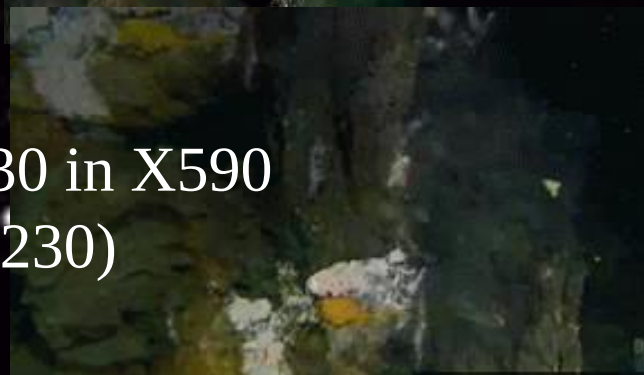
ASTR/GEOL-2040: Search for life in the Universe, Lecture 3

One-off additional
office hours
this Tuesday: Sep 5
8 – 10 in X490



Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590
and Wednesdays 11-12 in D230)

Darwinian evolution

- More individuals produced than survive
- Struggle for existence (limited resources)
- Individuals show variation (often subtle)
- Individuals produce similar offspring

Works also/especially at the molecular level:
RNA can replicate itself → RNA world

RGS p.2, Lon p.168, BS p.164,181

Natural selection is

A. the occasional mutations that occur in DNA;
B. the mechanism by which advantageous traits are preferentially passed on from parents to offspring;
C. the idea that organisms can develop new characteristics during their lives and then pass these on to their offspring.

BS p.195

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Lamarck is usually remembered for his belief in the inheritance of acquired characteristics, and the *use and disuse* model by which organisms developed their characteristics. Lamarck incorporated this belief into his theory of evolution, along with other more common beliefs of the time, such as spontaneous generation. The inheritance of acquired characteristics (also called

BS p.182

Again: What is life?

automatically implies
input of matter & energy

- Replicate &
- Evolve through natural selection

Still unclear how life got started
Chemical vs biological evolution
Where exactly is the threshold?

Any definition may be challenged
as we have new observations

RGS p.2, BS p.164-165

2nd law of thermodynamics

- When left alone, a system undergoes conversions that lead to increasing disorder
- Consider life in sealed box: use up all molecules and energy …

BS p.157

Which of the following is not a key property of life?

A. The maintenance of order in living cells

B. The ability to evolve over time

C. The ability to violate the second law of thermodynamics?

RGS p.3, Lon p.171, BS p.166-167

Which of the following is not a key property of life?

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RGS p.3, Lon p.171, BS p.166-167

The other law of thermodynamic

- 1st law of TD: energy is conserved
  - can be transferred between different reservoirs (thermal, kinetic, chemical)
- 2nd law of TD: each time energy is transferred, disorder of Universe incr.
  → Life creates order & messes up surroundings

Lon p.161-163, BS p.157

Building blocks of life

- Rothery, Gilmour, Sephton (RGS) pp. 4-12
- Longstaff (Lon) pp. 175-183
- Bennett & Shostak (BS) pp. 167-169
- pp. 176-183

Most abundant elements

Table 1.1 The ten most abundant elements in the Universe, Earth and life (expressed as atoms of the element per 100 000 total atoms).

Order	Universe		Whole Earth		Earth's crust		Earth's ocean		Humans	
1	H	92 714	O	48 880	O	60 425	H	66 200	H	60 563
2	He	7 185	Fe	18 870	Si	20 475	O	33 100	O	25 670
3	O	50	Si	14 000	Al	6 251	Cl	340	C	10 680
4	Ne	20	Mg	12 500	H	2 882	Na	290	N	2 440
5	N	15	S	11 400	Na	2 155	Mg	34	Ca	230
6	C	8	Ni	1 400	Ca	1 878	S	17	P	130
7	Si	2.3	Al	1 300	Fe	1 858	Ca	6	S	130
8	Mg	2.1	Na	640	Mg	1 784	K	6	Na	75
9	Fe	1.4	Ca	460	K	1 374	C	1.4	K	37
10	S	0.9	P	140	Ti	191	Si	–	Cl	33

- H and He in the Universe
- Nobel elements He, Ne, Ar, … highly unreactive (inert)
- Rest in Universe O, N, C, Si
- Human body H, O, C, N

Molecules in human body

Molecule	mass	sum
Water	65%	65%
Protein	20%	85%
Lipids	12%	97%
Other inorg (eg carbohydrates)	1.5%	98.5%
RNA	1.0%	99.5%
Other org	0.4%	99.9%
DNA	0.1%	100%

The building blocks of life

- Proteins (“meat”)
- Lipids (“fats”, cell boundaries)
- Carbohydrates (“sugars”)
- RNA & DNA

Why water?

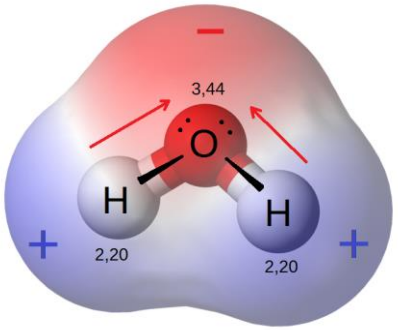
- To dissolve & transport organic molecules, → available for reactions
- Is liquid over wide *T* range
- Alternatives; lower *T*, reactions ***slow***

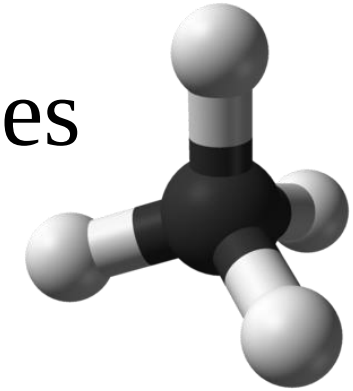
solvent	formula	freezing	boiling	range
water	H_2O	0°C	100°C	100°C
ammonia	NH_3	−78°C	−33°C	45°C
methanol	CH_3OH	−98°C	65°C	163°C
methane	CH_4	−182°C	−164°C	18°C
ethane	CH_3CH_3	−183°C	−89°C	94°C

RGS p.4, Lon p.171-173, BS p.246-248

Other reasons

- Ice floats & ***insulates*** deeper layers
- Water is a highly polar molecule
  → hydrogen bonds (very stable)
- Dissolves other polar molecules
  – Like dissolves like
- Does not dissolve apolar molecules
  → critical for existence of cells

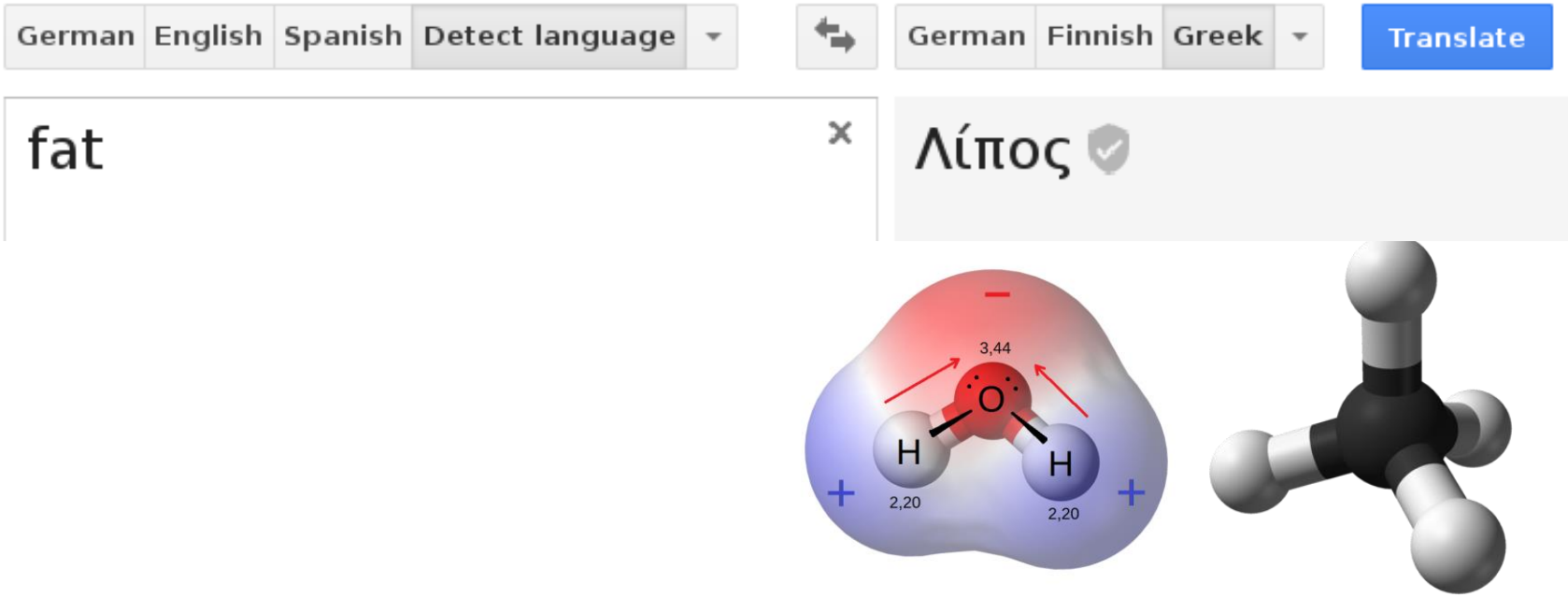




RGS p.5, Lon p.172-173, BS p.248

Water & fat

- Water does not dissolve apolar molecules
  → critical for existence of cells



RGS p.5, Lon p.172-173, BS p.248

Properties of lipids

- Water-insoluble
  - Act as cell membranes
- Energy substrates
  - Fats (used by migrating birds)
- Fatty acids
  - Double bond = unsaturated

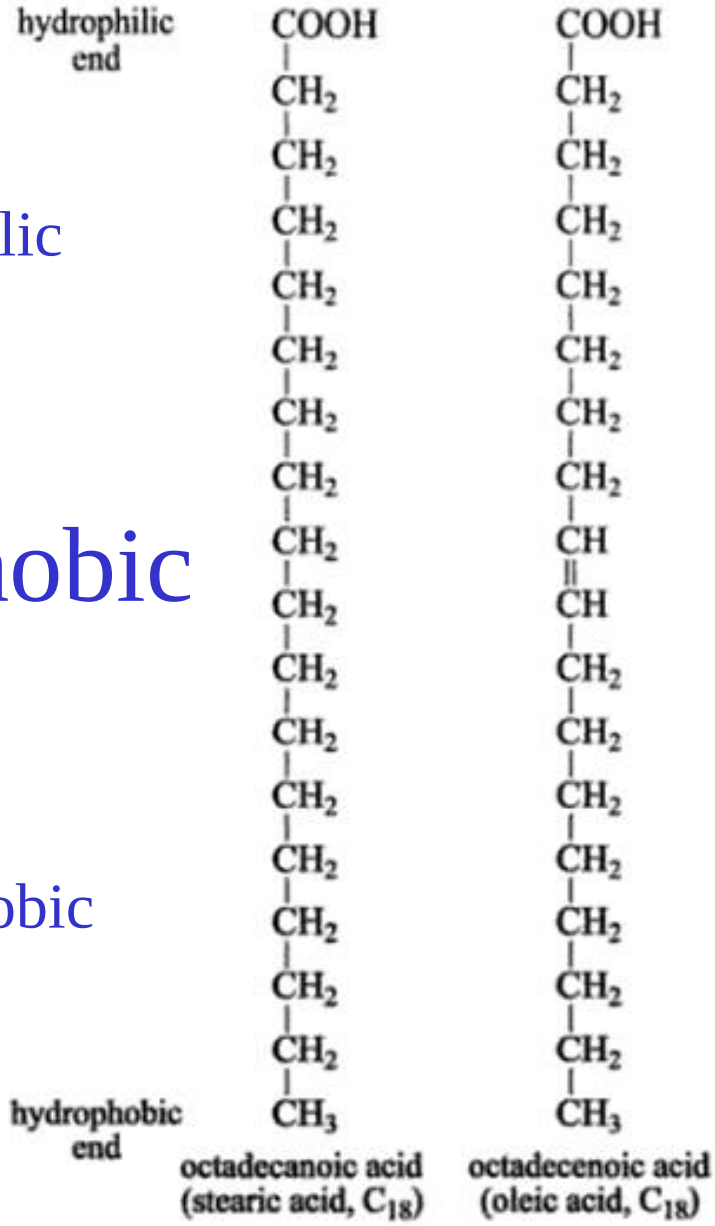
RGS p.4, Lon p.171-173, BS p.168

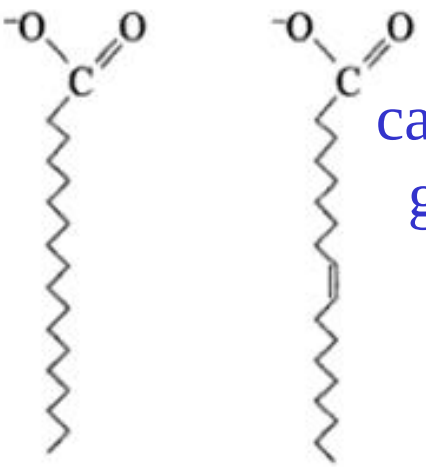
Cells are made of lipids

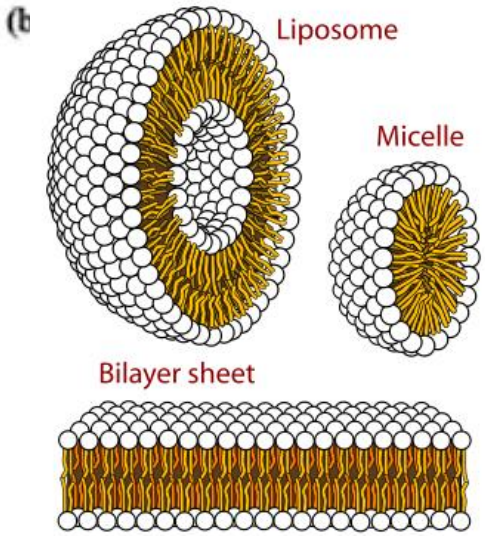
hydrophilic

→ amphobic

hydrophobic

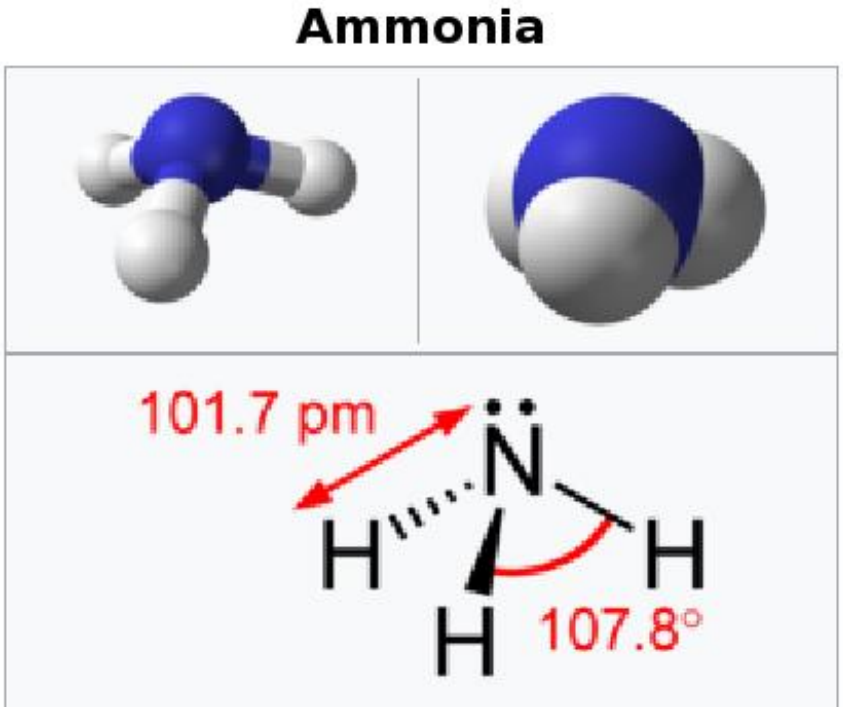




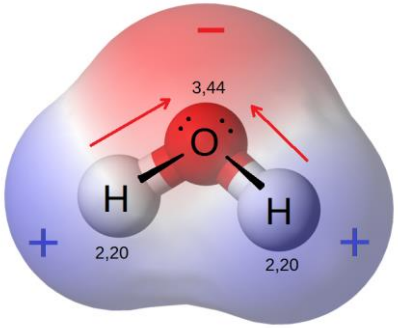


Ammonia NH_3

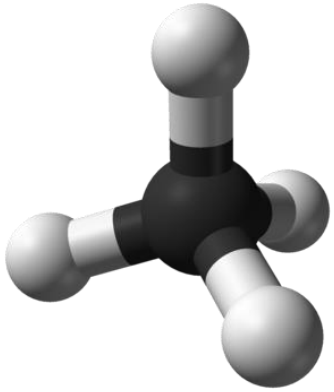
- Only weakly polar
- Cells could dissolve



H_2O



CH_4



RGS p.5, Lon p.172-173, BS p.248

Why carbon

- Versatile, because it can bond with a large range of different atoms
- Carbon compounds can readily dissolve in water

RGS p.3, BS p.164-165

Why not silicon?

- Si is larger, so bonds are weaker
- Si does not form double or triple bonds as easily
- SiO_2 is solid, not mobile like CO_2
- In Earth's crust, Si is 1000x more abundant than C, but C won

RGS p.3, Lon p.171, BS p.166-167

Common carbon compounds

- carbohydrates
- hydrocarbons

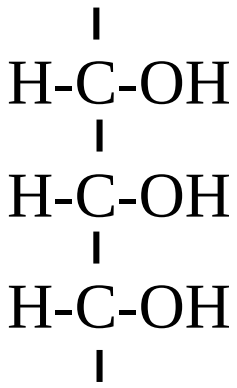
Common carbon compounds

- Hydrocarbons: made up entirely of hydrogen & carbon

  CH_3-CH_2-CH_2-CH_2-CH_2-CH_3

- Carbohydrates: made up of hydrogen, carbon, & oxygen

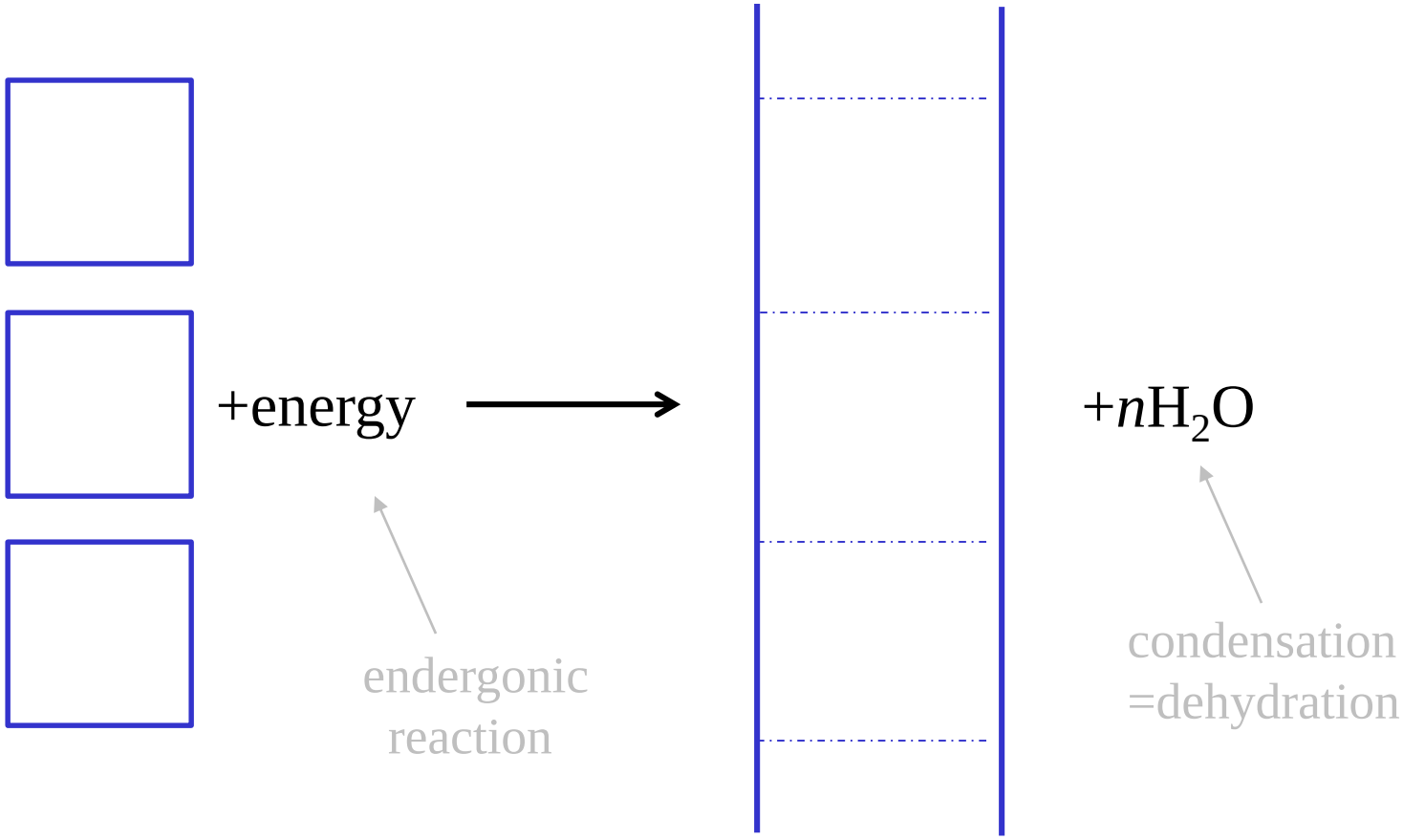
  $C_m(H_2O)_n$



These endings have names

- –COOH carboxyl group
- –OH hydroxyl group
- $–CH_3$ methyl group
- $–NH_2$ amino group (=amine group)

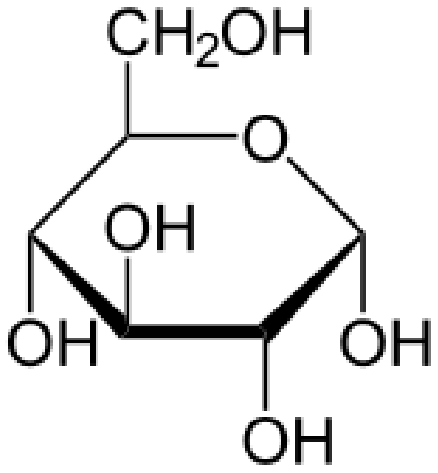
building macromolecules

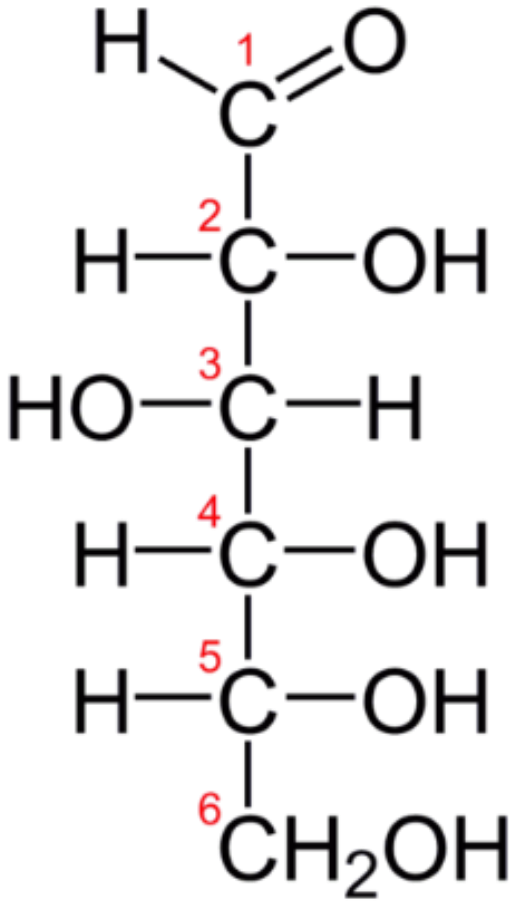


$(CH_2O)_n$ = "life"

- Glucose=hexose =monosaccharide = $C_6H_{12}O_6$

chemists drop C & H





What we talked about

– Why carbon, & not silicon-based

– Why water?

– pp. 3-8, Sects. 1.1 & 1.2