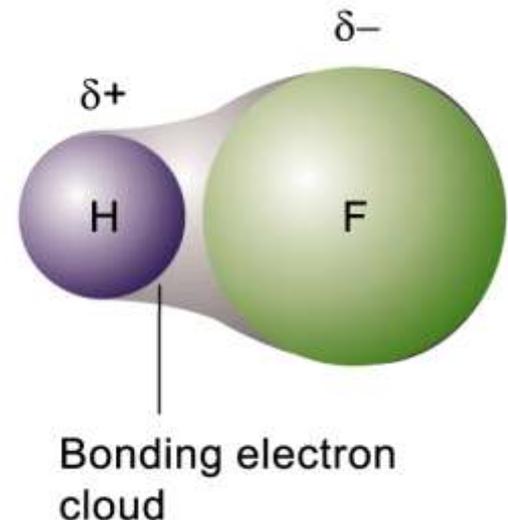


# Hydrogen Bonding

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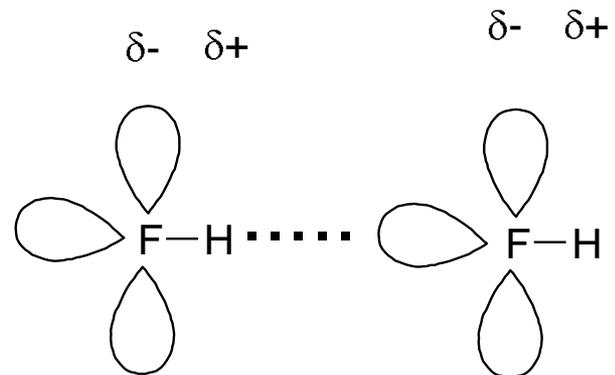
# Hydrogen bonding

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



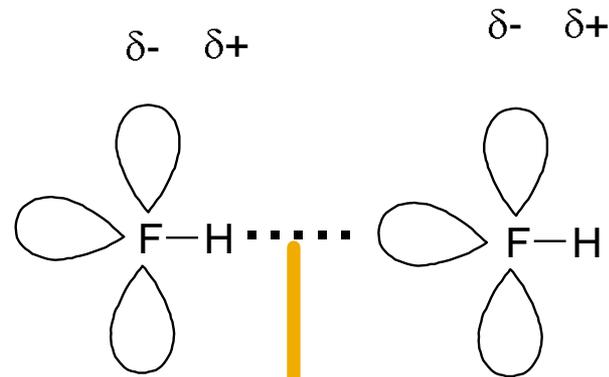
# Hydrogen bonding

- 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



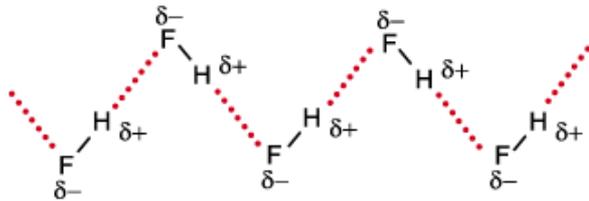
Hydrogen bonding

# Hydrogen Bonding

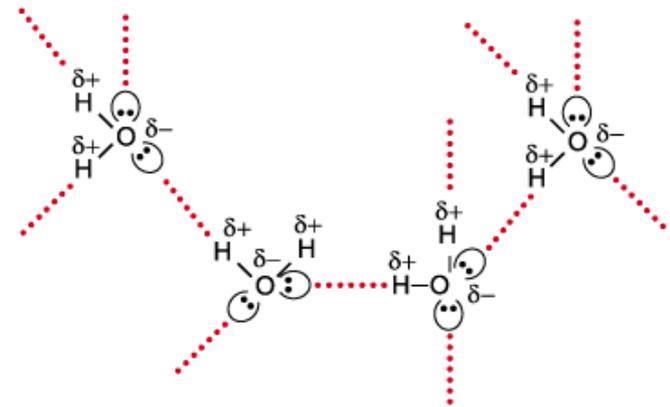
- Essential requirements for formation of hydrogen bond:
  - A hydrogen atom **must be directly bonded to a highly electronegative** atom (e.g. F, O and N)
  - An **unbonded pair of electrons (lone pair electrons)** is presented on the electronegative atom

# Hydrogen bonding

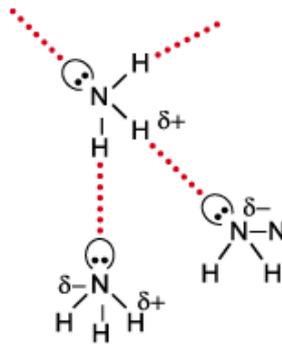
## ■ Examples



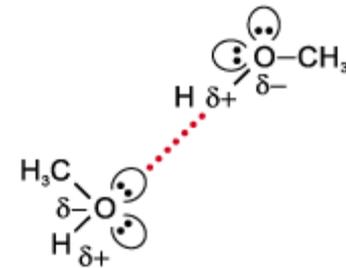
Hydrogen fluoride (HF)



Water (H<sub>2</sub>O)



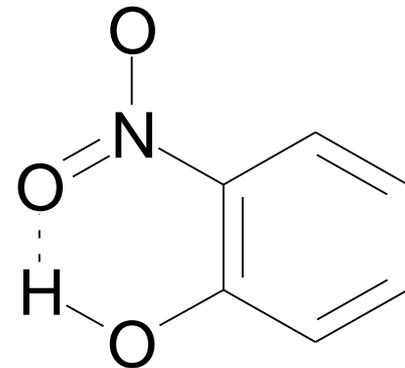
Ammonia (NH<sub>3</sub>)



Methanol (CH<sub>3</sub>OH)

# 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

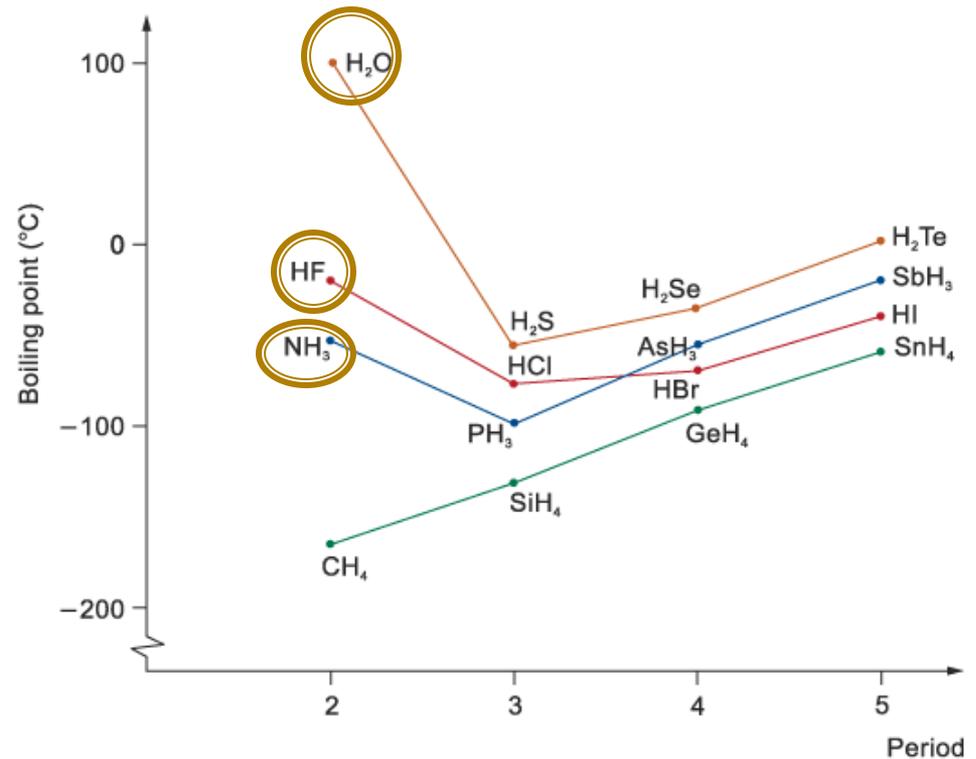


# Importance of Hydrogen Bonding in Physical Phenomena

- Anomalous Properties of the second period hydrides

Questions:

1. Why do  $\text{H}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{HF}$  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 $\text{NH}_3$ , $\text{H}_2\text{O}$ and $\text{HF}$ 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  $\text{NH}_3$ ,  $\text{H}_2\text{O}$  and  $\text{HF}$

# 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
$\text{NH}_3$	3	1	1
$\text{H}_2\text{O}$	2	2	2
HF	1	3	1

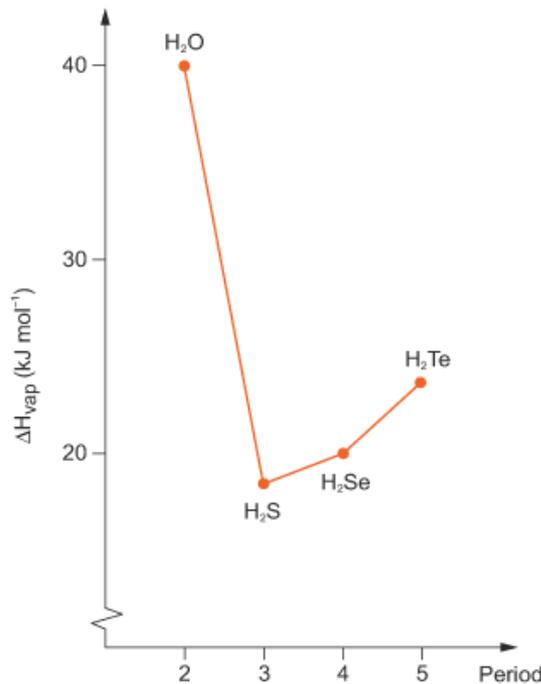
- $\text{H}_2\text{O}$  can form **2** hydrogen bond per molecule
- $\text{NH}_3$  and HF can form only **1** hydrogen bond per molecule
- The boiling point of  $\text{H}_2\text{O}$  is higher than  $\text{NH}_3$  and HF

## 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 **NH<sub>3</sub>**
- HF has a higher boiling point than  $\text{NH}_3$

# Importance of Hydrogen Bonding in Physical Phenomena

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



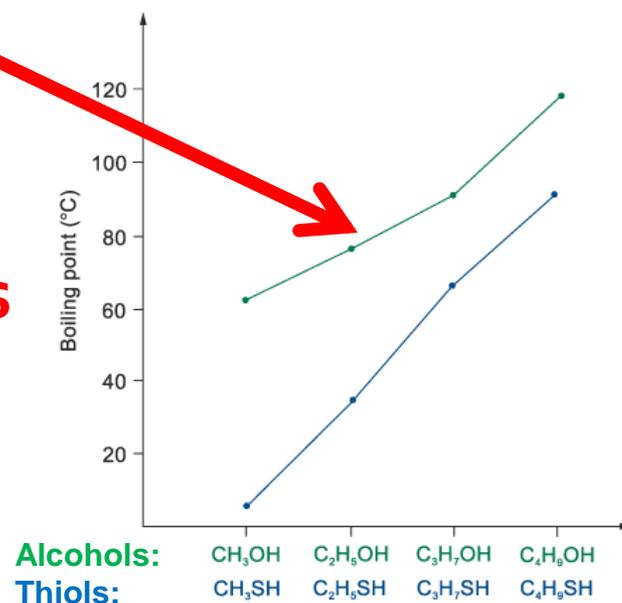
**Question:**  
Explain why H<sub>2</sub>O has the largest enthalpy of vaporization than H<sub>2</sub>S, H<sub>2</sub>Se and H<sub>2</sub>Te.

- Explanation:
  - In  $\text{H}_2\text{O}$ , there are **intermolecular hydrogen bonds** between molecules
  - However, in  $\text{H}_2\text{S}$ ,  $\text{H}_2\text{Se}$  and  $\text{H}_2\text{Te}$ , 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
  - $\text{H}_2\text{O}$  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



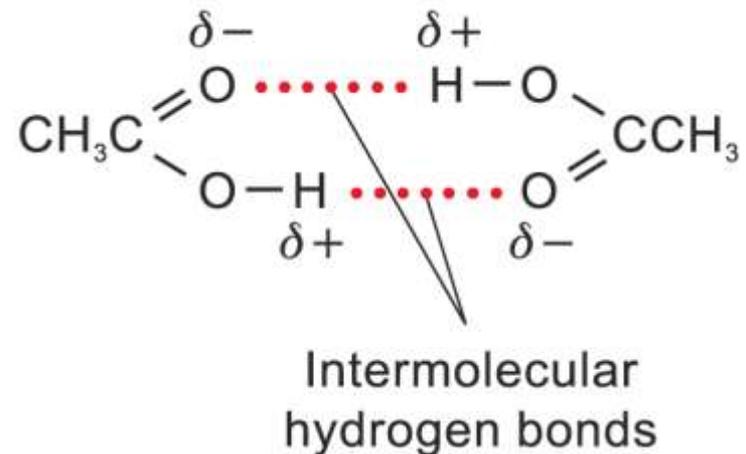
- Alcohols of low molecular masses are **soluble** in water because they can form **intermolecular hydrogen bonds** with water molecules

# 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

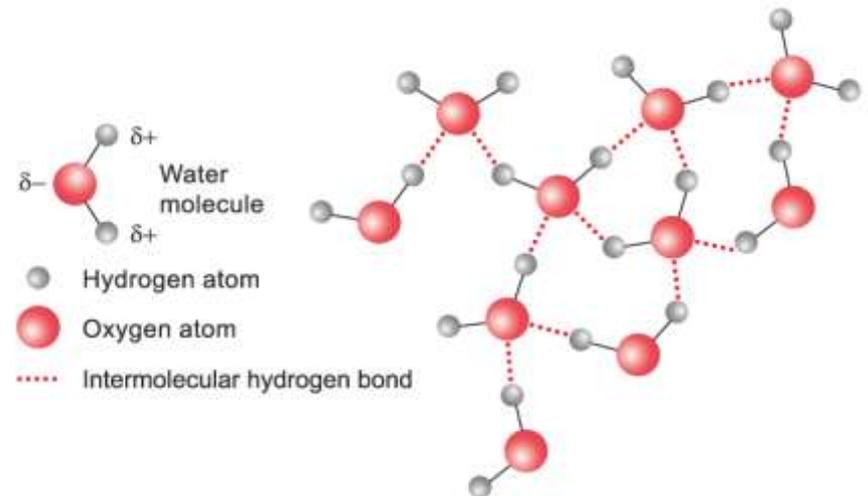
E.g. Ethanoic acid ( $\text{CH}_3\text{COOH}$ )

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



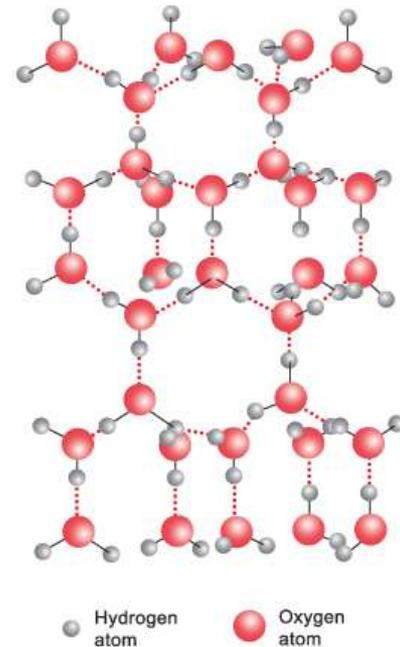
# Importance of Hydrogen Bonding in Biochemistry

- 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 H<sub>2</sub>O molecule is **tetrahedrally** bonded to 4 other H<sub>2</sub>O 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

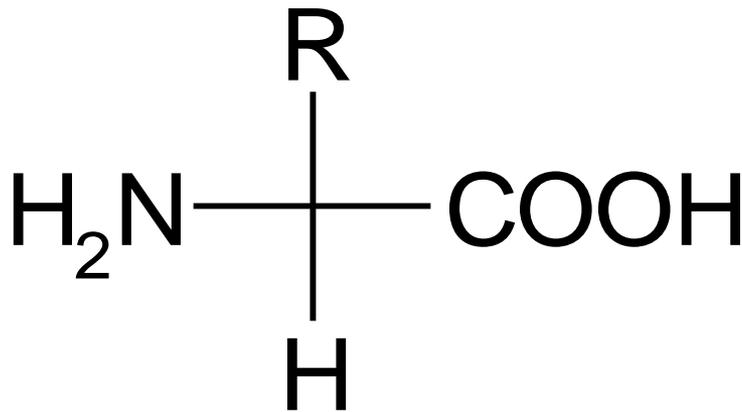


- Youtube video clip  
(Why do ice float?)

<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**

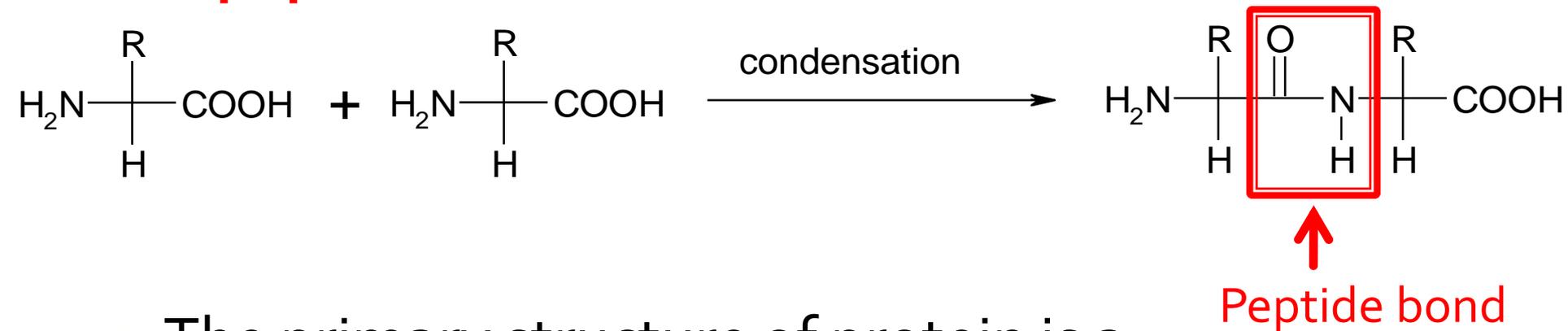


R: a hydrogen atom  
or an alkyl group

NH<sub>2</sub>: amine group

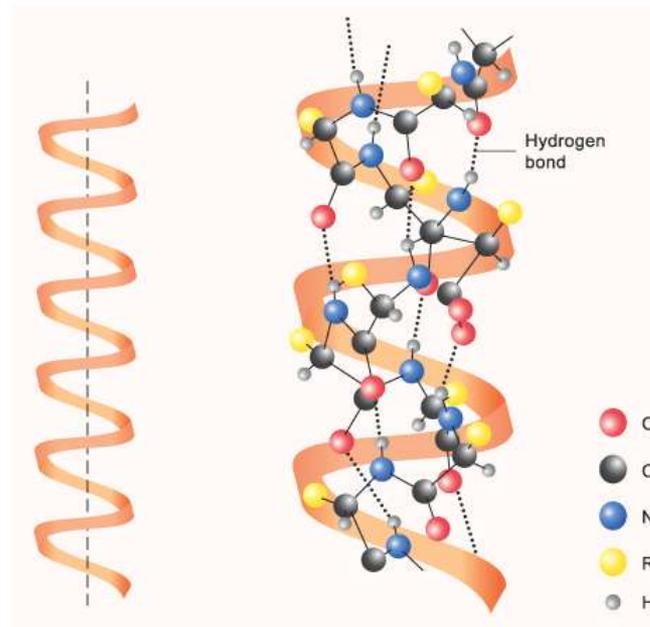
COOH: carboxylic  
acid group

- 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

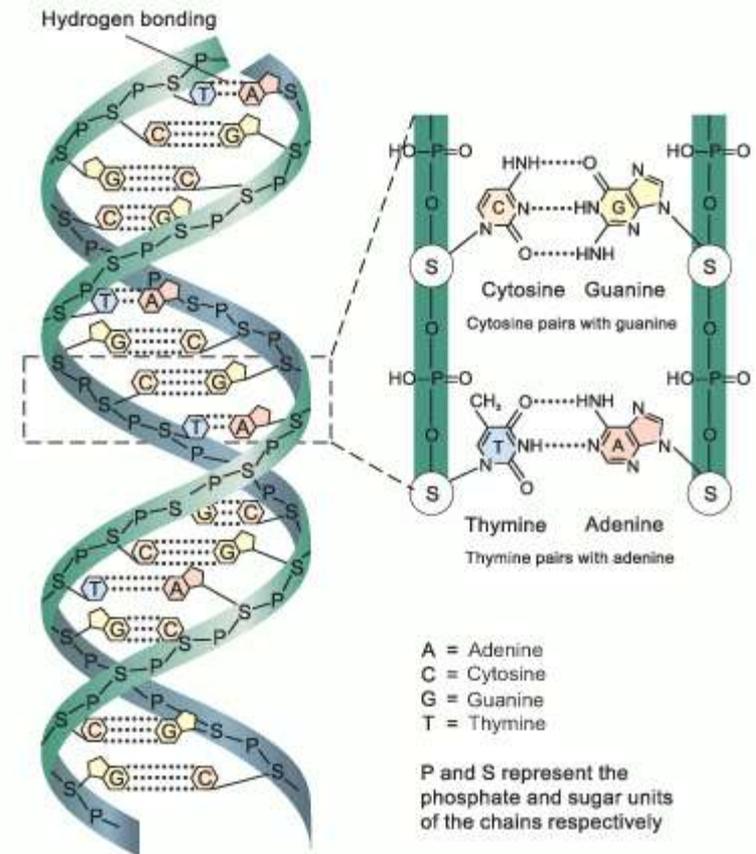


- Youtube clip:

<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](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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