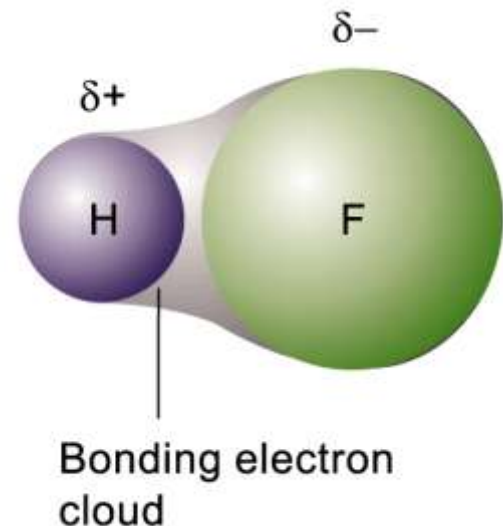


Hydrogen Bonding

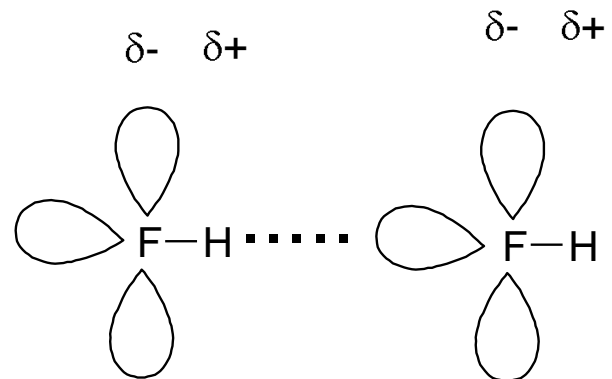
Hydrogen bonding

- When hydrogen is bonded to a highly electronegative atom (such as **nitrogen**, **oxygen**, **fluorine**), the bonding electron pair is drawn towards the **electronegative** atom



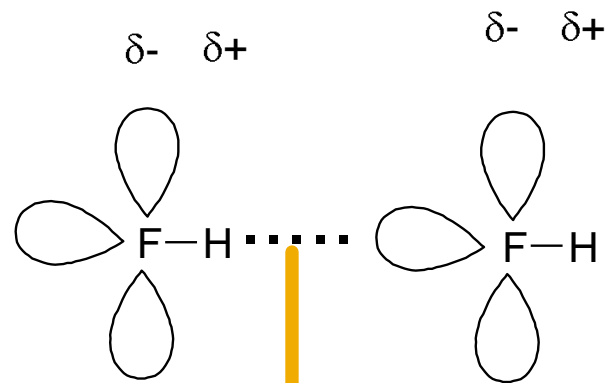
Hydrogen bonding

- Hydrogen has no **inner shell** electron and is very small in size, the positive charge density developed is **high**
- The nucleus of hydrogen atom is exposed to attraction by nearby electron cloud, a **lone pair electrons** on the electronegative atom



Hydrogen bonding

- Definition:
 - Electrostatic **attraction** between **hydrogen** atoms bonded to small, strongly **electronegative** atoms (N, O and F) and the **lone pair electrons** on these electronegative atoms



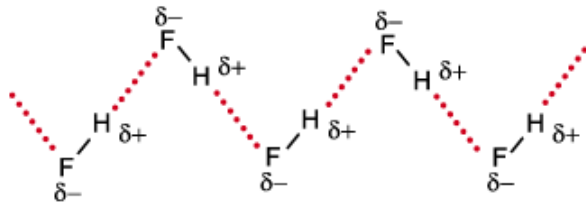
Hydrogen bonding

Hydrogen Bonding

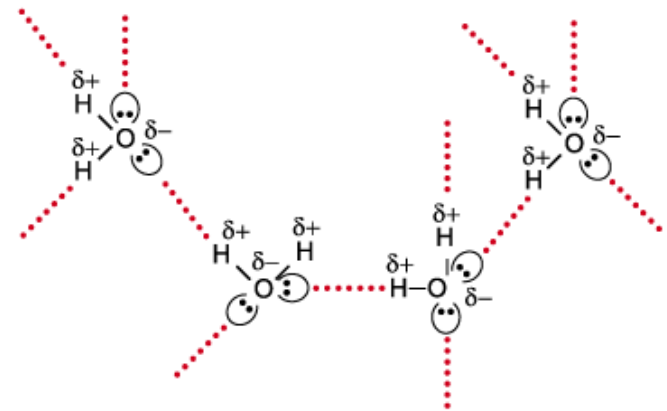
- Essential requirements for formation of hydrogen bond:
 - A hydrogen atom **must be directly bonded to a highly electronegative** atom (e.g. F, O and N)
 - An **unbonded pair of electrons (lone pair electrons)** is presented on the electronegative atom

Hydrogen bonding

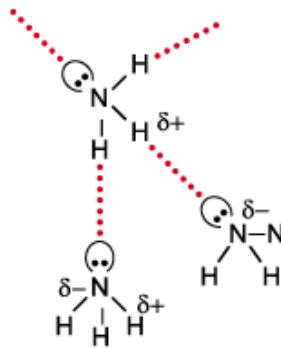
■ Examples



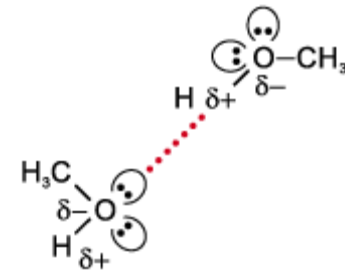
Hydrogen fluoride (HF)



Water (H₂O)



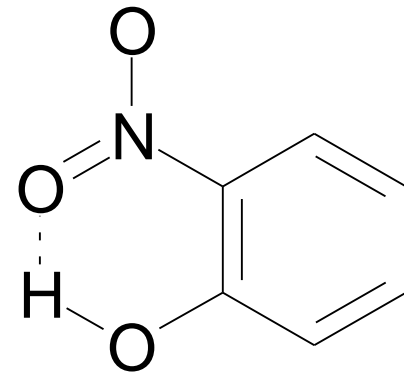
Ammonia (NH₃)



Methanol (CH₃OH)

Special Notes

- Intermolecular hydrogen bond:
 - Hydrogen bond formed **between two molecules**
- Intramolecular hydrogen bond:
 - Hydrogen bond formed **between two different atoms in the same molecule**
- Intermolecular hydrogen bond is stronger than van der Waals' forces

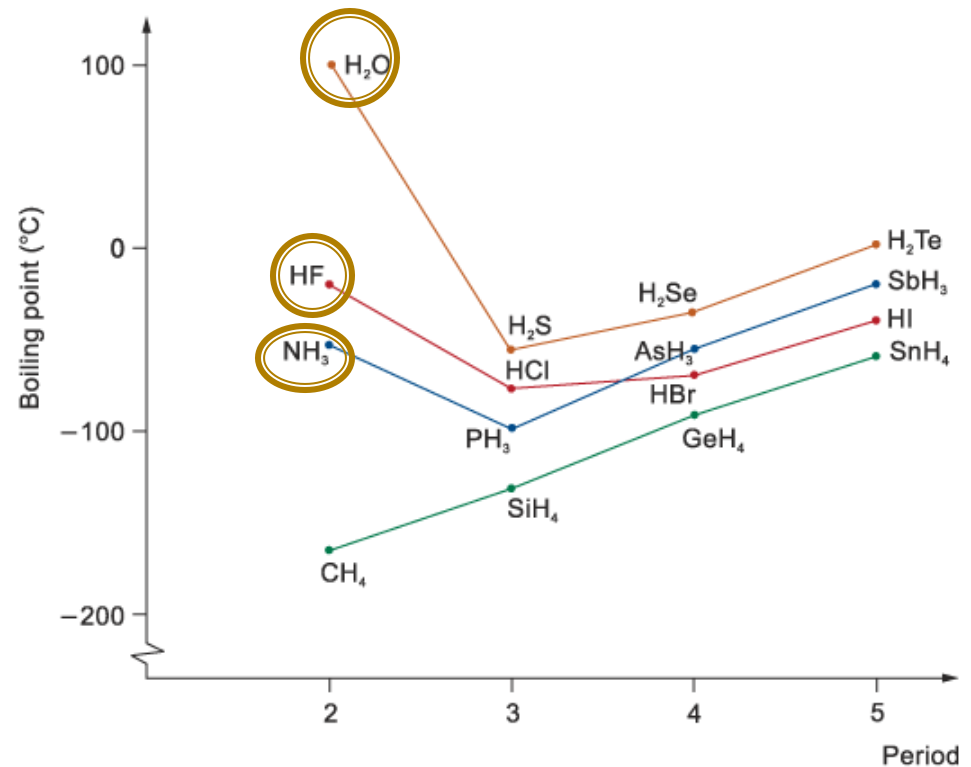


Importance of Hydrogen Bonding in Physical Phenomena

- Anomalous Properties of the second period hydrides

Questions:

1. Why do H_2O , NH_3 and HF have abnormally high boiling point?
2. Explain why the order of boiling point is $\text{H}_2\text{O} > \text{HF} > \text{NH}_3$.



Q1: Why do NH_3 , H_2O and HF have abnormally high boiling point?

- Explanation:
 - N, O and F are highly **electronegative** atoms
 - Formation of **intermolecular hydrogen bonds** in their hydrides.
 - Intermolecular hydrogen bonds are much **stronger** than van der Waals' forces
 - More energy is needed to break the hydrogen bonds in NH_3 , H_2O and HF

Q2: Explain why the order of boiling point is $\text{H}_2\text{O} > \text{HF} > \text{NH}_3$

■ Explanation

	No. of H atoms available for hydrogen bond formation	No. of lone pair electrons available	No. of hydrogen bonds can form per molecule
NH_3	3	1	1
H_2O	2	2	2
HF	1	3	1

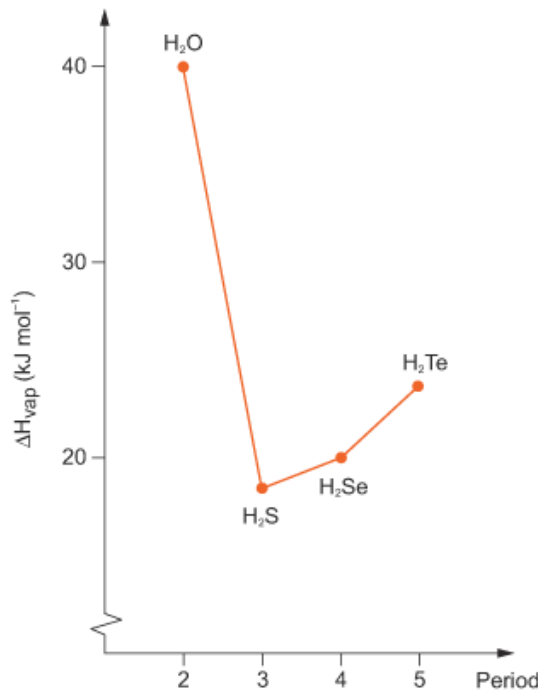
- H_2O can form **2** hydrogen bond per molecule
- NH_3 and HF can form only **1** hydrogen bond per molecule
- The boiling point of H_2O is higher than NH_3 and HF

Q2: Explain why the order of boiling point is $\text{H}_2\text{O} > \text{HF} > \text{NH}_3$

- Comparing N and F, **F** is more electronegative
- The intermolecular hydrogen bond formed between **HF** molecules is stronger than **NH₃**
- HF has a higher boiling point than NH_3

Importance of Hydrogen Bonding in Physical Phenomena

- Enthalpy of vaporization
 - Energy required to vaporized **one mole** of liquid



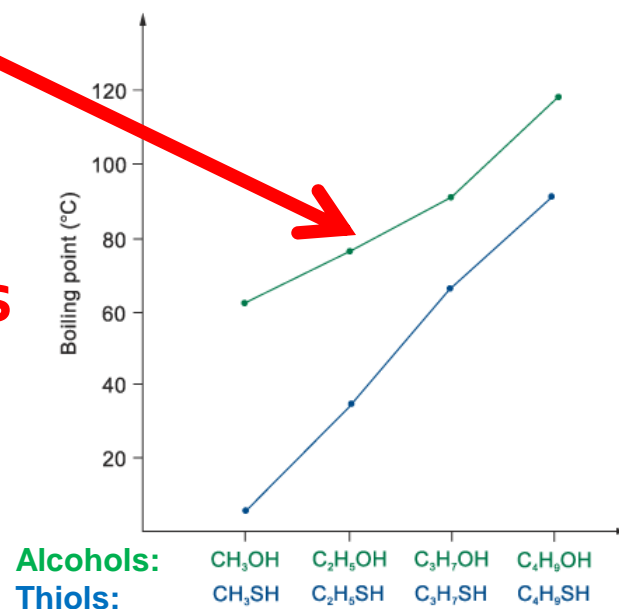
Question:
Explain why H₂O has the largest enthalpy of vaporization than H₂S, H₂Se and H₂Te.

- Explanation:
 - In H_2O , there are **intermolecular hydrogen bonds** between molecules
 - However, in H_2S , H_2Se and H_2Te , the interaction between molecules is **dipole-dipole interactions**
 - The strength of hydrogen bond is **stronger** than **dipole-dipole interactions**
 - To break the hydrogen bonds, **more** energy is required
 - H_2O has the largest enthalpy change of vaporization

Importance of Hydrogen Bonding in Physical Phenomena

■ Boiling Point and Solubility of Alcohols

- The boiling points of alcohols are higher than the thiols because there are **intermolecular hydrogen bonds** between alcohol molecules, but only **dipole-dipole interactions** between molecules of thiols



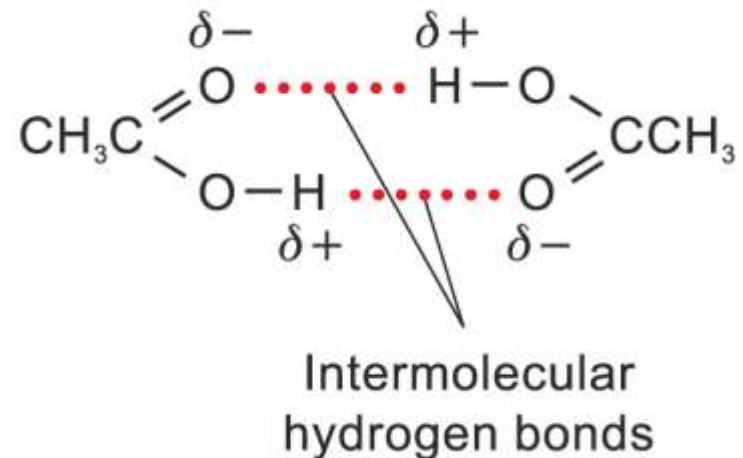
- Alcohols of low molecular masses are **soluble** in water because they can form **intermolecular hydrogen bonds** with water molecules

Importance of Hydrogen Bonding in Physical Phenomena

- Dimerization of Carboxylic Acid
 - It happens when carboxylic acids are dissolved in **non-polar** solvents or in **vapour** state

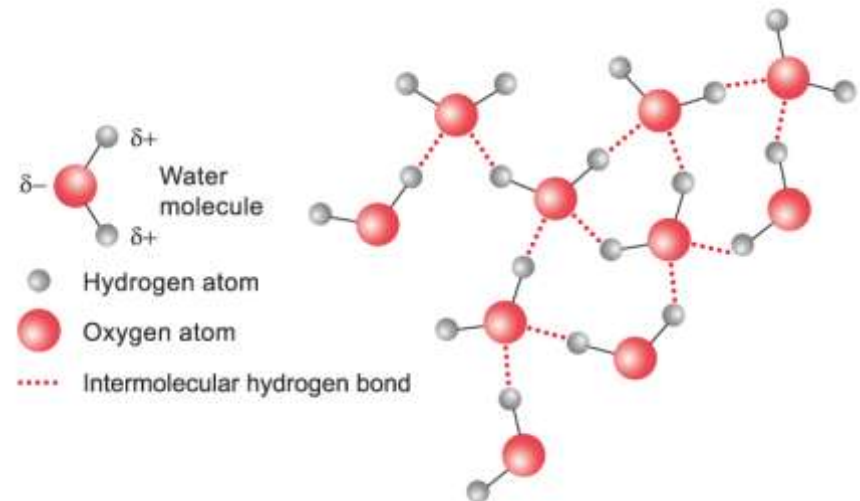
E.g. Ethanoic acid (CH_3COOH)

- Ethanoic acid molecules form **dimers** through the formation of **intermolecular hydrogen bonds**



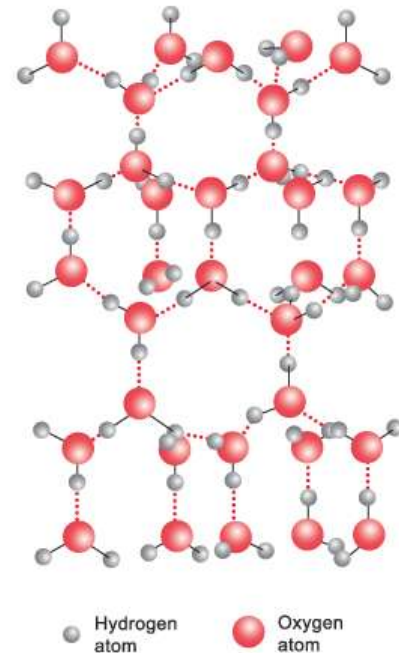
Importance of Hydrogen Bonding in Biochemistry

- Hydrogen bonding in ice and water
 - **Intermolecular hydrogen bonds** exist in both water and ice
 - In water, molecules are in constant motion. **Intermolecular hydrogen bonds** are formed and broken continuously.
 - The arrangement of molecules is **random**



- In ice, the molecular motion is **restricted**. The molecules are arranged in a way to form the **maximum** number of hydrogen bonds

- Each H₂O molecule is **tetrahedrally** bonded to 4 other H₂O molecules by hydrogen bonds
- Creates an **open structure** and gives rise to a **lower** density of ice than water
- Insulates the water below and prevents complet solidification → keep fish survive in polar regions

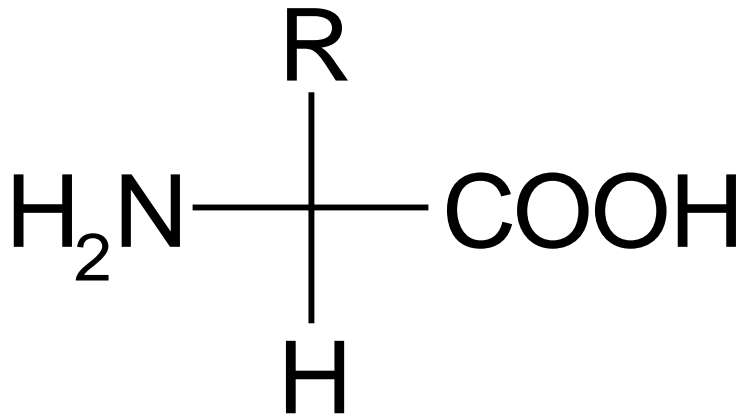


- Youtube video clip
(Why do ice float?)

<http://www.youtube.com/watch?v=UE1-iBJja4Y&feature=related>

Importance of Hydrogen Bonding in Biochemistry

- Hydrogen Bonding in Proteins
 - The building block of protein is **amino acid**

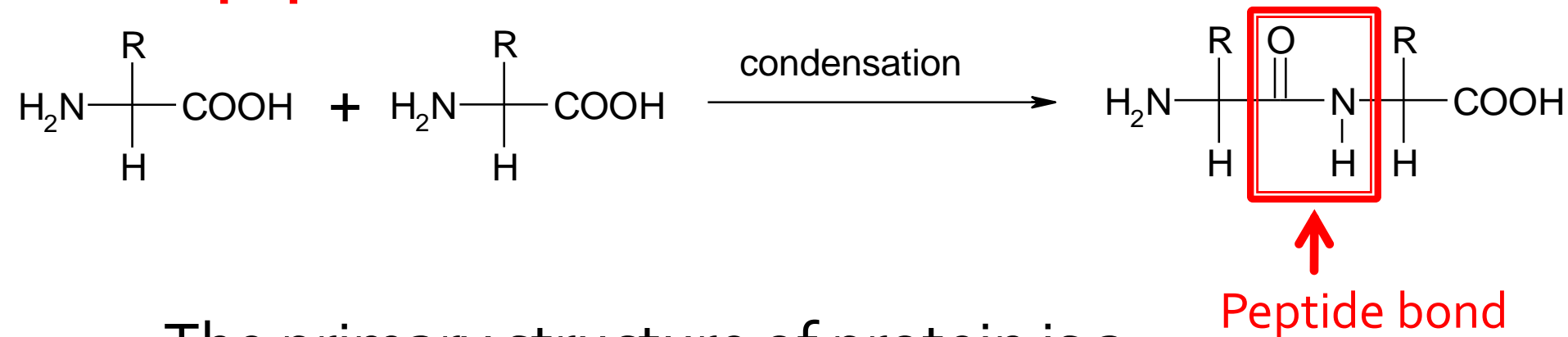


R: a hydrogen atom
or an alkyl group

NH₂: amine group

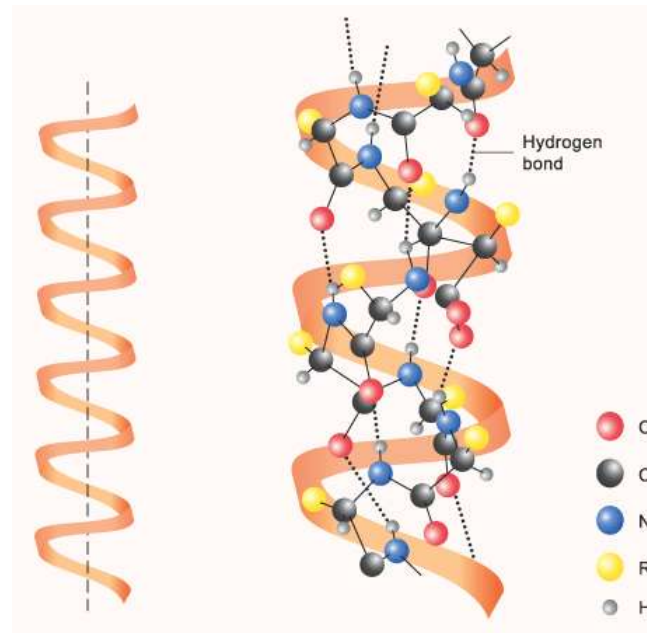
COOH: carboxylic
acid group

- The combination of two amino acids will form a **dipeptide**



- The primary structure of protein is a **polypeptide**, which is a polymer of amino acids
- Polypeptide chains form a helical structure between N-H and C=O groups
 - Creates the secondary structure of protein

- Secondary Structure of Protein

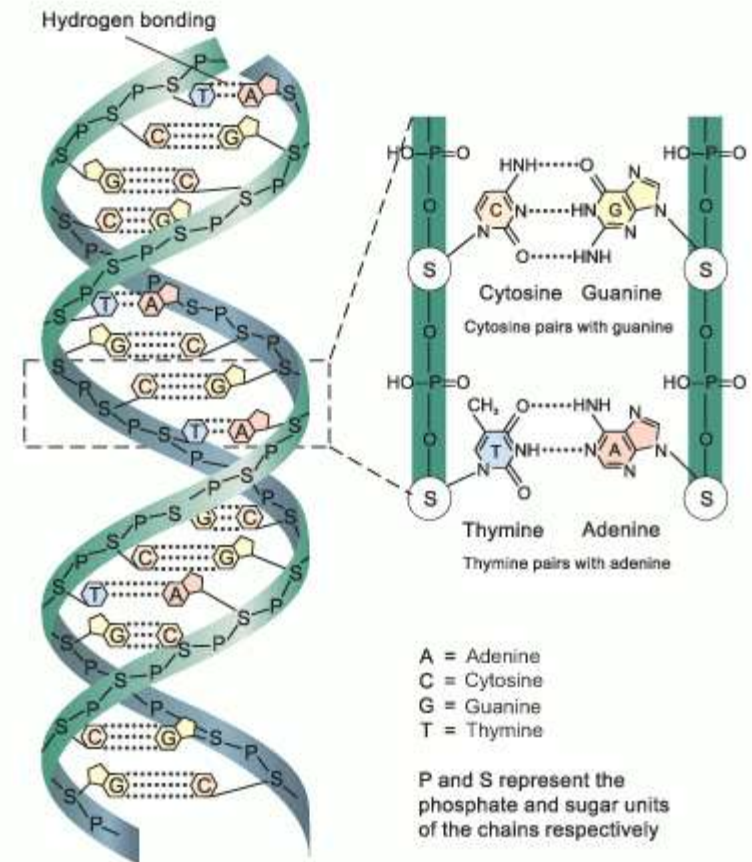


- Youtube clip:

<http://www.youtube.com/watch?v=lijQ3a8yUYQ>

- Hydrogen Bonding in DNA
 - DNA stands for Deoxyribose Nucleic Acid
 - DNA contains genetic information
 - Consists of **2** macromolecular strands spiralling around each other in the form of a **double helix**

- Structure of DNA
 - The building block of DNA is nucleotide
 - Nucleotide:
 - A sugar
 - A phosphoric acid unit
 - A nitrogen-containing heterocyclic base (Adenine, Thymine, Cytosine, Guanine)
 - Photo:



http://en.wikipedia.org/wiki/File:Nucleotides_1.svg

- The two nucleic acid chains are held together by hydrogen bonds, that are formed between specific pairs of bases on the chains
- Hydrogen bonds of base pairs in DNA:
 - Adenine – Thymine
 - Cytosine – Guanine
- Structure of DNA

<http://www.youtube.com/watch?v=qy8dk5iS1f>

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