Metals in biological systems (A2)

Scopes:

- understand that some metals are essential to life and able to explain the chemistry involved.
- recognise that some metals are toxic and discuss, in chemical terms, the problems associated with heavy metals in the environment entering the food chain – for eg. mercury.

Some metals are essential to life

Many metal ions play vital roles in metabolism. Some are found naturally in our bodies and are essential for health.

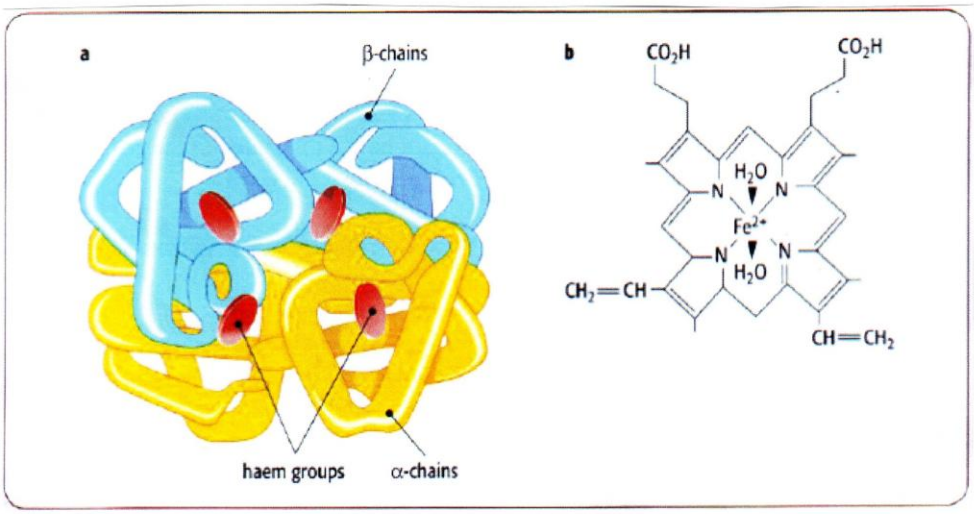
1. Iron (II) ions, Fe^{2+} are a component of haemoglobin. Iron is also involved in the function of cytochromes, which are linked to ATP production in oxidative phosphorylation.
2. Zinc ions, Zn^{2+} act as cofactors in many enzyme catalysed reactions.
3. Sodium and potassium ions are involved in maintaining electrolyte balance in our cells and in generating nerve impulses.

Iron and haemoglobin

Haemoglobin is an oxygen-carrying protein present in red blood cells.

Haemoglobin consists of two pairs of polypeptide subunits α and β.

A haem group, which contains Fe^{2+} ions, is bonded to each subunit.



a. The structure of haemoglobin showing α and β chains

b. The structure of haem when not bound to a protein.

Each haem group can bind one oxygen molecule.

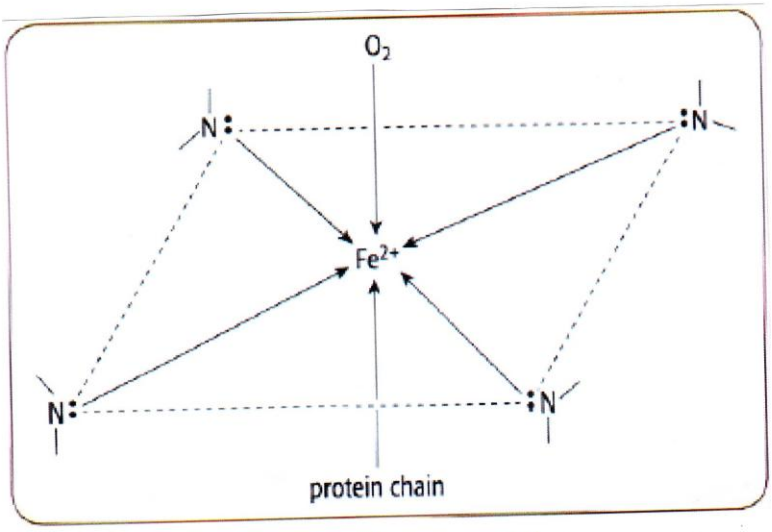
Each of the four haem groups can bind one oxygen molecule at the same time.

So the overall reaction for a complete molecule of haemoglobin (Hb) is:

$$Hb + 4O_2 \rightleftharpoons HbO_8$$

oxyhaemoglobin

Each Fe^{2+} ion acts as the centre of a complex ion. The ligands are the four N atoms of the haem, the N atom of an amino acid (histidine) side-chain on the polypeptide and an oxygen molecule.



The complex ion in haemoglobin

As the equation $Hb + 4O_2 \rightleftharpoons HbO_8$ show, the binding of oxygen to haemoglobin is an equilibrium process. In the lungs, where the oxygen concentration is high, the position of equilibrium moves to the right, so oxygen is bound to haemoglobin.

In muscle tissues, where the oxygen concentration is low, the position of equilibrium moves to the left, so oxygen is released for cellular respiration.

The oxygen is less strongly bound to the Fe^{2+} ion than the other ligands.
It is removed when the red blood cells reach the tissues where oxygen is required.
The oxygen ligand can be replaced by another ligand that binds more strongly to the Fe^{2+} ion.
Carbon monoxide molecules will also bind to haemoglobin, occupying the site normally occupied by oxygen.
Carbon monoxide molecules are bound 200 times more strongly than oxygen in an irreversible reaction.
Thus carbon monoxide is very poisonous because it can cause haemoglobin to lose its oxygen-carrying function.

Exercise 1

Haem is an important prosthetic group which contains iron at its centre.

a. Prosthetic groups and coenzymes are both cofactors. What is the difference between a prosthetic group and a coenzyme?

b. Give two important feature about the attachment of oxygen to each haemoglobin molecule.

c. Name another important group of proteins that contain the haem group.
Where are these proteins located in the cell.

Workings

a. Prosthetic groups are permanently bound to a particular enzyme
Coenzymes are not permanently bound to an enzyme.

b. The oxygen molecule is a ligand and it attaches to an Fe^{2+} ion at the centre of a haem group.
The bonding of oxygen molecule to Fe^{2+} ion is strong enough for it to travel in the blood without being displaced easily by other ligands.
It is removed when the red blood cells reach the tissues where oxygen is required.

c. myoglobin in muscle tissue