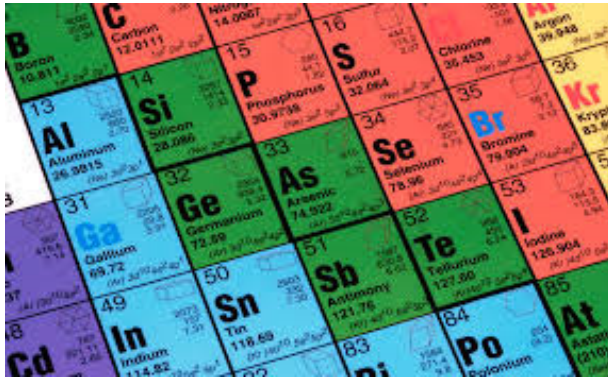


## *Constraints for the origin of life*

### *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

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Uut Ununtrium	114 Fl Flerovium	115 Uup Ununpentium	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium
			58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium	

## Elements of life

Periodic Table of Elements

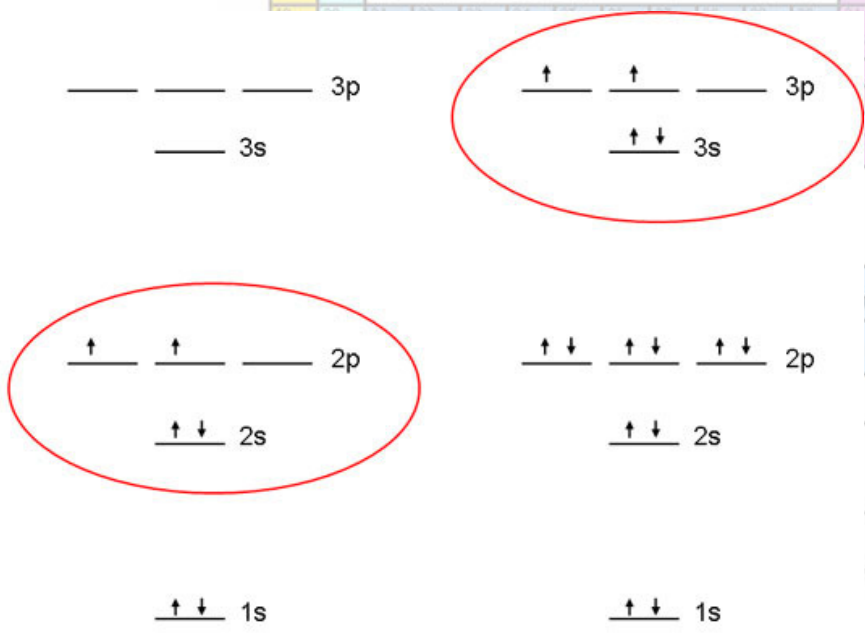
Group 4

1	2	3	4	5	6	7	8	9	10
1	H	He							
2	Li	Be	B	C	N	O	F	Ne	
3	Na	Mg	Al	Si	P	S	Cl	Ar	



Star Trek: The Devil in the Dark

Increasing Energy



**Carbon**  
6 total electrons  
4 valence shell electrons  
Can form 4 covalent bonds

**Silicon**  
14 total electrons  
4 valence shell electrons  
Can form 4 covalent bonds

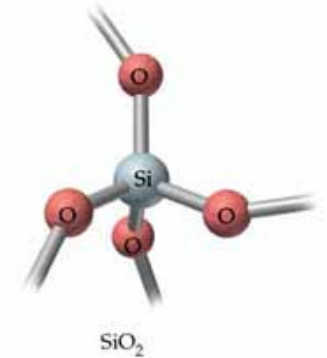
69	70	71
Tm	Yb	Lu
101	102	103

### Silicon:

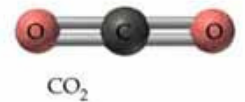
- can form multivalent structures
- Earth's surface – 2nd most abundant element

## Elements of life

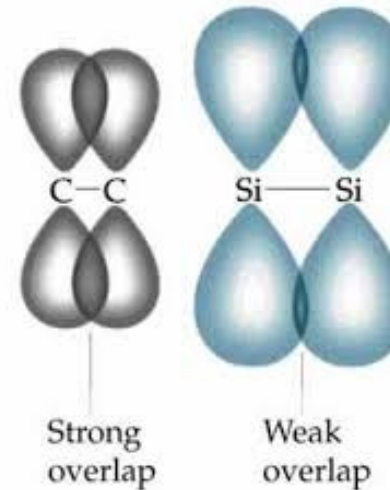
Si-O bond far more stable than Si-Si, Si-H or Si-N  
→ oxidation almost irreversible



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



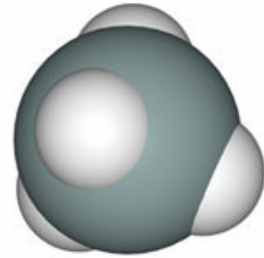
Multiple bonds of carbon are stabilized,  
silicon - destabilized



## *Elements of life*



**Methane, CH<sub>4</sub>**  
(flammable)  
(gas at room temperature)  
(stable)



**Silane, SiH<sub>4</sub>**  
(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 organisms based on water

## *Solvents of life*

### Advantages of water:

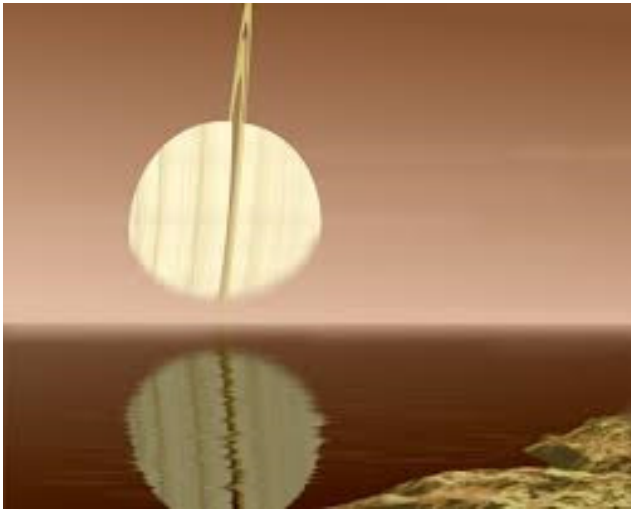
- ice floats → nutrient transport, temperature modulation
- High heat capacity 4.2 J/g\*<sup>0</sup>C (3x of rocks or metals),  
heat of vaporization 41 J/g  
→ both help to moderate Earth's climate
- Liquidity range – 100<sup>0</sup>C
- High dielectric constant – water is a very good solvent
- High molecular density 55.5 mol/L – „hydrophobic effect“:  
H<sub>2</sub>O forces dissolved molecules to organize to minimize the entropic cost
- H, O – very abundant in the Universe (1st, 3rd)  
H<sub>2</sub>O – 2nd most abundant after H<sub>2</sub>





## Solvents of life

Alternative solvents  
HF, NH<sub>3</sub>, CH<sub>4</sub>, H<sub>2</sub>



**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 <sub>2</sub> O	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 <sub>3</sub>	-78 to -34	40.0	4.6	23	25	1.2
Methane	CH <sub>4</sub>	-182 to -161	26.4	2.9	8	2	1.1
Hydrogen	H <sub>2</sub>	-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



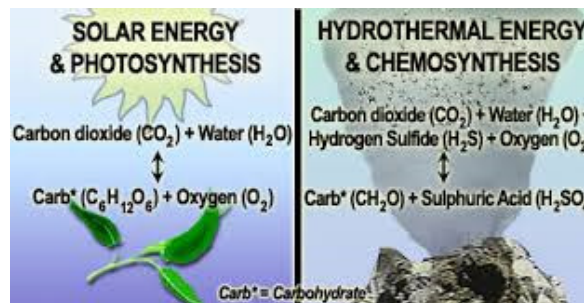
### Geothermal/chemical



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
$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$	Hydrogen bacteria
$2\text{H}_2\text{S} \rightarrow \text{S} \rightarrow \text{S}_2\text{O}_3^{2-} \rightarrow \text{SO}_4^{2-}$	Colorless sulfur bacteria
$\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$	Iron bacteria
$\text{NH}_3 \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^-$	Nitrate, nitrite bacteria

## *Other constraints 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

