CHEM 191
Chemical Reactions in Aqueous Solution

Module 1 Lecture 9

Molecules in Biological Environments

1

Module 1 Lecture 9

Learning objectives

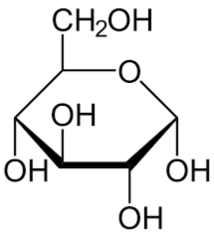
- Recognise the structural features of a molecule which makes it polar or non-polar
- Understand how water solvates ions and polar molecules
- Understand how the pH of the solution determines the ionisation state of a molecule
- Understand how non-polar molecules behave in water
- Understand the structure and fundamental roles of membranes

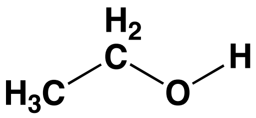
2

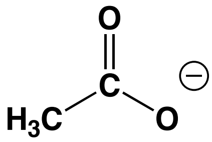
Polar vs non-polar molecules

A **polar molecule** is one which forms 'favourable' interactions with water molecules. These would include molecules with polar bonds and molecules with charged regions. Polar molecules are also called **hydrophilic** (water loving)

eg







Water is itself a polar molecule – "like dissolves like"

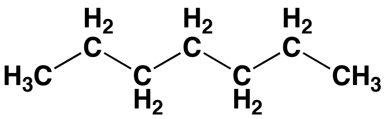
Useful fact to remember alcohols do **NOT** ionise

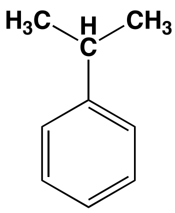
3

Polar vs non-polar molecules

A non-polar molecule is one which does not have any polar bonds or charged parts.

eg





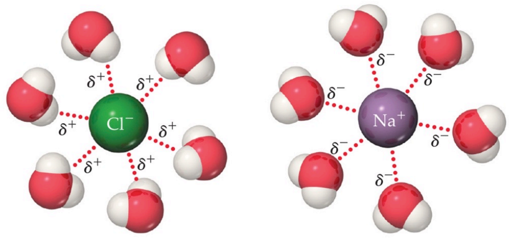
Non-polar molecules will not dissolve in water but will dissolve in other non-polar solvents. Non-polar molecules are also called **hydrophobic** (water hating).

4

Water is a polar molecule

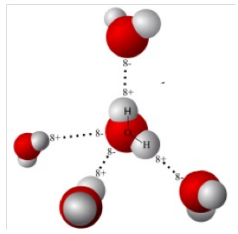
Water - principal component of most cells

Polar nature of water enables electrostatic interaction with other charged molecules
- **hydration**



Water molecules participate in **Hydrogen Bonding** to themselves

Hydrogen Bonding is a very powerful driving force

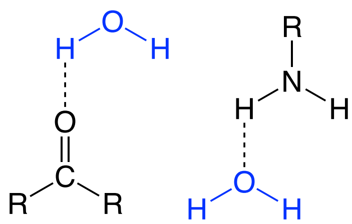


5

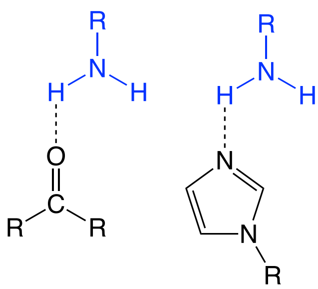
Hydrogen Bonding

Various types of hydrogen bonding are found in biological molecules.

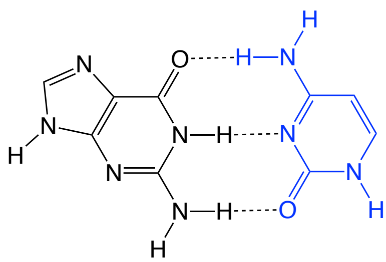
Solvation by water



Within proteins



Within DNA and RNA



6

Ionisable Functional Groups

Many molecules (or parts of molecules – **functional groups**) found in biological systems can exist in both charged and uncharged forms.

For example CH_3COOH and CH_3COO^-

The **ionisation status** is influenced by

1. The pH of the aqueous environment
2. The propensity of particular ionisable functional groups to ionise (fundamental physical property) – ie the pK_a

7

Ionisable Functional Groups

Recall the Henderson-Hasslebach equation for buffers – when the concentrations of the weak acid and the conjugate base are the same, pH = pK_a

$$\text{pH} = 4.74 + \log\frac{(0.100)}{(0.100)} = 4.74$$

Another way to think about this is that

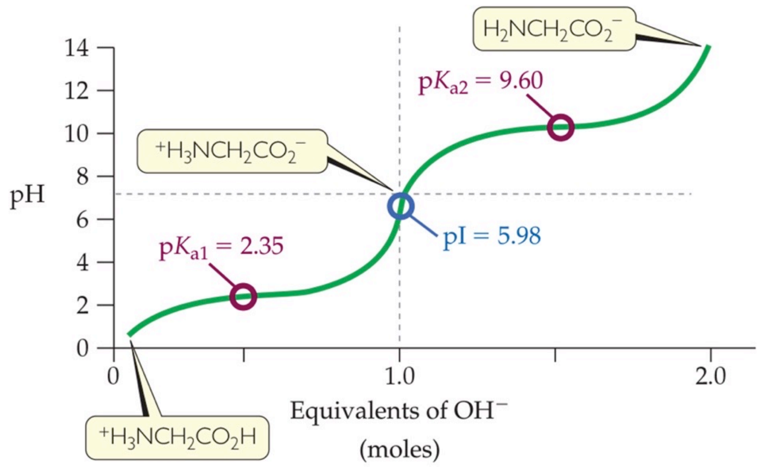
pK_a = pH of environment in which half (50%) of the functional groups of the molecule are ionised

>1 pH unit *below* pK_a ~90% molecules *protonated*

>1 pH unit *above* pK_a ~90% molecules *deprotonated*

8

Titration curve for glycine

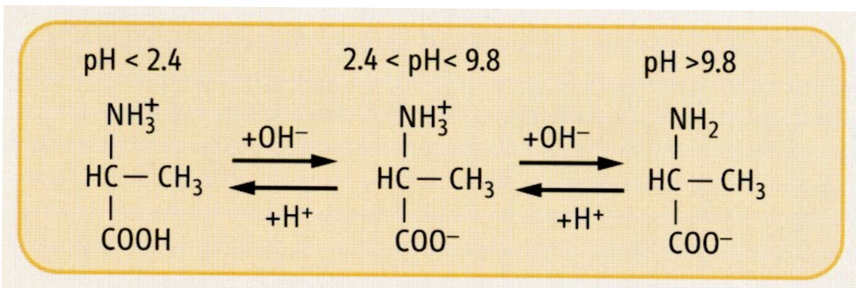


◄ **FIGURE 29.18 Titration of glycine with aqueous NaOH solution.** pK_{a1} relates to the pK_a of the carboxylic acid, while pK_{a2} relates to the pK_a of the ammonium ion.

9

Ionisable Functional Groups – amino acids

Ionisation possibilities for an amino acid eg alanine



$pK_{a\,1} = 2.4$
$pK_{a\,2} = 9.8$

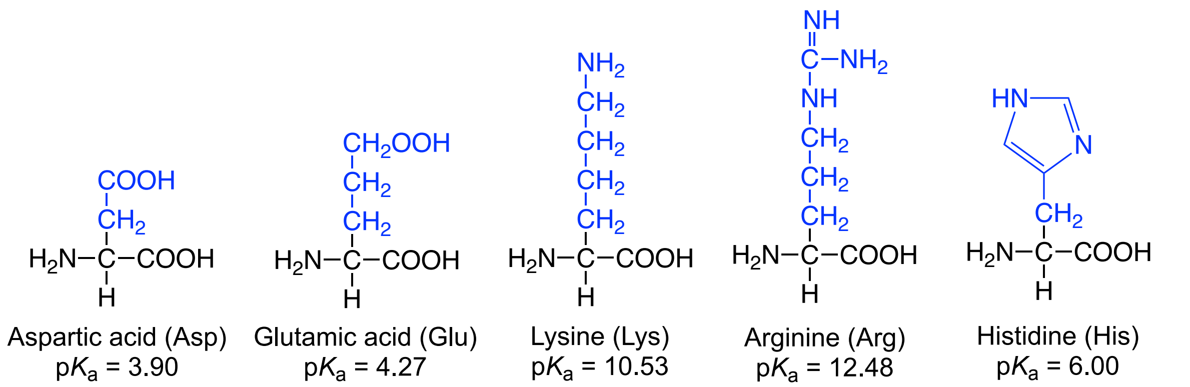
An α-amino group is *protonated* when charged (+ve)

An α-carboxyl acid group is *deprotonated* when charged (-ve)

10

Ionisable Functional Groups – amino acids

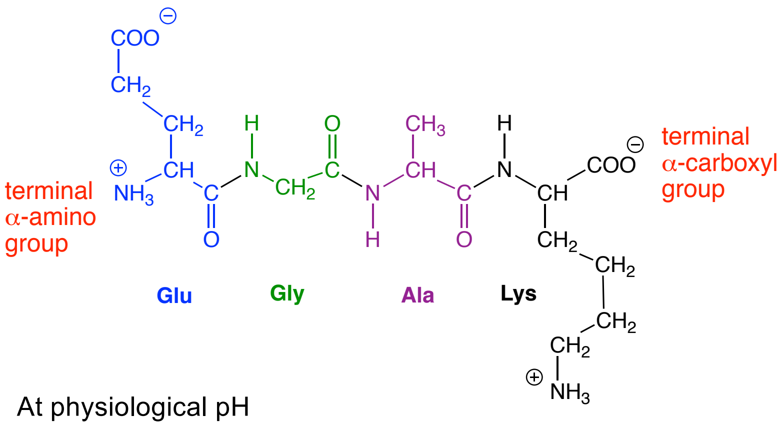
Side Chains of some amino acids also contain ionisable functional groups, so their ionisation state depends on the pH of the solution as well.



Ionisable Functional Groups – proteins

In a protein (a long chain of amino acids bonded together), most of the α-amino and α-carboxyl groups on amino acids are involved in these bonds and not available for ionisation.

Net charge on such molecules then relies on the ionisable side chain groups (the R groups) and the N- and C-termini (at the end of the chain)



At physiological pH

Ionisable Functional Groups – buffers

- To function properly biological systems require molecular components to be in a particular state of ionisation and charge for the evolved purpose
- Variations in pH in the aqueous environment therefore need to be minimised by using **buffers**
  - The blood buffering system utilises bicarbonate - proteins and other molecules also contribute
  - The intracellular buffering system utilises phosphate - proteins and other molecules also contribute
- Also, some specialised cell environments may vary more widely in pH

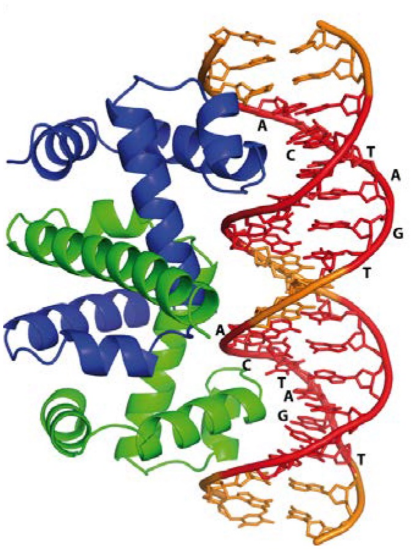
13

Ionisable Functional Groups

Many ionisable groups on macromolecules contribute to charge distribution and influence the shape and nature of interactions of the molecule.

For example,

DNA is negatively charged. For a protein to successfully interact with the DNA, the protein must be positively charged.

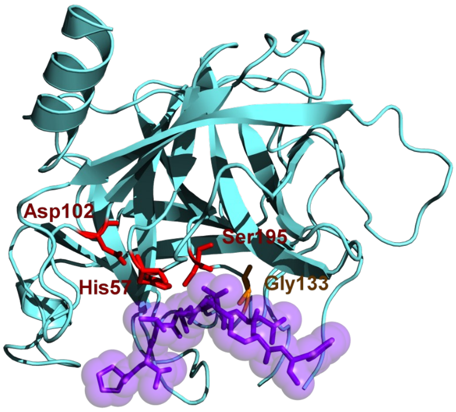


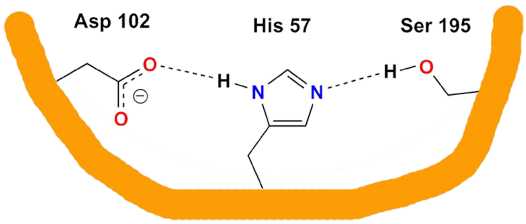
14

Ionisable Functional Groups – enzymes

The ionisation state of amino acid side chains is also crucial for the operation of some enzymes

Eg the active site of Chymotrypsin, a protease (and enzyme which breaks down proteins) contains a **catalytic triad** of amino acid side chains.





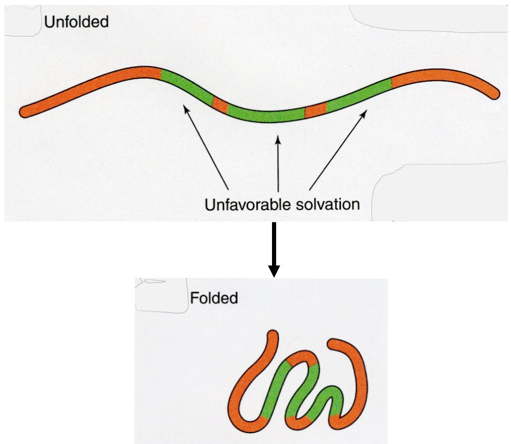
15

Non-polar molecules in water

Water molecules will attempt to **hydrate** a non-polar molecule in an aqueous environment by forming a constrained *hydration shell* around the molecule

Non-polar molecules aggregate together in aqueous solution

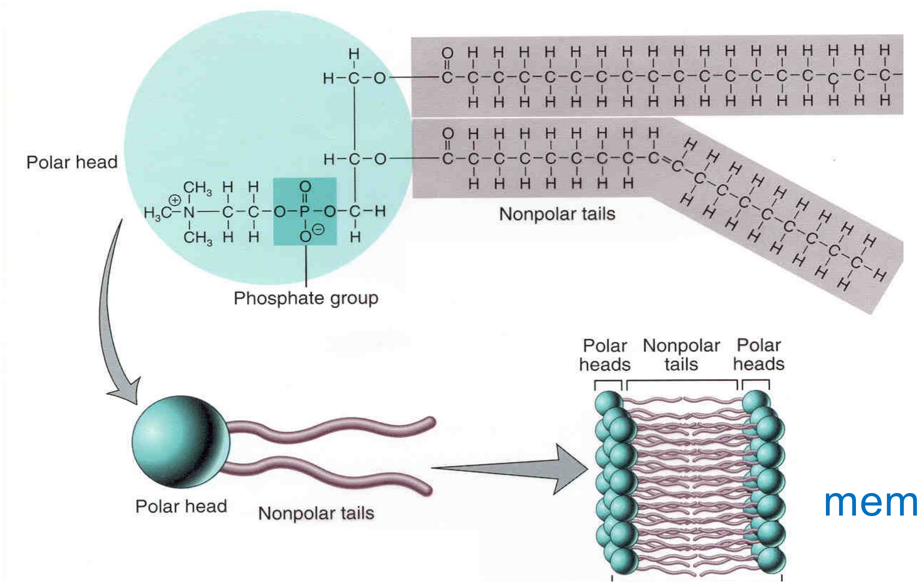
Non-polar regions of macromolecules (eg proteins) “hide” away from aqueous environment



Figs 2.8, 2.9, p31,
Pratt and Cornely

16

Molecules with Polar and Non-polar regions - Phospholipids



membrane

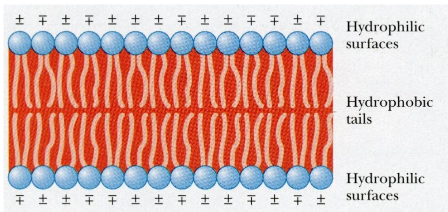
17

Membranes

Biological membranes provide non-aqueous barriers in aqueous environments in cells

Polar head groups of lipids arranged in bilayers interact with the aqueous environment

The non-polar membrane core formed by the lipid tails effectively constrains molecules to a particular location ie either inside or outside the membrane-bound compartment



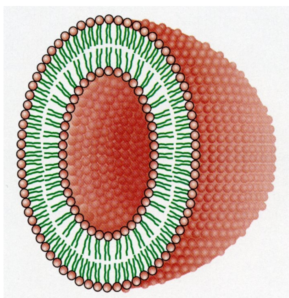


Fig 8.10, p192, Campbell and Farrell 5th ed.

Fig 2.12, p33, Pratt and Cornely

18

Membranes

- Lipid membranes are heterogeneous
- The lipid composition varies
- The membrane is a dynamic structure
- Other molecules associate with or are inserted in the membrane

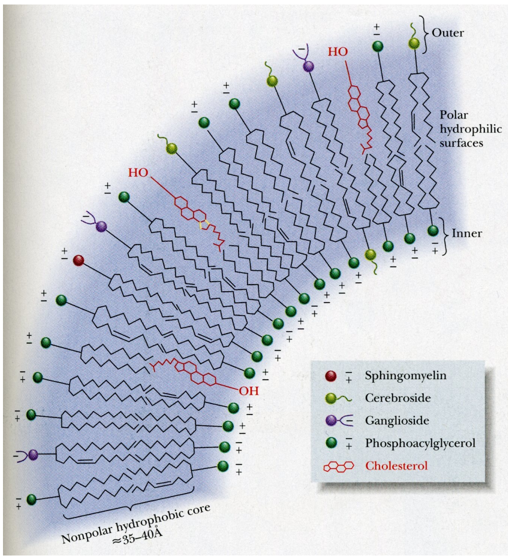


Fig 8.11, p193, Campbell and Farrell 5th ed.

19

Membranes

Other molecules (eg proteins) are inserted in membranes to enable:

(i) reception and communication of signals

(ii) transfer of molecules

- across the membrane from one cell compartment to another

The membrane may divide a cell, or an organelle within a cell

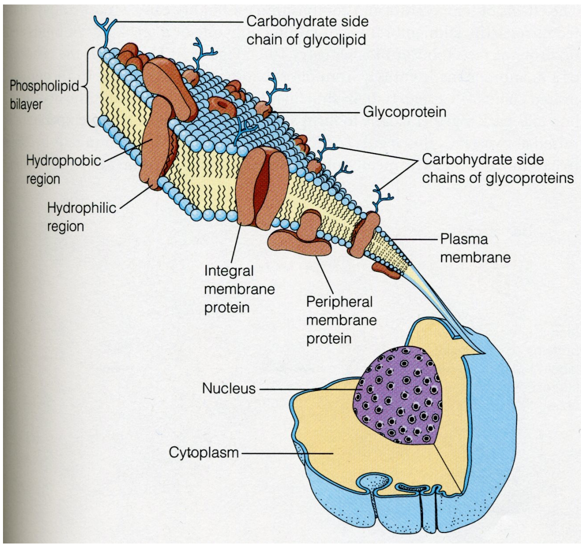


Fig 10.10, p325, Mathews, van Holde and Ahern 3rd ed.

20

Membrane-bound proteins

A variety of particular amino acid sequence arrangements have evolved for insertion in membranes (eg proteins forming pore structures)

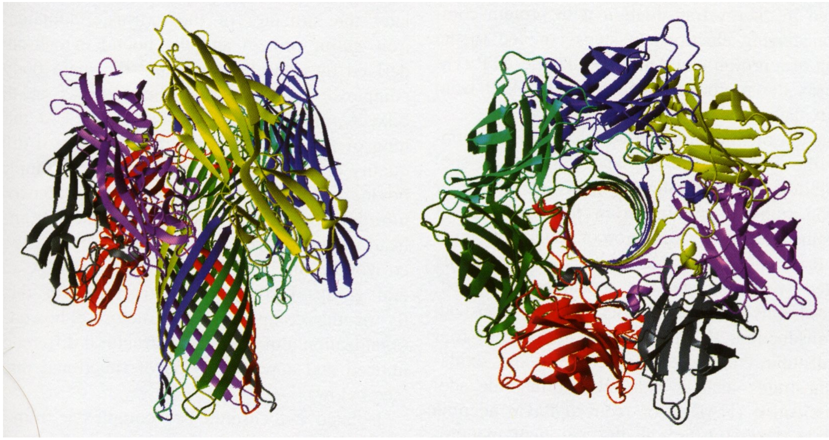


Fig 5.8, p113, Fig 5.31, p131, Whitford

21

✱ Homework ✱

No Problems Today

22