BIOLOGICAL CHEMISTRY I (BIOL 157)

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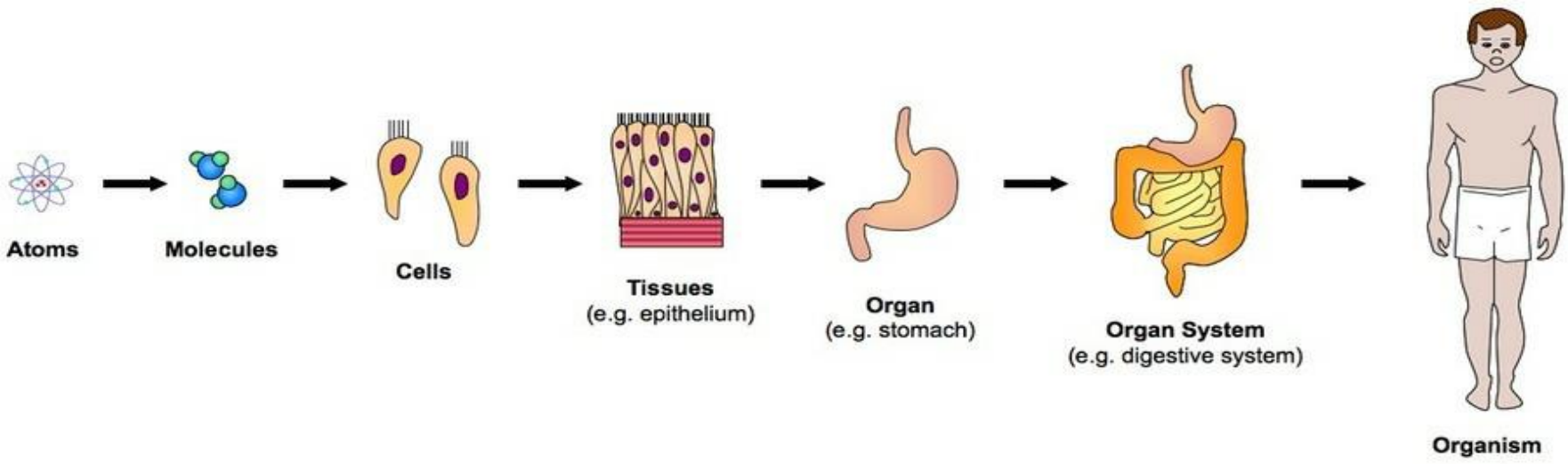
Lecture 1:
Elemental Composition of Cells

STUDY OBJECTIVES

- In this lecture, we will go through
  - How elements were formed: the origin of elements
  - The list of elements that make up living cells
  - Why some elements were incorporated in cells while others were excluded
  - Why carbon forms so many compounds.

Introduction

- All living cells and organisms are made up of elements which are intricately organized to form recognizable structures, characteristic of the cells or organisms.



Origin of Elements

- Elements are believed to have been formed through the following processes

  - Big bang
  - Fusion reactions in the stars
  - Artificial synthesis

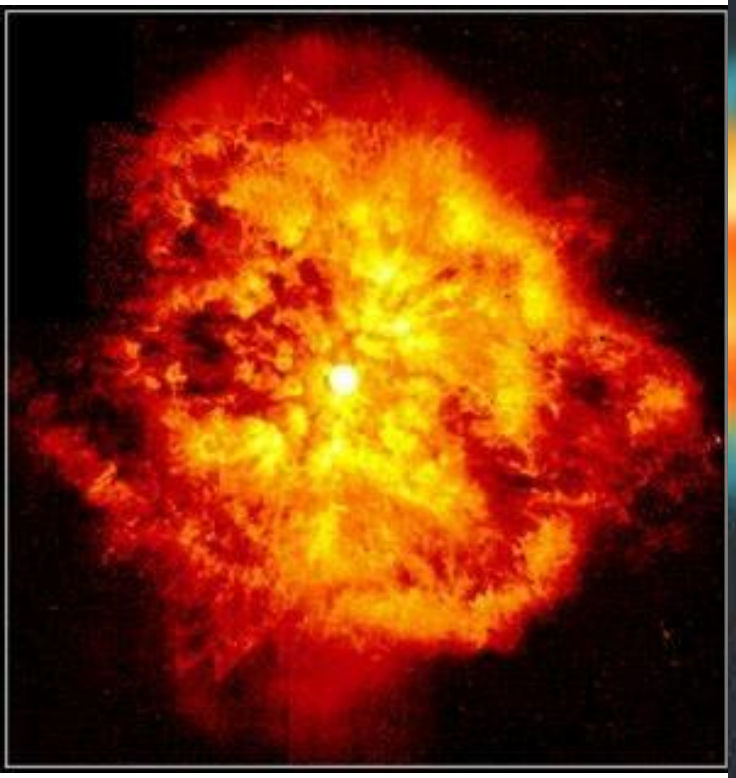
Forms naturally occurring elements

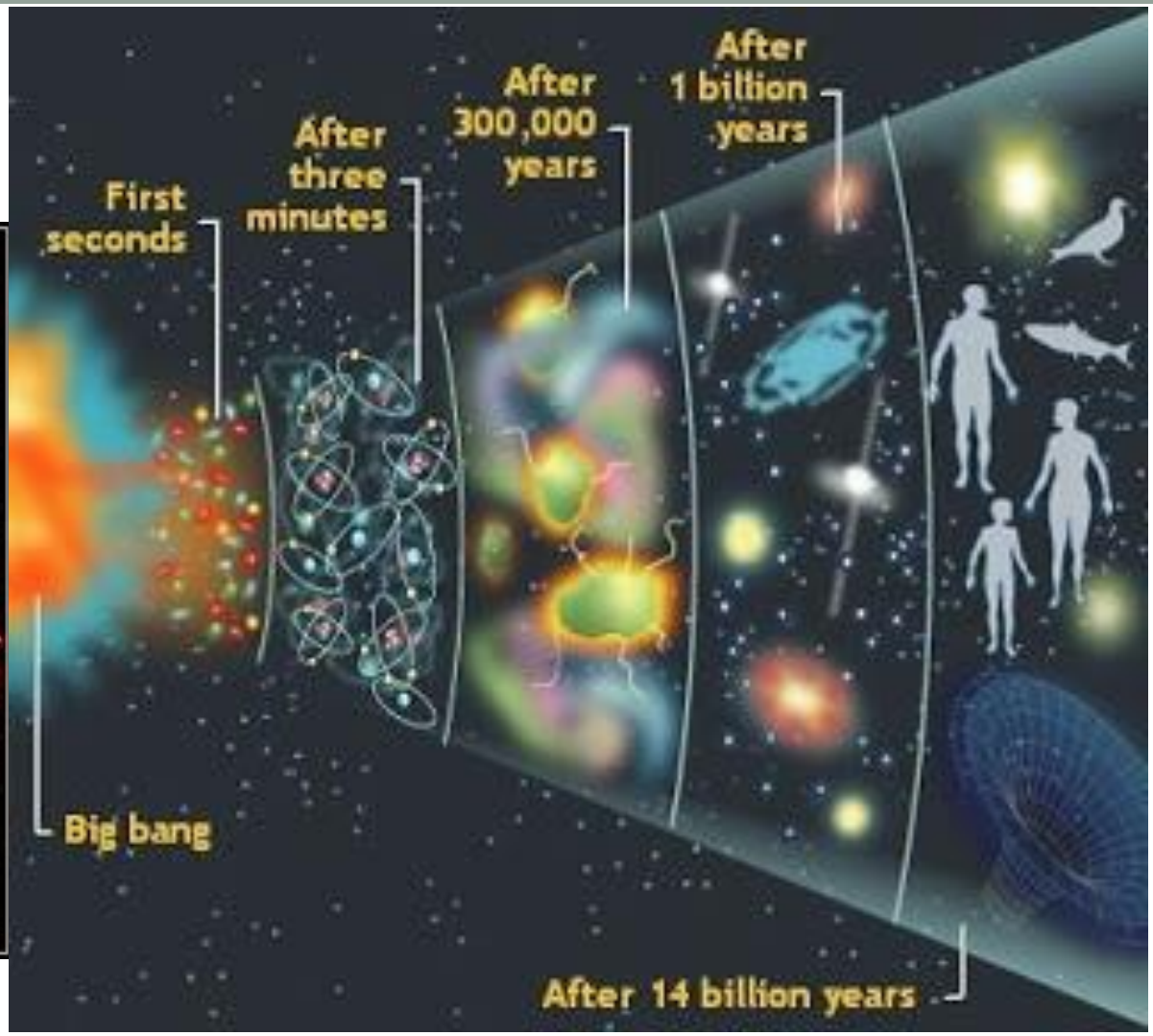
The Big Bang Theory

- Explosion of an infinitely hot and dense ball of primordial matter which led to the formation of Hydrogen and Helium.

- Gravitational forces brought together clouds of gas that eventually collapsed into vast galaxies made up of billions of stars.

- All the elements other than hydrogen and helium were formed in the centre of these stars, and these elements were released upon the explosion of some of these stars.



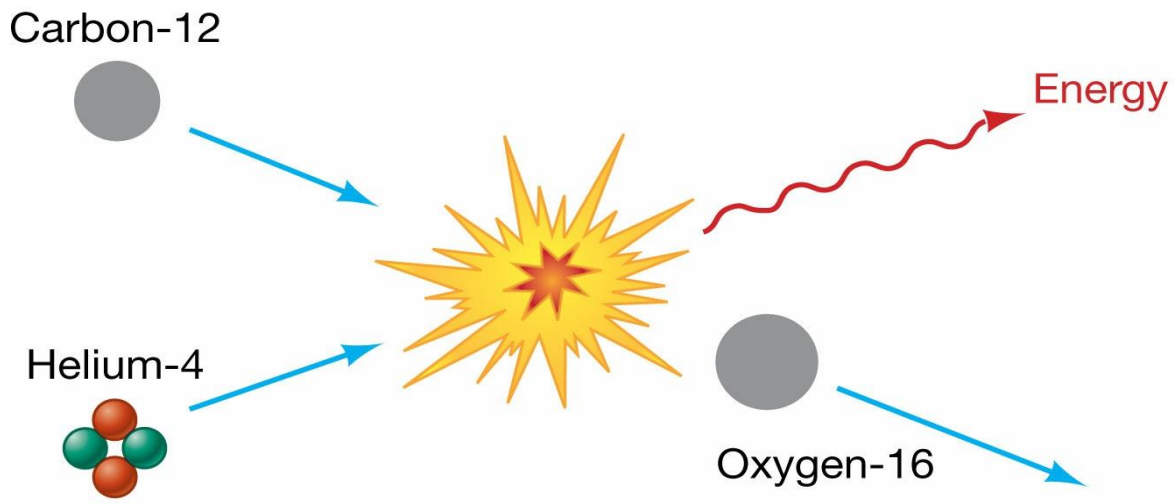

First seconds
After three minutes
After 300,000 years
After 1 billion years
Big bang
After 14 billion years

Fusion reactions in the star

- The very high temperatures and concentrations of reactants required for the formation of other elements can be achieved in the core of stars.
- The very high temperatures are required to overcome the electrostatic repulsion that exists between the positively charged nuclei, which must fuse.
- The fusion reactions radiate heat and light, so that a star is formed from the cloud of gas.
- At some point an enormous amount of energy is released that leads to the explosion of the star

- Most visible stars emit light created by the burning of hydrogen to form helium.
- The hydrogen that fuels most stars is eventually used up: in larger stars, the hydrogen gets exhausted much more rapidly in large stars like the sun.
- Upon the exhaustion of hydrogen, the core temperature of the star reduces, and the star begins to collapse.
- The heat released by the collapse causes the core temperature to rise to new levels until the ignition temperature for helium is reached.

- Two helium nuclei fuse to form beryllium (^{8}Be) nucleus which is unstable, and so does not survive for any length of time.
- Another helium nucleus can fuse with Be to form Carbon (^{12}C).
- Another fusion with helium forms oxygen (^{16}O).



- The largest atom that can form from the nuclear fusion reactions is iron.
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- Those atoms that are larger than Fe are formed when the neutrons resulting from the explosion of a star are captured by the nuclei of Fe atoms.

- The even-numbered elements are far more abundant than those with odd number mass numbers.

- The relative abundance of the elements is dependent on the mechanism of formation and the stability of the nuclei formed.

Laboratory synthesis of elements

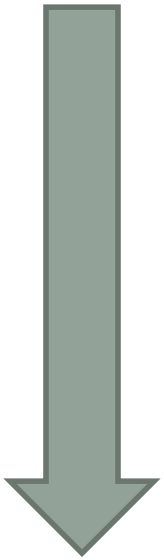
- New elements with atomic number beyond 92 (the transuranium elements) have been synthesized this way.

- In the process, high energy particles produced in cyclotrons are required to use with target nuclei.

- For example, Seaborg formed the synthetic element, Californium, by using a cyclotron to accelerate the nuclei of C-12 to fuse with U-238.

Elements utilized to form cells

- At present, there are over 117 elements, but less than a third of these elements are found in cells by natural selection.
- The percentage of atoms in the earth



Oxygen (48.86%)

Iron (18.84%)

Silicon (13.96%)

Magnesium (12.42%)

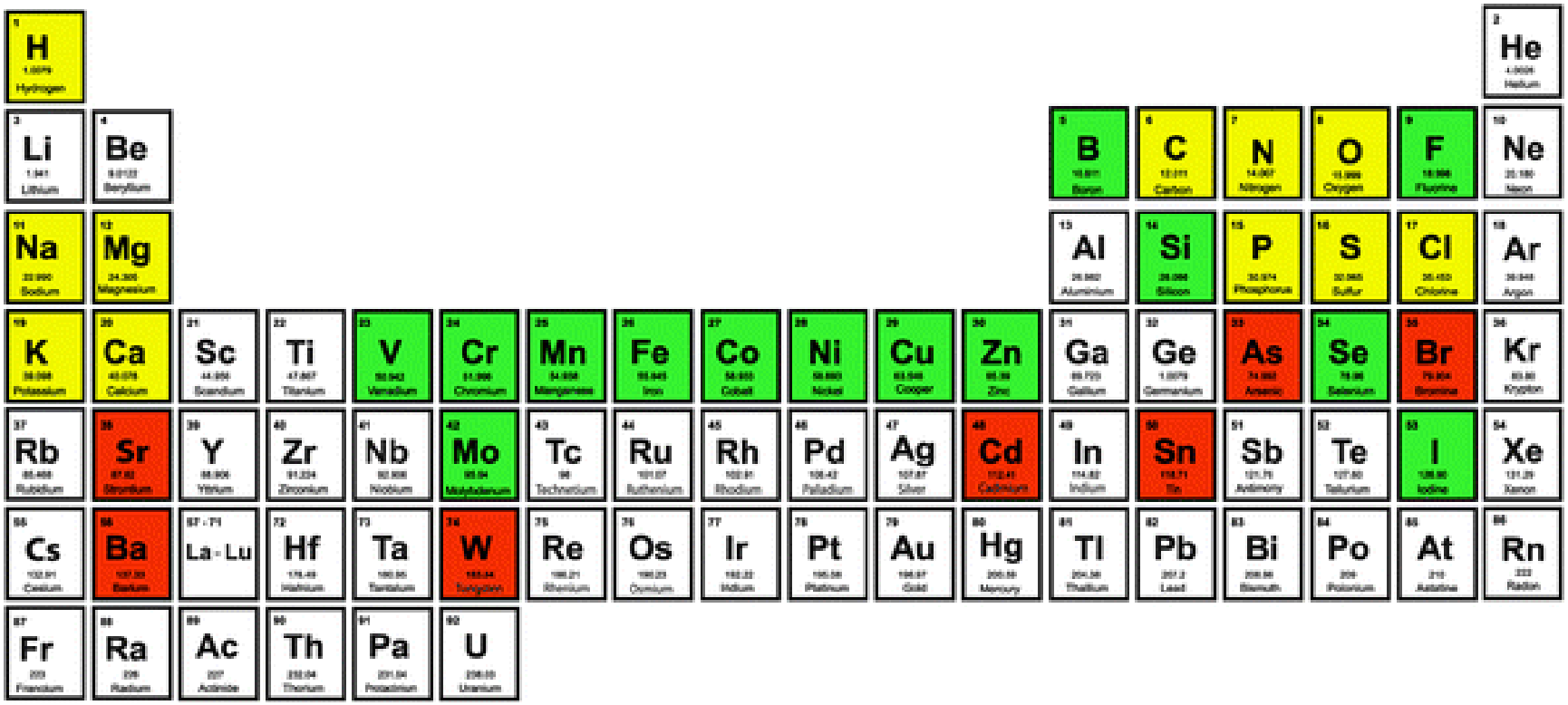
- The percentage of carbon is just about 0.10

- Furthermore, there is similarity in the concentration of the main ions in sea water and that of blood plasma: such ions like Cu^{2+}, Mg^{2+}, Ca^{2+}, Na^{+}, K^{+} etc.

- Almost every group on the periodic table has its representative in living cells (chemical democracy?)

- Major or Bulk elements which are carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur (CHONPS) – found in organic compounds of the cell.

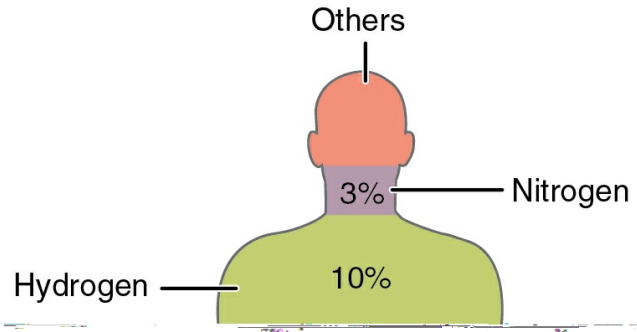
- Minor or Trace: Na, K, Mg, Ca, B, V, Mn, Fe, Co, Ni, Cu, Zn, Si, Se, Cl, Br and Cr – found in the fluids that bathe the cell.



Bulk biological elements

Trace elements believed to be essential for bacteria, plants or animals

Possibly essential trace elements for some species



Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5

Striking features of the major elements

- Majority are p-block elements
- They are able to form covalent bonds
- They are non-metals
- They have smaller atomic sizes/numbers
- They are neither too reactive nor inert.

Why is carbon so unique in its ability to form many compounds?

- Carbon has got an ideal size, neither too small nor too big and can form stable covalent bonds
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- Carbon is tetravalent
- It has the power of catenation
- Carbon is also able to form multiple bonds, either with itself or with other atoms.

Other elements with the capacity to make three or more bonds

Silicon

- Belongs to group IVA, thus tetravalent

- Has a larger atomic size, hence, Si – Si bonds (rare) are weak because two Silicon atoms cannot approach enough to overlap effectively
- Si-O bonds are so stable; chains of alternating Si and O atoms are essentially inert.

- Even though silicon is about 140 times more abundant than carbon in the earth crust, carbon has been preferentially incorporated in living cells.

Nitrogen

- It has five valence electrons when it forms N-N bond, hence, the bond energy will be low relative to that of C-C.
- When the N-N bond is formed, there remains a lone pair of electrons on the atoms.
- The repulsion between the lone pairs on the bonded nitrogen atoms will markedly reduce the bond energy of N-N bond.
- Therefore, we expect extended chains of nitrogen atoms to be very unstable.

Boron

- It has three valence electrons.
- Unlike nitrogen, it will form electron deficient compounds
- This will tend to limit the stability of boron compounds.

Reasons why other elements were not incorporated

- Artificial nature of some elements
- Inert nature of some elements
- Toxic nature of some elements
- Radioactivity of some elements

NB

- Even though some elements are non-essential to life, they may be valuable with regard to the quality of life.

  - Lithium compounds like Li_2CO_3 is for the treatment of schizophrenic conditions.
  - Platinum and gold complexes are anticancer and anti-arthritis preparations respectively.
  - Kaolin which contains aluminium has anti-diarrhoeal properties.

- Checkout this YouTube Videos on the Stellar Hypothesis
  - https://www.youtube.com/watch?v=_6JnZjwXs68&list=RD_6JnZjwXs68#t=539
  - https://www.youtube.com/watch?v=DXmX92H_2u8&list=RD_6JnZjwXs68&index=2
  - https://www.youtube.com/watch?v=sNDS0M4uMgw&index=3&list=RD_6JnZjwXs68
  - https://www.youtube.com/watch?v=OAZHvchPp0Q&index=4&list=RD_6JnZjwXs68
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