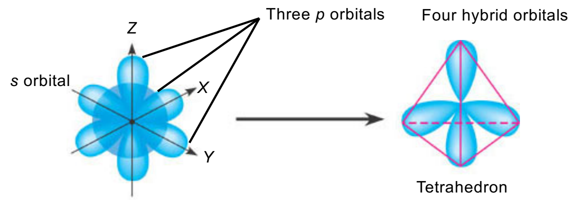
- **Van der Waals interactions**
  - occur when transiently positive and negative regions of molecules attract each other
- Weak chemical bonds
  - reinforce the shapes of large molecules
  - help molecules adhere to each other



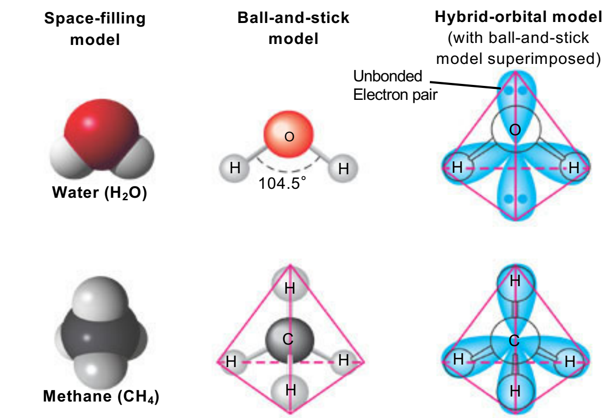
- Molecular Shape and Function:

  The precise shape of a molecule
  - is usually very important to its function in the living cell
  - is determined by the positions of its atoms’ valence orbitals

- In a covalent bond
  - The *s* and *p* orbitals may hybridize, creating specific molecular shapes

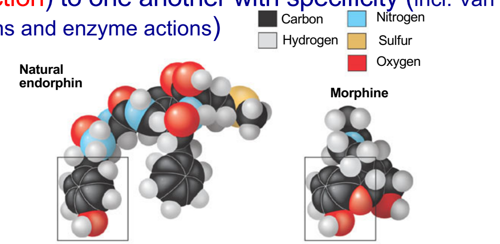


(a) Hybridization of orbitals. The single *s* and three *p* orbitals of a valence shell involved in covalent bonding combine to form four teardrop-shaped hybrid orbitals. These orbitals extend to the four corners of an imaginary tetrahedron (outlined in pink).

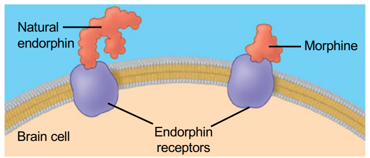


(b) Molecular shape models. Three models representing molecular shape are shown for two examples; water and methane. The positions of the hybrid orbital determine the shapes of the molecules

- Molecular shape (i.e. protein structure): Determines how biological molecules (made by covalent bonds) recognize and respond (i.e. function) to one another with specificity (incl. Van der Waals interactions and enzyme actions)



(a) Structures of endorphin and morphine. The boxed portion of the endorphin molecule (left) binds to receptor molecules on target cells in the brain. The boxed portion of the morphine molecule is a close match.



(b) Binding to endorphin receptors. Endorphin receptors on the surface of a brain cell recognize and can bind to both endorphin and morphine.

Chemical reactions make and break chemical bonds (ATP ---> ADP + Pi)

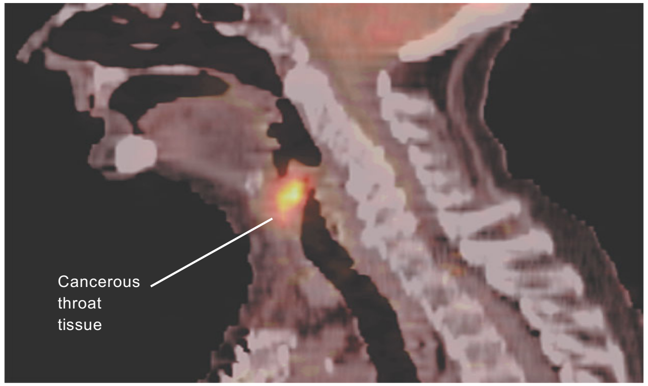
- A chemical reaction
  - is the making and breaking of chemical bonds
  - leads to changes in the composition of matter
  - ---> leads to change of structure
  - ---> leads to change of functions

Why do we need to know all this?

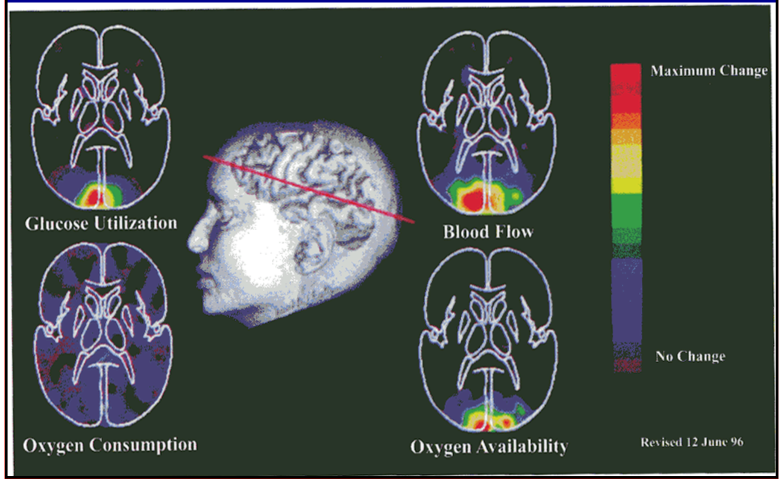
Practicable applications:

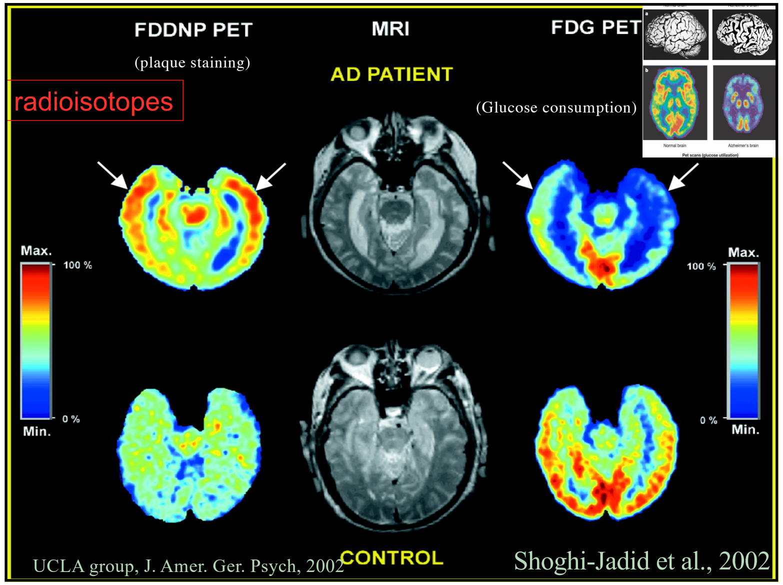
– can be used in biology

In vivo visualizing of human tissue – e.g. cancer detection



***In vivo* brain function (activity) analysis using imaging technologies such as Positron Emission Tomography (PET)**



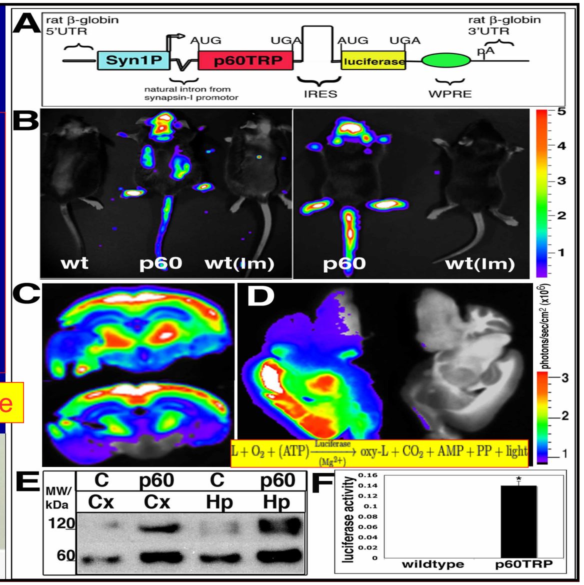


Bio-Genetic-Engineering

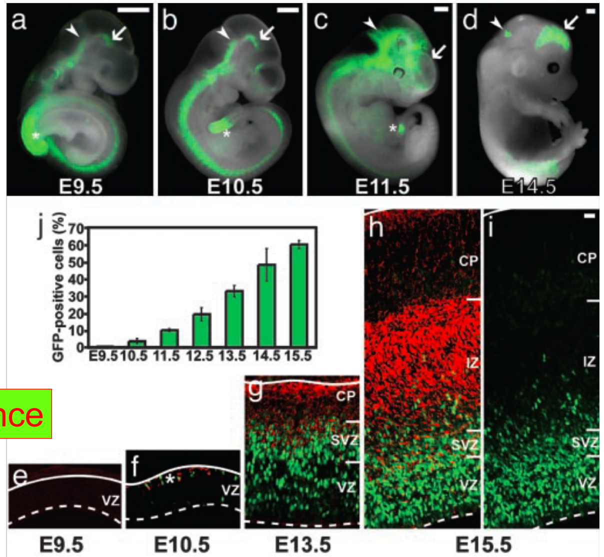
Establishing a p60TRP transgenic mouse model

***in-vivo*-Imaging in a living mouse**

bioluminescence



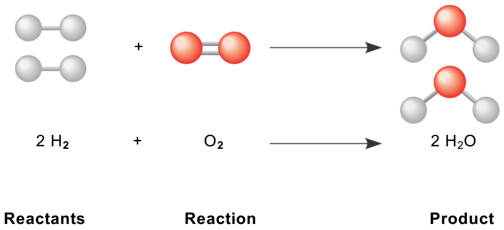
A Tis21-GFP Knock-In Mouse Reveals Neuron-Generating Progenitors in the Embryonic CNS.



fluorescence

- **Chemical reactions** convert reactants to products

An example:



Oxyhydrogen gas, electrolytic gas, detonating gas

See also: http://en.wikipedia.org/wiki/Oxyhydrogen

- Photosynthesis is a typical example of a similar chemical reactions used to synthesize ATP in mitochondria: $O_2 + 4\,e^- + 4\,H^+ \longrightarrow 2\,H_2O$

$\Delta G^{o'} = -193$ kJ/mol

----> Bio-Engineering: Bio-Fuel cells

Gibbs-Energie ΔG used for electrical power/electric current

Understanding photosynthesis provides ideas for the improvement of bio-fuel cells

- Chemical equilibrium is reached when the forward and reverse reaction rates are equal
- (---> Biochemistry: thermodynamic; in year-3)

$$A + B \underset{k2}{\overset{k1}{\longleftrightarrow}} C + D$$

Atom distribution across the phylogenetic tree of life