Molecules – General

Inorganic Molecules

~2.3rd 's of body consists of inorganic molecules

general characteristics:
- small molecules: only a few atoms & bonds
- little or no carbon atoms
- usually dissolve easily in water
- usually resist decomposition
- undergo rapid chemical reactions
- usually more likely to ionize

Major kinds of inorganic molecules inside cells:

1. Water
   - perhaps most important and most abundant molecule in the body
   - some animals up to 95% of body mass;
     average is 65-75%
   - can live for several weeks or a month without food
     but not more than a few days without water
   - its unique properties relate to its structure, strong
     polar nature and hydrogen bonds it can form

   a. Universal solvent
      - polar forces ions and polar molecules to disperse (ie. dissolve)
      - substances that dissolve readily in water = hydrophilic
        (water loving)
      - substances that do not dissolve in water = hydrophobic (water hating)
      - uncharged or nonpolar molecules
      - hydrophobic molecules tend to cluster together
      → not ‘bond’ but important in shape of some molecules and cellular structures

   b. chemical reactant
      - acts as main source of H atoms for organic molecules
      - also donates O atoms in some reactions

   c. ability to stabilize temperature
      - absorbs and releases heat slowly
      - high heat capacity: requires a much greater heat input
        to raise temp of water 1° C than any other substance
also gives up heat slowly
because of tight hydrogen bonds takes more E to get
them to comparable degree of motion (ie. cause an
increase in T)
takes 539 C to heat 1g of water past its boiling point –
hydrogen bonds resist separation (this is 2x’s ethanol,
5x’s chloroform)
as molecule of water evaporates it takes this heat
along with it therefore cools the rest of the liquid
\( \rightarrow \) temperature homeostasis
sweating \( \rightarrow \) cooling

d. acts as lubricant
serous membranes
heart, lungs, digestive system

e. cushioning
csf baths brain and spinal cord
fluid surrounds each cell

f. transport medium
blood, lymph
moves things from place to place

The human body is made up mostly of water;
\[ \sim 60 - 65\% \ (40 \ L) \]

Where is this water located?

This water can be visualized as occurring in several “compartments”:

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Fraction</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracellular</td>
<td>62%</td>
<td>25 L</td>
</tr>
<tr>
<td>Extracellular</td>
<td>38%</td>
<td>15 L</td>
</tr>
<tr>
<td>Interstitial</td>
<td>30%</td>
<td>12 L [80% of ecf]</td>
</tr>
<tr>
<td>Intravascular</td>
<td>8%</td>
<td>3 L [20% of ecf]</td>
</tr>
</tbody>
</table>

**Intracellular**

most of the fluid in the body = 2/3rd’s
inside all body cells

**Extracellular**

all fluid outside cells
\[ \sim 1/3 \text{rd of body water} \]
some is in tissue spaces between cells
\[ = \text{interstitial} \ (= \text{intercellular}) \]
30% of total fluids
some is circulating in vessels
= **intravascular**
(blood and lymphatic systems)
8% of total fluids

These compartments are interconnected:

outside ↔ intravascular ↔ interstitial ↔ intracellular

maintaining water and salt balance in each
compartment means maintaining a balance in body as a whole

they interact with the environment by specialized organ systems:

- **respiratory system**
- **excretory system**
- **digestive system**

**Fluid inputs:**
- digestive tract 2000ml
- metabolism 500ml
TOTAL: 2500ml

**Fluid outputs:**
- kidneys 1300ml
- lungs 450ml
- skin 650ml
- intestine 100ml
TOTAL: 2500ml

2. **Electrolytes (ions)**
molecules that tend to disperse in solution into charged atoms

organisms are extremely sensitive to changes in electrolyte composition

general functions of electrolytes:
a. help maintain salt/water balance
b. bone and teeth formation
c. functioning of nerve cells
d. enzyme activation

cations and anions
salts → cations and anions (but not H+ or OH-)
a. **Calcium**
   99% of Ca\(^{++}\) is in bones as reservoir (eg. Calcium phosphate)
   1% circulates in body fluids
   ? muscle cells
   functions:
   - blood clotting
   - synapses
   - hormone secretion
   - nerve impulses
   - muscle contractions

b. **Sodium**
   main cation (+) in extracellular fluid (ECF)
   main regulator of its volume
   also helps in acid/base balance
   nerve transmission
   muscle contractions

c. **Potassium**
   main cation in intracellular fluid
   nerve impulse transmission
   muscle contraction
   steady heartbeat

d. **Iron**
   most of body’s iron is in form of hemoglobin and myoglobin
   → oxygen transport and storage
   also used as cofactor in enzymes
   → ETS energy pathways
   → enzymes for AA, hormone and neurotransmitter synthesis

e. **Iodine**
   I\(_2\) (= iodine gas) is a poison, but I is essential for life
   integral part of 2 hormones of thyroid
   → regulate body temperature
   metabolic rate
   reproduction
   blood cell formation
   nerve and muscle function

**acids** and **bases**
acids → release H\(^+\) (proton donors)
bases $\rightarrow$ releases OH- (proton acceptors)
\[ \text{pH} = -\log [\text{H}^+] \]

pure water: $\# \text{H}^+ = \# \text{OH}^-$
$\Rightarrow$ neutral, pH=7

\[ \text{pH} = 7 = 0.000001 \text{ gm H}^+/\text{liter} \]

pH 6 is 10x’s more acidic than pH of 7

3. gasses

**O2 gas**
comprises about 20% of atmosphere
essential for aerobic respiration
waste product of photosynthesis
not same thing as oxygen atoms

**CO2 gas**
comprises 0.03% of earth’s atmosphere
source of carbon in organic molecules
waste product of respiration

**NO2 gas**

**N2 gas**
comprises 78% of air
N is required by all life to make eg proteins and DNA
yet few organisms can use N2 directly
only a few species of bacteria can do that
Organic Molecules

~1/3rd of body consists of organic molecules

large – made of 100’s, 1000’s 10,000’s atoms

contain lots of carbon = carbon backbone
  carbon can form 4 covalent bonds
  easily forms chains, rings, branching structures

also usually contain lots of
  H, O, N and P atoms

usually only a small part of organic molecules are involved in the chemical reactions of metabolism

these “reactive parts” of organic molecules = functional groups

complex organic molecules have carbon backbone
  with various functional groups attached:
    eg:  -OH (hydroxyl), -COOH (acid), -NH2 (amino),

the functional groups determine
  1. the family and properties of the organic molecules
  2. the kinds of reactions these molecules will enter into

may or may not dissolve easily in water

all major organic molecules can be used for energy production (but not vitamins)

major kinds of organic molecules:
  1. carbohydrates
  2. lipids
  3. proteins
  4. nucleic acids (include ATP)
  5. vitamins

most larger organic molecules are polymers of smaller units:
  carbohydrates → monosaccharides (simple sugars)
  proteins → amino acids
**fats**

**nucleic acids**

→ fatty acids & glycerol

→ nucleotides
Carbohydrates

sugars and starches, fiber

comprise 1-2% of total body mass

larger ones contain long chains of carbon atoms
  → many chemical bonds
  → huge store of chemical energy

general formula: \((\text{CH}_2\text{O})_n\)

Kinds
Simple Carbohydrates = sugars
Complex Carbohydrates = starches and fiber

simple sugars (monosaccharides)
simplest kinds of carbohydrates
5 or 6 carbon atoms
many kinds based on arrangement of atoms
-ose = sugar
eg. glucose, fructose, ribose, deoxyribose

**glucose (C\text{6H12O6})**
  is one of two sugars in every disaccharide
  most polysaccharides are made from units of glucose

**fructose (C\text{6H12O6})**
  the swearest of sugars
  same chemical formula as glucose, different structure
  this different arrangement stimulates taste buds for sweet
  even more than does glucose
  occurs naturally in fruits and honey
  is an additive in high fructose corn syrup

**galactose (C\text{6H12O6})**
  rarely occurs by itself in nature
  usually part of a disaccharide

disaccharides
  hook two monosaccharides together
eg.

\[
\text{glucose} + \text{glucose} = \text{maltose}
\]
in process of forming disaccharide, a molecule of water is removed = **dehydration synthesis**

addition of water to break bond = **hydrolysis**

eg. sucrose, lactose

**sucrose**
- fructose-glucose
- fruits, veggies, grains
- table sugar: refined from sugar cane, sugar beets

**lactose**
- galactose-glucose
- main carbohydrate in milk (30 – 50% of milks energy)

**starches** (complex carbohydrates)
- complex carbohydrates
- simple sugars polymerize to form starches
- consist of many glucose units and sometimes a few other kinds of sugars
- = polysaccharides
- eg. “starch”, glycogen, “fiber”

“starch”
- virtually all starchy foods come from plants
- plant cells store glucose as starch
- long branched or unbranched chains
- packed tightly in wheat and rice grains and tubers
- also high in legumes (peas, beans)
- almost all “starchy foods” are from plants
- provide much of the food energy for people worldwide:
  - rice → Asia
  - wheat → Canada, US, Europe
  - corn → Central and South America
  - millet, rye, oats, barley

**glycogen**
- = animal starch
- long heavily branched polymer
- animal cells store a small amount of sugar as glycogen
- meats only contain a limited amount since its broken down quickly after slaughter
not found in plant cells
important in our bodies
each of our cells stores some sugar in form of
glycogen
~1lb/person
~1/3\textsuperscript{rd} in liver cells
liver glycogen plays critical role in glucose
homeostasis
can quickly release glucose into blood when
levels drop
~2/3\textsuperscript{rd}s in muscle tissue
muscles can respond to energy demands
quickly by converting it to glucose for energy
production

“fiber”
structural part of plant
not same thing as starch \(\rightarrow\) undigestible
cellulose, hemicellulose, pectins, lignins, cutins, tannin, gums
different kind of linkages between subunits
\(\rightarrow\) body lacks enzymes to split them apart
fibers important nutritionally:
affect time to absorb other nutrients from GI tract
improves flow of materials through intestine
used as fiber in breads etc = “sawdust”
some may be fermented by gut bacteria to produce
additional nutrients

\textit{soluble fibers:} \quad \textit{fruits, oats, barley, legumes}
\textit{slow stomach emptying}
\textit{delay glucose absorption}
\textit{lower cholesterol levels}

\textit{insoluble fibers:} \quad \textit{veggies, wheat, cereal}
\textit{accelerates chyme thru intestine}
?delays? glucose absorption

pectins
\quad = jellies and jams

lignins
\quad \rightarrow \text{resist decomposition}

\textbf{General Functions:}
1. decomposition to provide most energy for cell
   in form of ATP
   most cells in body get most energy from
carbohydrates (esp brain and RBC’s)
breakdown of Carbo’s releases energy for day to day activities
2. excess food converted to glycogen
   mostly stored in liver and muscles
3. synthesis of glycoproteins and glycolipids
   cell markers, transport
4. ribose and deoxyribose to synthesize DNA and RNA
5. synthesis of cellulose (plants) and chitin (fungi and insects)

   cellulose is most abundant organic molecule on earth
Lipids

Fats and oils, waxes
- Oils → liquid at room temperature
- Fats → solid at room temperature

Most abundant organic molecules in body
- (14 - 20% in lean adult)

Many different kinds:
- Triglycerides
- Phospholipids
- Eicosanoids (leukotrienes, prostaglandins, etc)
- Steroids

**Nutritional sources:**
- Triglycerides:
  - Saturated
    - Esp animal tissues
    - Also some plant oils: cocoa, palm, coconut
  - Monounsaturated
    - Olive oil, peanut oil
  - Polyunsaturated
    - Linoleic acid & linolenic acid are essential nutrients
      - Corn, safflower, sunflower, sesame oil

Also contain C, H, and O
- But many more C & H and less O than carbohydrates

Most contain even number of C’s in chains up to 24 C’s long
- Esp common are 18 C fatty acids (eg. stearic acid)
- Longer chain FA’s characteristic of meats and fish
- Medium and short chain FA’s mainly in dairy products

Most fats are polymers of
- Glycerol,
- Fatty acids, and
- Sometimes phosphates

**Structure & Function of Different Kinds of Lipids**

1. **Triglycerides:**
   - 90% of dietary fats and oils are triglycerides
   - Also are predominant lipid found in body
   - Polymers of glycerol (3C’s) and 3 Fatty Acids
saturated
only single covalent bonds between
  carbon backbone
  fully loaded with H’s
  increased risk of atherosclerosis

fats not fully loaded with H’s have double
  bonds between 1 or more carbon atoms

monounsaturated
  one C=C double bond
  eg. oleic acid in olive oil

polyunsaturated
  2 or more C=C double bond
  eg. linoleic acid common in vegetable oil

  responsible for much of the flavor, tenderness,
  aroma and palatability of foods

generally, the longer the carbon chain, the more liquid the fat at room
  temperature
also, the degree of saturation affects firmness of fats at room
  temperature
  eg. polyunsat veg oils are liquid
  sat animal fats are hard
  eg. butter is harder than margarine because it is
    more saturated
  but palm and coconut oils are saturated even
    thought they are of vegetable origin

saturation also affects stability
all fats can get rancid when exposed to oxygen (oxidation)
polyunsat fats spoil more readily because their double bonds are
  less stable
  can preserve them by:
  1.  use sealed, air tight refrigerated containers for storage
  2.  add antioxidants (eg. BHA, BHT, Vit C & E)
  3.  increase saturation (hydrogenation)
    → protects against oxidation
    → alters texture of foods
      becomes more solid
      eg. hydrogenated veg oils become margarine
      makes pie crusts flaky
      makes pudding creamy
    → but lose health advantage of polyunsaturation
makes trans fatty acids as by product
linked to heart disease

Functions:
carry with them fat soluble vitamins: ADEK
store excess food energy: 2x’s energy/gm
than carbohydrates contain
insulation from heat and cold
insulation around neurons = myelin
used to synthesize some “tissue hormones”

2. Phospholipids
replace one fatty acid with phosphate group
the Phos group makes them dissolve in water
the FA’s make them soluble in fats
used as emulsifiers in mayonnaise and
candy
Functions:
all cell membranes
help lipids move across membranes
eg. fat soluble vitamins, hormones, etc
act as emulsifiers to keep frats suspended in
blood and body fluids
eg. lecithin (linoleic acid)
used in cell membrane
myelin sheath
prostaglandins
not an essential nutrient (don’t need lecithin
supplements)

3. Sterols
lipid compound with multiple rings
characteristic 4-ring structure
both plant and animal foods contain sterols but
only animal food contains the sterol cholesterol
eg. cholesterol
sex hormones
bile salts
vitamin D
cortisol

Functions
used to manufacture
bile
sex hormones
adrenal hormones
Vitamin D
cholesterol
   NOT used for energy
   structural basis of bile salts
   basis of steroid hormones
   used in cell membrane (90% of all body
   cholesterol is in cell membranes)

cholesterol isn’t bad
its made and used by liver
the liver contributes much more cholesterol to body than
does diet
cholesterol synthesis depends on:
   a. availability of raw materials: CHO’s, fats, proteins
   b. extent of bile production
   c. presence of regulator hormones
      eg. insulin small meals → low insulin
      → low cholesterol synthesis
cholesterol harmful effect occur when it forms deposits on
artery wall → leads to atherosclerosis

4. Eicosanoids
   fatty acid containing 5-C ring
   prostaglandins and leukotrienes

   Functions:
   hormone like lipids that
   help regulate blood pressure
   modify responses to hormones
   affect inflammatory response
   allergies
Proteins

second most abundant organic molecules in body
(15-18%).
much more complex structure than either
carbohydrates or lipids
contain: C, H, O, N and S
often polymers of 100’x or 1000’s amino acids
(MW of 6000 to 40M)

amino acid:
  amino group: -NH₂
  acid group: -COOH
  R group → unique for each AA

20 different kinds of amino acids (22 in bacteria)
→ ~ half are essential nutrients

connected by peptide bonds:
  amino group of one AA joined to acid group of
  another
  → small chains = polypeptides
  → long chains = proteins

extremely large number of different kinds of proteins

each protein is composed of a unique combination of
  these amino acids

most proteins are a few dozen to several hundred
  amino acids long

many proteins are so large that their exact structure
  has not yet been determined

normally the AA’s released in digestion are used to synthesize new proteins in
  the body

but they can also be used as an alternate energy source

their different 3-D shapes determine their function
  eg. some form hollow spheres and store other
  molecules inside
  eg. some form long, rodlike fibers such as
    collagen, actin, myosin
  eg. specific shape of enzyme proteins determines
which reactions they will facilitate

**sequence of amino acids**  
\(\rightarrow\) **conformation**  
\(\rightarrow\) **function**

1º *structure*  
\(\rightarrow\) specific sequence of AA’s  
small changes in AA alters shape and  
therefore their function  
eg. sickle cell anemia (1 AA different)

2º *structure*  
few proteins exist as straight chains of amino acids  
most are coiled or twisted into secondary structure  
eg. spiral, helices, pleated sheets  
most common secondary structures are spirals or helices  
\(\rightarrow\) created mainly by hydrogen bonds

3º *structure*  
some proteins have additional coiling, looping and twisting  
hydrogen and sulfide bonds cause molecule to bend back upon itself in characteristic fashion

4º *structure*  
when a protein consists of several similar protein subunits  
eg. hemoglobin

proteins are very sensitive to environmental changes  
\(\rightarrow\) changes in temp, pH, salts, etc can cause them to “denature” and become nonfunctional  
they uncoil or loose their shape and function  
eg. cooked cheese, eg mozzarella and swiss, becomes stringy \(\rightarrow\) proteins unwind and get hooked together end on end by calcium cmpds  
eg. albumin in cooked egg turns solid
dietary protein is needed mainly for synthesis of new proteins in body;
not generally used for energy
    but can be if needed
the AA’s of a protein are used to synthesize:
    as structural elements or fibers
        eg. collagen in bones and teeth, tendons and
            ligaments, arterial walls
        eg. actin and myosin in muscle cells
hormones
    messenger molecules
        eg. insulin
transport
    oxygen $\rightarrow$ hemoglobin
    lipids (HDL’s, LDL’s)
    hormones
    iron
membrane carriers
    facilitated diffusion
    active transport
antibodies
    =albumins = globulins
    attaches to antigen in inactivate or kill it
buffers
    can absorb and release $\text{H}^+$
regulate salt/water balance
    osmotically active $\rightarrow$ attract water
    as proteins build up draws water in (edema)
clotting
    fibrinogen
photoreceptors
    eg. rhodopsin is light sensitive changes shape with light hits
        it to generate a nerve impulse
enzymes
    up to 50,000 different kinds of reactions in each cell
        $\rightarrow$ each requires specific enzyme
    eg. digestive enzymes, enzymes needed for
        synthesis
the body can synthesize $\sim$ half of the 20 AA’s
8 AA’s are essential to adults and must be gotten in diet
    (10 in children)
complete vs incomplete proteins
Nucleic Acids

comprise <1% by wt of body but vitally important:
   1. stores genetic code (genes on chromosomes)
   2. controls cell division (mitosis and meiosis)
   3. regulates metabolism
      → by controlling enzyme synthesis

very complex molecules that represent the basis for all life

two major kinds of nucleic acids
   DNA
   RNA

both are polymers of nucleotides

each nucleotide consists of three major parts:
   sugar
   phosphate
   Nitrogen base
DNA

structurally differs from RNA:
sugar = deoxyribose (instead of ribose)
N bases: adenine, thymine, guanine, cytosine
double strand of nucleotides
connected in ladder like fashion
held together by N bases

DNA Structure

only a few different kinds of atoms make up the DNA molecule:  C H O N P

DNA is a long polymer of smaller units = nucleotides

each nucleotide is made of three even smaller pieces:
sugar
phosphate
Nitrogen base

each DNA molecule consists of a double strand of these nucleotides
these two strand spiral around each other to form a double helix
the S and P alternate to form the backbone of each strand
the N bases are connected by hydrogen bonds to join the 2 strands together
there are 4 different kinds of bases possible in the DNA molecule:

- **purines**: adenine & guanine
  \[ A \quad G \]

- **pyrimidines**: thymine & cytosine
  \[ T \quad C \]

The purine and pyrimidine bases of opposite strands are connected in **ladder-like** fashion by **hydrogen bonds**

The two strands are:
- **antiparallel**
- **complementary**
  - **A** only binds to **T**
  - **C** only binds to **G**

It is the specific binding requirements of the N-bases that allows replication → if you know 1 strand, you know the other

**RNA**

uracil instead of thymine
ATP & Energy Use

Energy used and released inside cell must be controlled.

It is generally produced from the catabolism of organic molecules especially glucose.

ATP is a special energy transfer molecule.

It exists mainly in two forms:
- High energy ATP
- Lower energy ADP

ATP = adenosine triphosphate: $A\sim P\sim P\sim P$

Between the phosphorus atoms are “high energy” bonds.
- They release 4-6 x’s more energy than that released when “ordinary” bonds are broken.

ATP releases energy

ATP stores energy

One form of AMP = cyclic AMP often controls the activity of other enzymes in cell.
- It is a regulator molecule.

ATP is the immediate source of energy for cells.
- Food breakdown releases energy from food and stores it as ATP until needed.

The energy released by the catabolism of glucose is used for various processes in cells:

1. Active Transport and Bulk Transport
- Moving things in and out of cell against
concentration gradients

2. Bioelectricity
   - all cells possess an electrical potential across the cell membrane

   - some cells are able to rapidly alter this electrical potential difference = excitable cells

   - this produces the ability to produce and conduct a nerve impulse along a neuron

3. Movement
   contraction of muscle cells requires large amounts of ATP

   also beating of cilia and flagella and the amoeboid movement of WBC’s

4. Anabolic Reactions (biosynthesis)
   the formation of new organic molecules requires ATP since new bonds are made

5. Bioluminescence

additional energy transfer molecules:
   NAD, FAD & NADP
Vitamins - General

vitamins are small organic molecules:
1. other than proteins, carbohydrates, lipids and nucleic acids
2. don’t form polymers
3. most cannot be made by body
4. used in very small amounts
5. cannot be broken down for energy
   but may play an important role in energy pathways
   as coenzymes and cofactors

categorized as:
water soluble and fat soluble vitamins
→ affects: what foods they are found in
if and where they are stored in
body
toxicity
how they are eliminated

Water Soluble

dissolve easily in water, not fat
sensitive to heat and light
→ generally don’t store well
→ lost in cooking
absorbed directly into blood and travel freely throughout the body
generally not stored well in body
→ eliminated daily by kidneys
→ fewer toxicities
→ needed in frequent, small doses
B’s, C

Fat Soluble vitamins

dissolve easily in fat, not water
generally more heat and light stable
→ not destroyed by cooking or storage
first enter lymphatic system
generally require protein transport molecules to travel in blood
blood concentrations are maintained because body retrieves them from storage as needed
stored in liver and fat cells and accumulate; not readily excreted
→ don’t need every day
→ easier to have toxicity:
can reach toxic levels if consumed in excess
→ needed in less frequent doses

play major roles in growth and maintenance
their presence affects health and functions of
  eyes
  skin
  GI tract
  lungs
  bones and teeth
  nervous system
  blood

tend to appear in different foods than water
  soluble vitamins

A, D, E, K