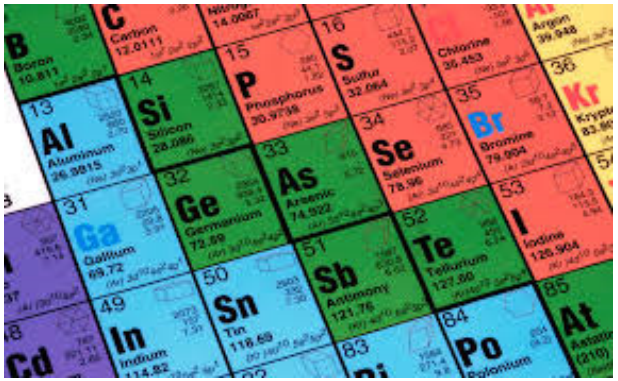
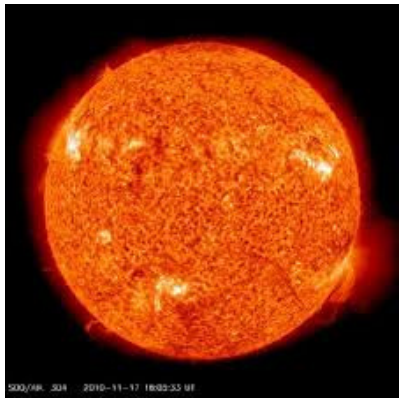
Constrains for the origin of life

Elements of life



Solvents for life

Energy for life

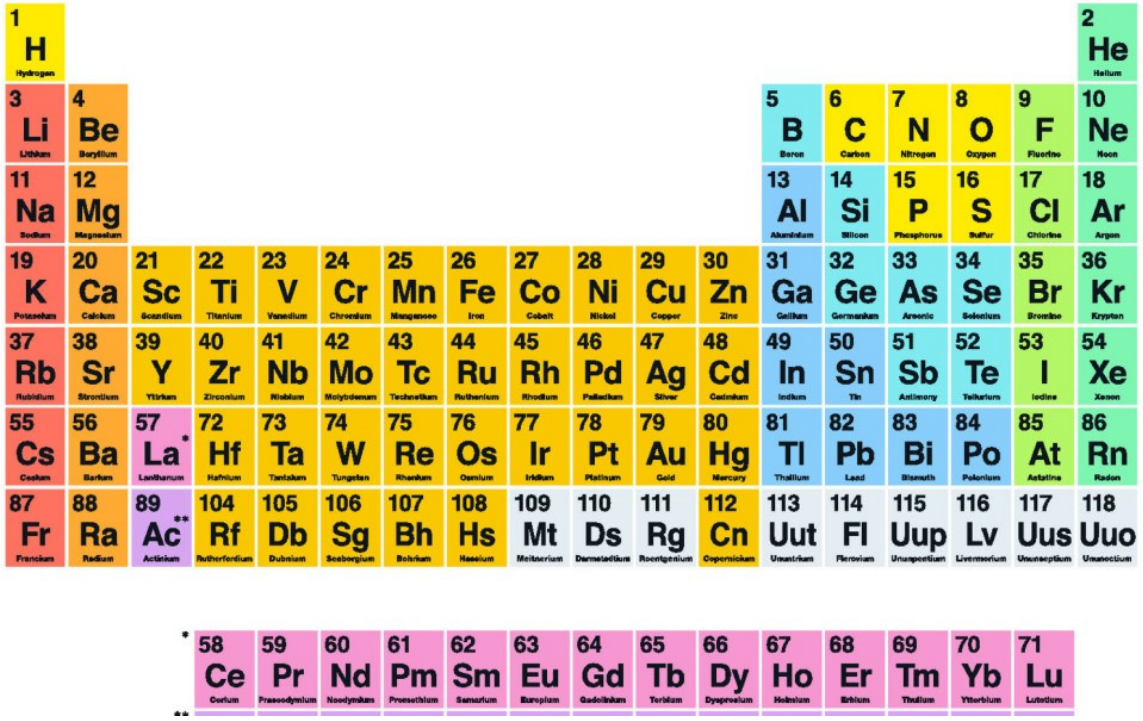


Other limitations

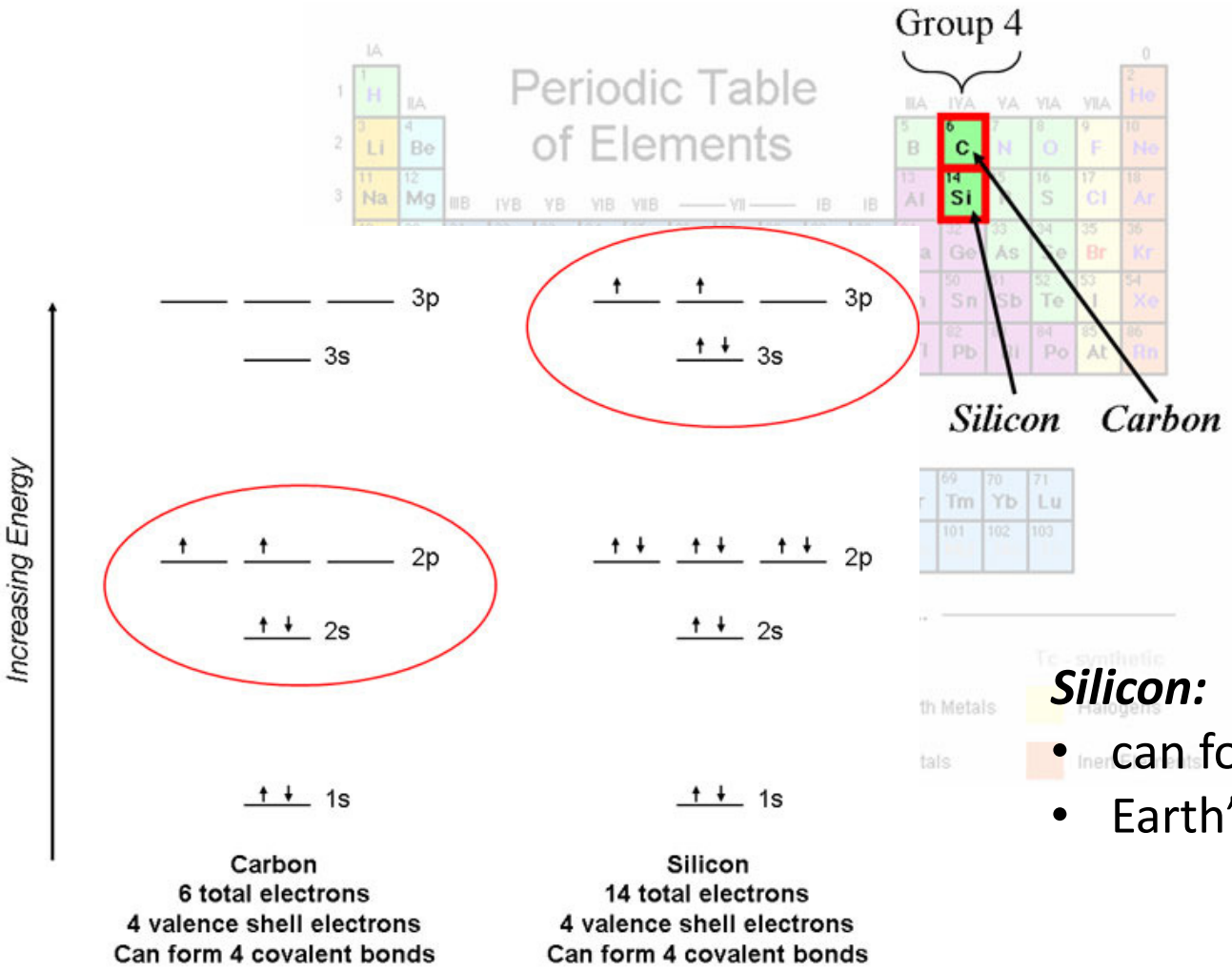
Elements of life

Carbon-based life well-justified:

- self-replicating chemical systems need sufficient complexity
- Carbon is tetravalent and can form complex structures (unlike H, He, Li, O, or F)
- Fourth most common element in the Solar system



Elements of life



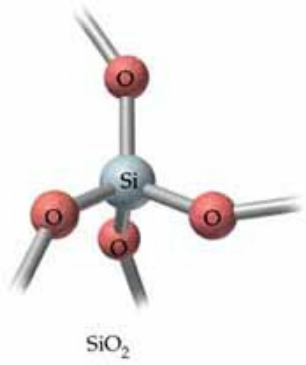
Star Trek: The Devil in the Dark

Silicon:

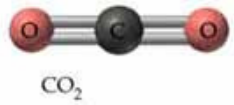
- can form multivalent structures
- Earth's surface – 2nd most abundant element

Elements of life

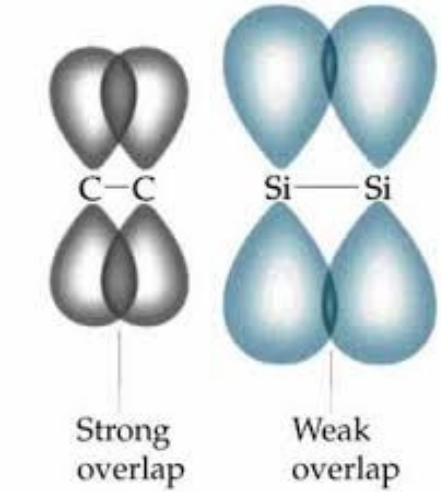
Si-O bond far more stable than Si-Si, Si-H or Si-N
→ oxidation almost irreversible



Energy of C-C bond comparable to C-O, C-N and C-H
→ easy exchange between elements



Multiple bonds of carbon are stabilized,
silicon - destabilized



Elements of life

Methane, CH_4
(flammable)
(gas at room temperature)
(stable)

Silane, SiH_4
(flammable)
(gas at room temperature)
(extremely unstable)

DOW CORNING

Silicon is less well suited to support complex chemistry than carbon.

Other atoms are far worse than silicon

Solvents of life

Life requires a solvent to move molecules around

Solvents of life

Terrestrial organsims based on water

Solvents of life

Advantages of water:

- ice floats → nutrient transport, temperature modulation

- High heat capacity 4.2 J/g*^{0}C (3x of rocks or metals),
  heat of vaporization 41 J/g

→ both help to moderate Earth's climate

- Liquidity range – 100^{0}C

- High dielectric constant – water is a very good solvent

- High molecular density 55.5 mol/L – „hydrophobic effect":
  H_2O forces dissolved molecules to organize to minimize the enthropic cost

- H, O – very abundant in the Universe (1st, 3rd)
  H_2O – 2nd most abundant after H_2

Solvents of life

Alternative solvents
HF, NH_3, CH_4, H_2

TABLE 1.3
Physical properties of potential biological solvents

Solvent	Formula	Liquid range (°C, at atmospheric pressure)	Molar density (mol/L)	Heat capacity (J/g K)	Heat of vaporization (J/g)	Dielectric constant	Density ratio: solid to liquid
Water	H_2O	0 to +100	55.5	4.2	41	80	0.9
Hydrogen fluoride	HF	−83 to +20	48.0	3.3	0.4	84	1.8
Ammonia	NH_3	−78 to −34	40.0	4.6	23	25	1.2
Methane	CH_4	−182 to −161	26.4	2.9	8	2	1.1
Hydrogen	H_2	−259 to −253	35.0	0.008	0.5	1	1.3

HF – similar physical properties to water,
but fluorine cosmologically rare (100,000 x less than oxygen)

Energy for life

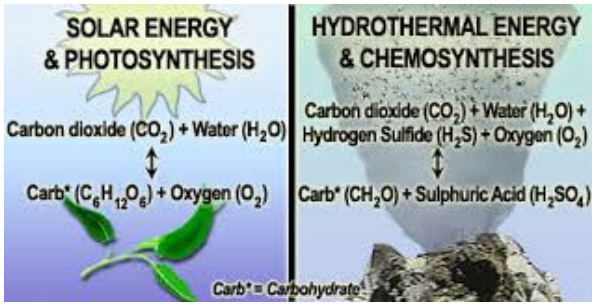
The energy of stars

Geothermal/chemical

Life creates order from disorder → need for energy

High energy photons absorbed by plants
→ nutrients absorbed by animals;
both patterns used to run metabolic processes

However, not the only available source of energy
→ Further lecture on extremophiles



Energy-producing oxidation reaction	Type of bacteria
$2H_2 + O_2 \rightarrow 2H_2O$	Hydrogen bacteria
$2H_2S \rightarrow S \rightarrow S_2O_3^{2-} \rightarrow SO_4^{2-}$	Colorless sulfur bacteria
$Fe^{2+} \rightarrow Fe^{3+}$	Iron bacteria
$NH_3 \rightarrow NO_2^- \rightarrow NO_3^-$	Nitrate, nitrite bacteria

Other constrains for the origin of life

Life requires a condensed medium → rocky solid planets with available solvent
not enough support on gas giant planets (Jupiter)

Life requires time to be formed → unstable environment (overheating, asteroids, supernovae) is detrimental