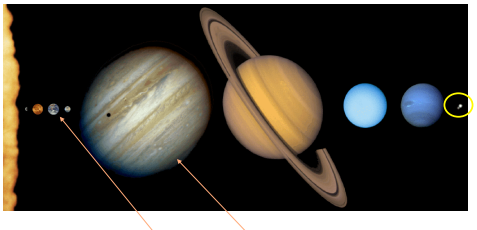
Chapter 1: Introduction

1.1 Planet Earth
1.2 The environment
1.3 Basic chemistry

Our Planetary system



Pluto
no longer planet

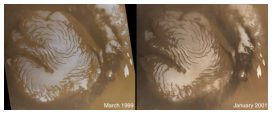
Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune

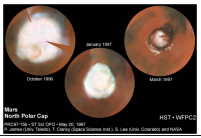
small terrestrial planets

huge ice or gaseous planets (outer planets)

Sun has over 99.8 % of the mass of the solar system

- Earth is unique in that it has liquid water covering bulk of its surface
  - Life developed
- Water elsewhere in solar system?
- Much interest in Mars
  - Polar caps have solid CO_2 and H_2O
  - Some seasonal variation
  - But **liquid** water??

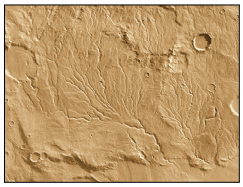




Water on Mars?

- Dendritic drainage patterns
  - suggest water once flowed on Mars?

Fossilized drainage pattern (Rubh-al-Khali desert, Yemen), Earth



Mars

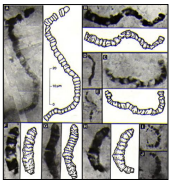
Planet Earth

- Mass: 5.98 x 10^{24} kg
  - (5.98 million billion billion kg)
- Circumference: 40 041 km

- Diameter: 12 742 km
- Age: 4.6 billion years old
- Oldest rock: ~4.55 billion years old (northern Quebec)

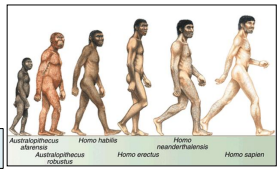
Life on Earth

- Fossilized life forms reported in 3.4 – 3.5 billion year old rocks
  - Filament structures resembling micro-fossilized "life"



Schopf (1993), *Science*

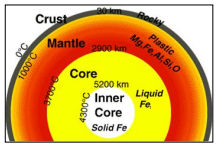
- Humans appeared 3.5 – 4.4 million years ago
- Modern humans ~200, 000 years

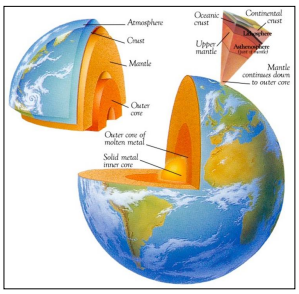


If Earth was 24 hours old, humans would have appeared at 23h59

Earth's structure

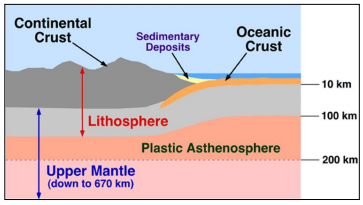
- Core
  - Rich in Fe and Ni
- Mantle has a variable composition
  - Fe, Mg, Al, Si and O
  - 2800 km thick





Earth's structure

- Asthenosphere
  - Uppermost part of mantle
  - Temp. and pressure make the rock ductile
- Lithosphere
  - Crust and uppermost mantle
  - Rigid, outermost shell of the Earth

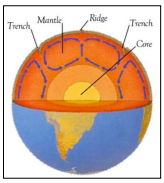


- Crust
  - Rocky outer "skin", composed of O (45%), Si (27%), Al (8%), Fe (7%), Ca, Mg, Na, etc.
  - **Continental crust** (~45 km thick), primarily composed of granite
  - **Oceanic crust** thinner (~8 km), primarily composed of basalt
  - Oceanic crust denser than continental crust

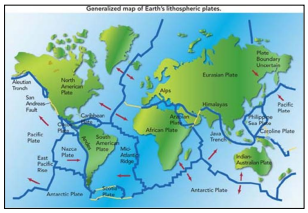
Dynamic Earth

- Earth's surface is constantly changed and reworked via a range of processes operating over vastly different scales of space and time:
  - Plate tectonics: volcanoes, earthquakes, etc
  - Rock cycle: igneous, metamorphic, sedimentary
  - Glaciations: climatic changes
  - Element cycling: e.g. carbon, nitrogen, sulfur, etc.
  - Erosion and weathering

Plate tectonics



- Earth's internal heat drives convection currents in mantle
  - Causes movement of overlying crust tectonic plates
- Earth's surface consists of about 15 main tectonic plates
  - Move at 2 – 15 cm per year
  - Different types of plate boundaries cause:
    - Formation of new crust
    - Earthquakes
    - Volcanism and mountain building



Simplified rock cycle

Three primary types of rock make up rock cycle:

1. Igneous
   - Formed from cooling of molten rock
2. Sedimentary
   - Formed by precipitation and/or cementation of particles, compressed to form new rock
3. Metamorphic
   - Heat and pressure transform igneous or sedimentary rocks

Carbon cycling

Photosynthesis

CO_2 (+4) inorganic → CH_2O (0) organic

← Oxidation

Sulfur cycling

oxidation

S^{2-} S^{o} $(SO_4)^{2-}$

Sulfide (-2) Sulfur (0) Sulfate (+6)

reduction

Iron cycling

oxidation

Fe^{2+} Fe^{3+}

Ferrous iron (+2)
Reducing conditions

Ferric iron (+3)
Oxidizing conditions

reduction

Forms of energy

- Solar energy is essential for the various ecosystems, especially for **photosynthesis**
- Solar energy heats up the atmosphere and the oceans (evaporation)
- The energy received by the Earth is returned as electromagnetic radiations. There is a balance
- Primary production

Definitions of the Environment

- Government of Canada (1988):

  "The components of the Earth, including air, land, and water, all layers of the atmosphere, all organic and inorganic matter and living organisms, and the interacting systems that include all of these components"

- Environment Canada (1993):

  "Everything that surrounds and affects or influences an organism or a group of organisms; it includes both living and nonliving components as well as both natural and human-built elements"

1.2 Environment

- **Lithosphere**: solid reservoir (rocks, soil, sediments, etc.)
- **Hydrosphere:** liquid reservoir (oceans, lakes, rivers, glaciers, etc.)
- **Atmosphere**: gas reservoir (air and other gases)
- **Biosphere**: living reservoir (microorganisms, plants, animals, humans, etc.)
- **Ecosphere**: includes lithosphere, atmosphere, biosphere, hydrosphere

Pollutants

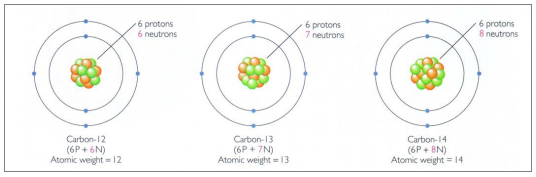
- **Point sources:** discrete, localized, and often readily measurable discharges of chemicals: oil spills, snow dumps, etc.
- **Nonpoint sources:** more difficult to measure because they often cover large areas or are a composite of numerous point sources: gas emissions from cars, fertilizer runoffs, etc.
- **Sinks:** processes that remove a substance from a certain reservoir: precipitation

Environmental issues

- Do we replant as many trees as we cut?
- Which wildlife species and habitats are threatened?
- Is the climate changing?
- What is the status of the stratospheric ozone layer?
- Are we protecting enough natural areas?
- Are air pollution and water pollution getting worse?
- How sustainable are Canada's renewable resources?
- Do we recycle enough? (383 kg garbage/person in Canada and only 20% recycled)

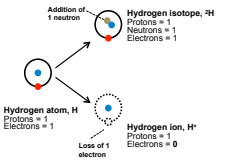
1.3 Basic chemistry

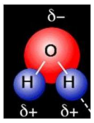
- Atoms
  - electrons, neutrons and protons
- Isotopes
  - Atoms of an element possessing a variable number of neutrons
    - E.g. (^{2}H: deuterium; ^{3}H: tritium)

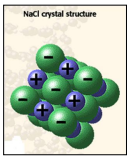


Basic chemistry

- Ions
  - atoms which can gain or lose electrons
    - E.g. Cl^-, Cu^{2+}, etc
- Molecules
  - group of atoms which share or transfer electrons
    - E.g. O_2, H_2O, NaCl
- Ionic species
  - charged molecules
    - E.g. HCO_3^-, SO_4^{2-}, etc.







Basic chemistry - pH

- pH is measure of the hydrogen ion (H^+) concentration
  - Affects solubility of many elements (ex. Al, Fe, etc)

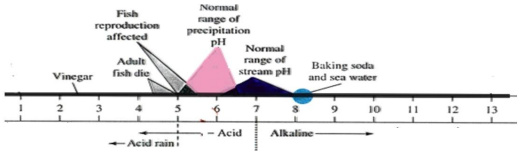
pH = -log [H^+]

acidic conditions: pH < 7
neutral pH : pH = 7
alkaline conditions: pH > 7

pOH = -log [OH^-]

pH + pOH = 14

pH of natural waters



- Major sources of acidity in waters include:
  - Carbonic acid (H_2CO_3)
    - dissolution of CO_2 and carbonate minerals
  - Organic acids
    - breakdown of vegetation
      - Soil porewaters in tropical climates (intense biological productivity) may be pH < 4
  - Sulfuric acid
    - oxidation of sulfide minerals, FeS_2 in particular in mining areas leading to acid mine drainage (AMD)

Acidic waters - Crater lakes

Pinatubo (Phillipines) one year after 1991 eruption

native sulphur

pH 0.3

Kelimutu, Indonesia
Tiwu Nuwa Muri Koo Fai crater lake
(Lake of Young Men and Maidens)

Poás (Costa Rica) – most acidic crater lake in the world (pH~0)

Continuous degassing of HCl, H_2S, SO_2 from underlying magmas keep these waters acidic

Redox chemistry

- Oxidation/reduction: effect on solubility, transport
- Important in element cycling (C, N, Fe, Mn, U, Cr, As, Se, etc)

oxidation: loss of electrons

$Fe^{2+} = Fe^{3+} + e^-$

reduction: gain of electrons

$Fe^{3+} + e^- = Fe^{2+}$

Rules for Assigning Oxidation State

1. Oxidation state of all elements in their free form is always zero
   - E.g. N_2 (g), oxidation state of N = 0
   - Fe metal, oxidation state of Fe = 0
2. Oxidation state of **H** is usually **+1,** and **O** is **-2**
   - (unless in free form of H_2 or O_2, where they are zero [rule 1])
3. Oxidation state of a mono-atomic ion equals its charge
   - E.g. Na^+ is +1
4. The sum of the oxidation states of the atoms in a molecule is equal to the charge of that molecule

Assigning Oxidation State - Examples

Cl_2 (g)

Cl is in its pure form, so ox. st. = 0

NH_4^+ (aq)

H = +1

Total species charge = +1 = (N) + (4 x +1), so **N = -3**

HCO_3^- (aq)

H = +1, O = -2

Total species charge = -1 = (+1) + (C) + (3 x -2), so **C = +4**

Redox reactions

- Always coupled
  - **Red**uction of one constituent accompanied by **ox**idation of another

Reduced$_a$ + Oxidized$_b$ → Oxidized$_a$ + Reduced$_b$

e.g. Oxidation of Fe(II) by oxygen:

$4Fe^{2+}$ (aq) + O_2 (g) + $4H^+$ (aq) = $4Fe^{3+}$ (aq) + $2H_2O$ (aq)

Fe(+2) **O(0)** **Fe(+3)** **O(-2)**

Terminology and units

anoxic conditions: absence of O_2
oxic conditions: presence of O_2
aerobic vs anaerobic:
    use of O_2 by microorganisms
redox potential:
    pe = -log {e}
    positive: low {e}, oxidizing
    negative: high {e}. reducing

Concentrations and units

Concentration:
g/L, g/g. vol/vol, mole/L, ppm, ppb, etc.

Ex: [Cu] in river is 30 ppb, what is the molar concentration?

Ex: [Fe] in lake water is 60μmole/L, what is the concentration in g/L?

Prefixes: m = milli (10^{-3}), μ= micro (10^{-6}) and n = nano (10^{-9})