**APES Ch. 3 Notes: Ecosystems and How They Work**

**3.1 Notes**

I. Matter, Energy and Life

A. matter in living and nonliving systems

1) chemistry terms for review

a) **matter**—anything that *takes up space and has mass* (see "B")

b) **Law of Conservation of Matter (Mass)**—*matter can neither be created nor destroyed; it merely changes form*

- exception: nuclear reactions

c) **Law of Conservation of Energy** (First Law of Thermodynamics)—*energy forms are interconvertible;* matter can neither be created nor destroyed; it merely changes form

- exception: nuclear reactions

d) **energy**—the ability to affect matter; the ability to do work (see "B")

e) **atom**—*smallest "building block of matter" which retains the properties of that matter*

- if an atom is split (fission), it no longer retains its original properties

f) subatomic particles (main ones): $p+$, $n^o$, $e^-$

g) **molecule**—two more atoms chemically combined/bonded

- can have *nonpolar covalent bonds*—equal sharing of $e^-$ (example: $N_2$)
- can have *polar covalent bonds*—charge imbalance; unequal sharing of $e^-$ (example: $H_2O$)

h) **formula unit**—two or more ions chemically combined/bonded

- has *ionic bonds*—electron "taken" from cations by anions

i) **element**—a specific type of atom

- *major elements in living things: C, H, N, O, P, S*

j) **compound**—two or more different elements bonded together

k) **organic**—*carbon-based; of living things*

- *natural organic*—naturally occurring carbon-based substances
- *synthetic organic*—human-made carbon-based substances

l) **inorganic**—*having no C-C or C-H bonds*

m) **solution**—*a homogeneous mixture*

2) earth layers: crust, mantle, outer core, inner core

a) **lithosphere**—Earth's *crust and upper mantle*

b) **hydrosphere**—all *water* on Earth, in all forms and locations

- oceans, ponds, rivers, humidity, polar caps, springs, aquifers, groundwater, glaciers…

c) **atmosphere**—layer of gases surrounding Earth

*troposphere, stratosphere, mesosphere, thermosphere, ionosphere*

3) more earth science terms to review

a) biosphere contains the living systems on Earth

b) **rock**—*a combination of minerals*

- *igneous—from lava/magma*
  types: intrusive and extrusive
- *sedimentary—sediment compaction and cementation*
  types: clastic (chunky), chemical, organic

- *metamorphic—from temperature and pressure extremes*

c) **mineral**—*hard, naturally-occurring, inorganic substances with a definite crystalline structure*

B. energy considerations
1) matter and energy = components of the Universe
2) **matter**—anything that can be weighed when gravity is present
3) **energy**—the ability to affect matter
a) types of energy
- *kinetic*—energy in motion
- *potential*—energy of position
- *chemical*—energy stored in bonds
- *radiant, thermal, nuclear…*

b) energy units
- *calorie—amount of heat energy needed to raise the temp of 1 g of $H_2O$ by 1°C.*
- *Calorie = diet calorie = 1kcal = 1000 cal*

c) energy laws: Laws of Thermodynamics
- *First Law = Law of Conservation of Energy*
- *Second Law (Entropy)*
  *~ in any conversion, some unusable energy is lost*
  *~ entropy or disorder increases*
  *~ systems will move spontaneously toward increased entropy*
  - *Third Law (absolute zero)—as temperature drops to 0, entropy becomes constant*

C. energy changes in organisms and ecosystems
1) organic matter has high potential energy; breakdown releases energy
2) inorganic matter has low potential energy
3) producers

**PHOTOSYNTHESIS (requires E; low E to high E)**
**$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$**

a) **primary producer** = *green plants* = synthesize new organic materials (glucose)
b) *primary production—sustained photosynthesis*
c) gross primary production—total amount of photosynthetic activity
d) net primary production—rate of production
(total amount of photosynthetic activity - energy consumed by plants)

4) consumers
a) **cell respiration**—*process of breaking down organic molecules (molecules) to release energy*
- energy is released in small steps

**CELL RESPIRATION (emits E; high E to low E)**
**$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$**

b) **oxidation**—*release of energy*
c) *"burning"= release of energy all at once*
- body heat is released (proof of efficiency less than 100%)

5) the fate of food – organic material eaten by consumers:
    i. *oxidized for energy (over 60%)*
    ii. *used for growth, maintenance, repair, fat storage*
    iii. *passed as waste products*
        - cellulose = plant fiber; roughage
        - $CO_2$, $H_2O$, other compounds
6) *detritus feeders and decomposers—the detritivores*
    a) adaptations – digestion of cellulose
    b) breakdown of food into $CO_2$, $H_2O$, and other compounds
    c) release of heat energy
    d) *fermentation—cell respiration by partial breakdown of glucose into alcohol, acetic acid*
        - $C_6H_{12}O_6 \rightarrow CH_3CH_2OH + CO_2$ *(unbal.)*
        - *Products can also include* $CH_4$, $CH_3COOH$
    e) *anaerobic environments do not contain oxygen*

**3.2 Notes**

II. Principles of Ecosystem Function: energy flow and biogeochemical cycles

A. Energy flow in ecosystems

1) **primary production**
    a) *only ~2% of sunlight is harnessed for photosynthesis*
    b) *standing crop biomass—primary producer biomass total*
        - *tropical rain forest = high gross & net productivity*
        - *open ocean = high gross productivity, but low net productivity*
2) energy flow and efficiency
    a) *review of three options for energy use:*
        - *growth (or maintenance, repair, storage)*
        - *respiration (oxidized for energy)*
        - *waste*
    b) *Review of why trophic level biomass and energy drastically decrease up the pyramid (10% rule):*
        - *most standing biomass is not eaten by consumers (goes directly to the detritivores)*
        - *most (> 60%) is consumed for energy*
        - *some is undigested and passed as waste*
    c) energy flows in one direction— up through the biomass pyramid
    d) sunlight must supply the initial energy in almost all ecosystems, those with photosynthetic and not chemosynthetic producers
3) running on solar energy
    a) nonpolluting
    b) nondepletable (the sun is a star in "middle age" right now)

FIRST BASIC PRINCIPLE OF ECOSYSTEM SUSTAINABILITY:
(almost all) ecosystems use sunlight as their energy source.
SECOND BASIC PRINCIPLE OF ECOSYSTEM SUSTAINABILITY:
ecosystems dispose of wastes and replenish nutrients by recycling all elements

4) major biogeochemical cycles prevent waste buildup and recycle elements

B. biogeochemical cycles in detail

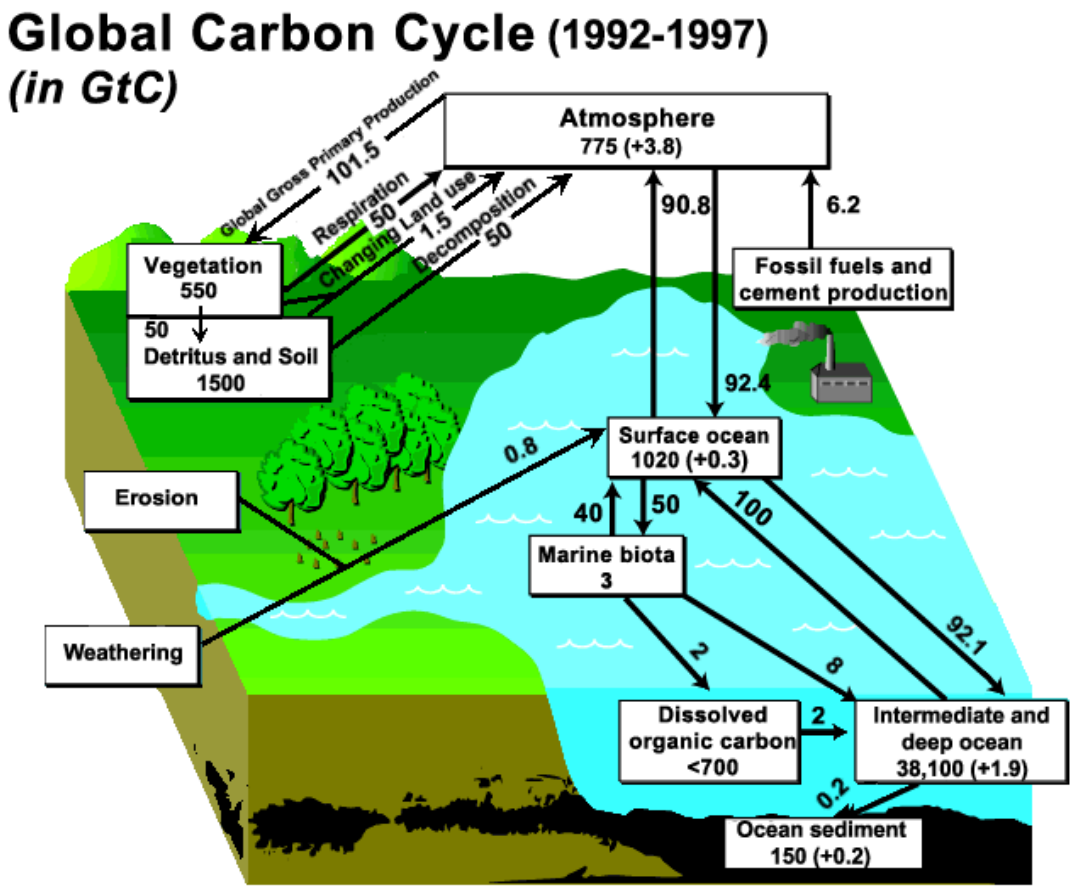
1) **carbon cycle** *(↑ = given off ↓ = taken in)*

a) *$CO_2$ released by combustion of organics & fossil fuels* ↑
b) *$CO_2$ released by respiration* ↑
c) *$CO_2$ released by decomposition* ↑
d) *volcano eruptions* ↑
e) *photosynthesis* ↓
f) *$CO_2$ in ocean water* ↓
g) *$(HCO_3)^-$ in ocean water* ↓
h) *$CO_2$ ↓, carbon stored in rocks ($CaCO_3$)*
i) *$CO_2$ ↓, carbon in $C_6H_{12}O_6$ from photosynthesis*
j) CARBON "SINKS"
- largest reservoir of carbon = sedimentary rocks
- second largest reservoir of carbon = ocean (dissolved $CO_2$ and aquatic organisms)

k) processes in water – reactions

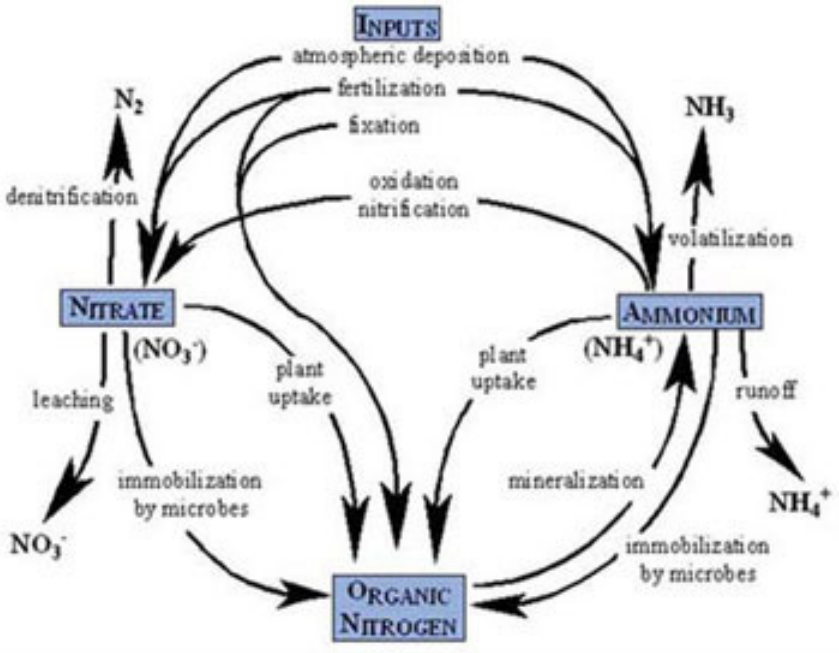
$CO_2 + H_2O \rightarrow HCO_3^-$ (bicarbonate ions) + $CO_3^{2-}$ (carbonate ions)
$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$ in shells/skeletons of aquatic organisms
$CaCO_3 \rightarrow$ buried, long period of time, pressure → limestone

CARBON CYCLE - from Carbon Dioxide Information Analysis Center, cdiac.ornl.gov



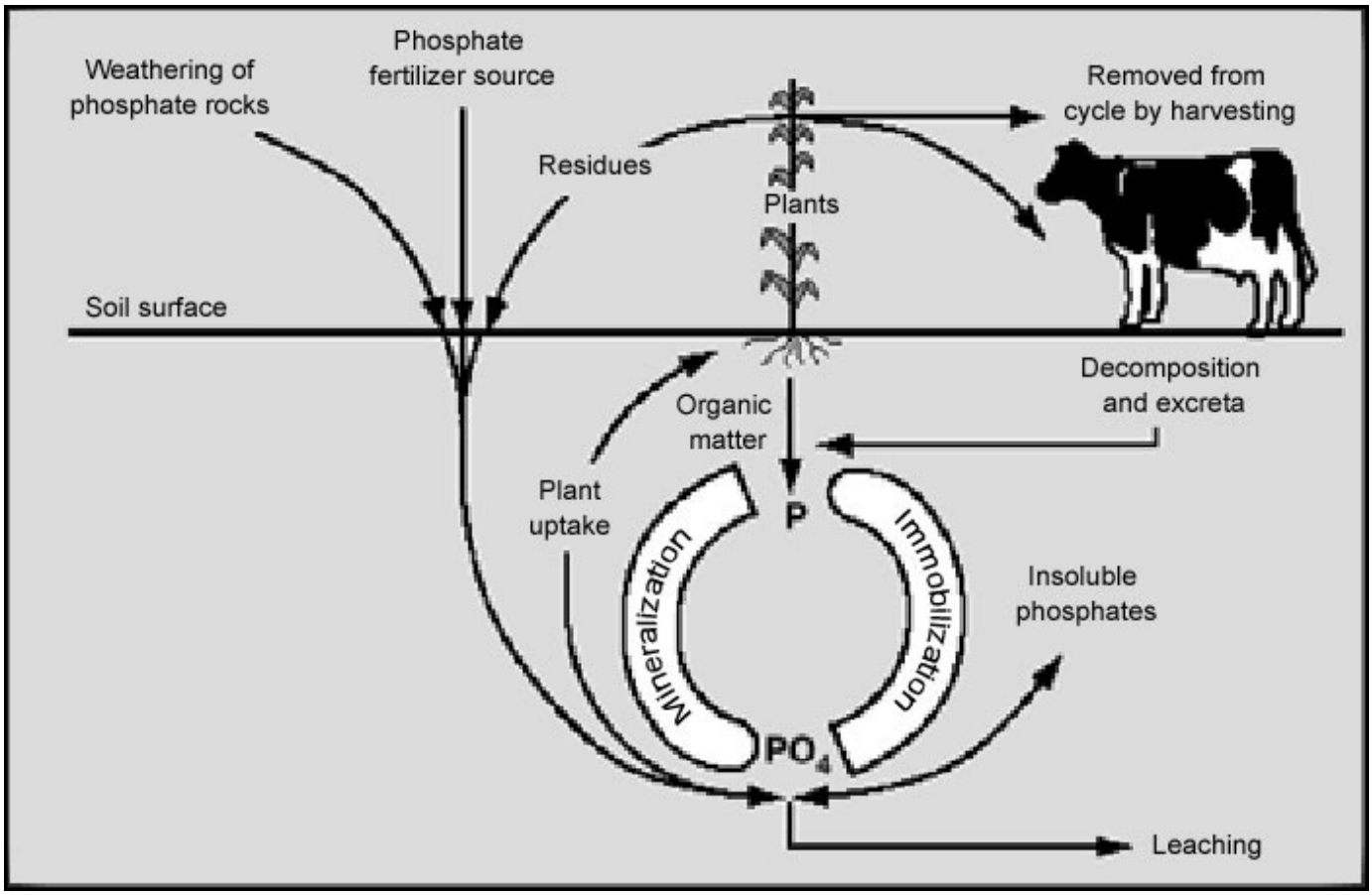
2) **nitrogen cycle** *(↑ = given off ↓ = taken in)*
   a) **nitrogen fixation—** *changing gaseous nitrogen ($N_2$) into a usable form for plants*
      i) *nitrogen-fixing bacteria & cyanobacteria* ↓
      ii) *nitrogen fixation-- lightning* ↓
      iii) *nitrogen fixation-- industrial* ↓ *(fertilizer)*
      iv) **legumes**—*plants with root nodules containing nitrogen-fixing bacteria*
      v) *reactions* ↓
         - $N_2 + 3H_2 \rightarrow 2NH_3$ first…
         - …then $NH_3 + H_2O \rightarrow NH_4OH$ $(NH_4^+ + OH^-)$
      vi) **ammonification**—*conversion of (often organic) $N_2$ into $NH_3$ by ammonifying bacteria*
   b) **denitrification**—*changing nitrates and nitrites in the soil to gaseous nitrogen*
      i) *denitrifying bacteria* ↑ *$NO_3^-$ and/or $NO_2^-$* → *$N_2$*
      ii) *anaerobic bacteria convert ammonia back into $N_2$ or $N_2O$* ↑
   c) other processes
      i) *death; decomposers put into soil* ↓ *(production of $NH_3$, $NO_3^-$, & $NO_2^-$)*
      ii) *fertilizer runoff into soil* ↓
      iii) *waste products, into soil* ↓
      iv) **assimilation**
         - inorganic $N_2$ is converted into organic molecules such as DNA, amino acids, and proteins ↓
         - plants assimilate nitrogen through their roots ↓
         - herbivores assimilate organic nitrogen by eat plants ↓
      v) **nitrification**—ammonia ($NH_3$) is converted to nitrate ions $(NO_3)^-$ (↓, nitrogen compound oxidation)

NITROGEN CYCLE from www.learner.org



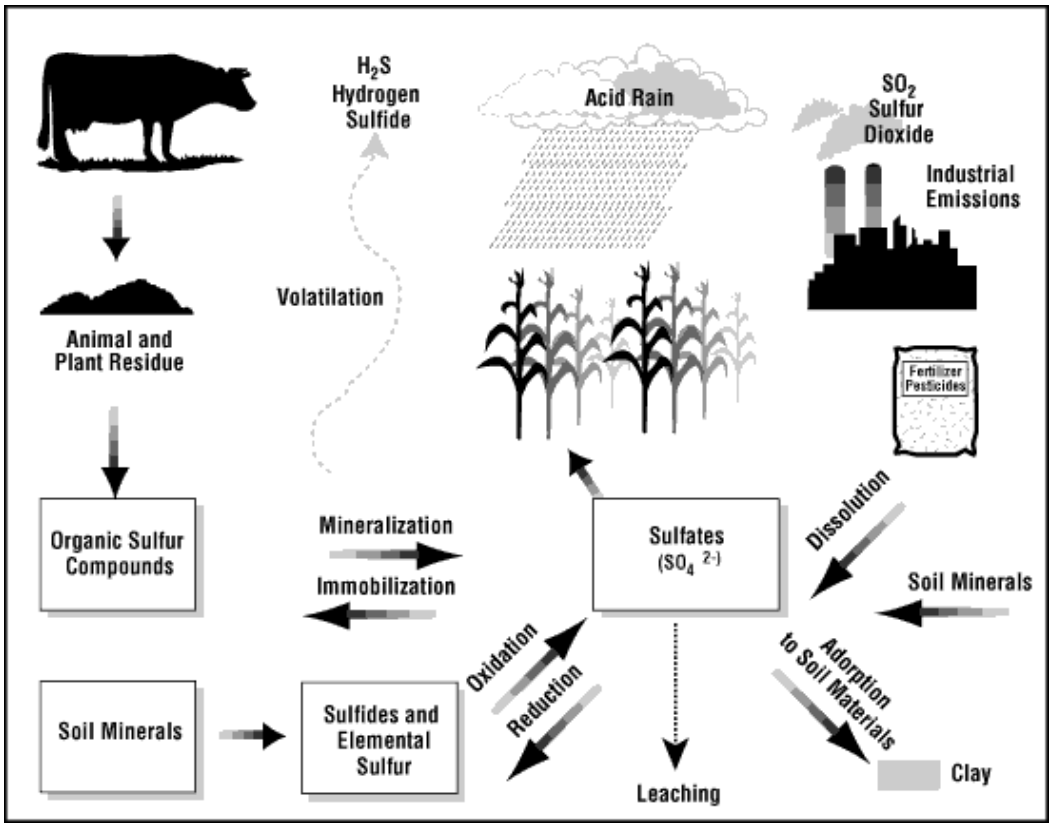
3) **phosphorus cycle**
   a) *no gaseous phase involved – a sedimentary cycle only* (all ↓)
   b) *water-soluble phosphate ion; insoluble phosphate precipitates;* **organic phosphate** ↓
   c) *waste products containing phosphate, $(PO_4)^{3-}$ ↓ to soil*
   d) *fertilizer on crops, $(PO_4)^{3-}$ ↓ to soil*
   e) *$(PO_4)^{3-}$ dissolved from weathering, ↓ into water*
   f) *$(PO_4)^{3-}$ absorbed by plants & changed into organic phosphate* ↓
   g) *$(PO_4)^{3-}$ in animal waste, ↓ to soil*
   h) *discharge of sewage, ↓ into water*

PHOSPHORUS CYCLE from www.learner.org



4) **sulfur cycle**
   a) an atmospheric cycle only
   b) $H_2S$ (hydrogen sulfide) and $SO_2$ (sulfur dioxide) released into atmosphere from natural (volcanoes) and non-natural sources ↑
   c) reactions
      - $H_2S + O_2 \rightarrow SO_2$
      - $SO_2 + O_2 \rightarrow SO_3$ (sulfur trioxide)
      - $SO_2 + H_2O \rightarrow H_2SO_4$ (sulfuric acid)
   d) acid deposition, sulfur returned to water and soil ↑
   e) sulfur compounds taken up by plants and animals
   f) combustion of S-containing coal ↑

SULFUR CYCLE – from NYU




**3.3 Notes**

III. Implications for Humans

A. *sustainability*

1) significance of energy flow
   - In general, it takes 10 pounds of grain to produce 1 pound of meat (more for beef, less for chicken)

2) another energy source
   a) *fossil fuels: coal, petroleum oil, natural gas*
      - nonrenewable resources

- pollution from combustion (smog, acid precipitation)

b) *solar energy*
c) *hydroelectric energy*
d) *geothermal energy*
e) *wind energy*
f) *nuclear energy*

3) sustainability and nutrient cycling
   i. **natural system** = *recycling of elements*
   ii. **human system** = *one-directional flow of elements*
      - landfills
      - pollutants in stormwater and groundwater
      - "disposable society"

B. value
   1) **natural capital**—*natural resources*
   2) ecosystems—provide goods and services
   3) natural ecosystems are undervalued because some functions they perform are not obvious
   4) incremental value—how changes in goods or services affect humans

Adapted from R. Costanza *et al.*, "The Value of the World's Ecosystem Services and Natural Capital," *Nature* Vol. 387 (1997).

Annual global value of Ecosystems Services = values in trillion $ U.S.

- 17.1 Soil formation
- 3.0 Recreation
- 2.3 Nutrient cycling
- 2.3 Water regulation and supply
- 1.8 Climate regulation
- 1.4 Habitat
- 1.1 Flood and storm protection

- 0.8 Food and raw materials production
- 0.8 Genetic resources
- 0.7 Atmospheric gas balance
- 0.4 Pollination
- 1.6 other

TOTAL = $ 33,000,000,000,000

C. managing ecosystems
   Ecological Society of America www.esa.org
   primary goal = to ensure sustainability
      - set clear goals
      - have valid models for clarification
      - be aware of interconnectedness
      - be aware of the dynamic changing nature of ecosystems
      - consider the context
      - have adaptability and accountability
      - consider humans as part of nature