# TAYLOR'S UNI. COLLEGE
# CHEMISTRY (9701)
# A Level

## APPLICATION CHEMISTRY:
## BIOCHEMISTRY
**(Part 4 – ATP &**
**Metals in Biological Systems)**

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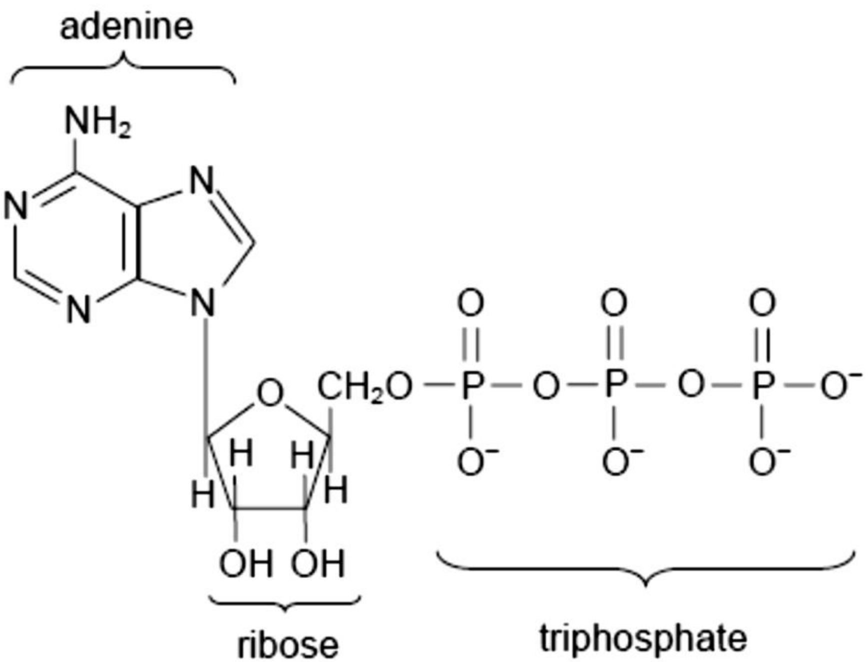
(Yellow Room; Table 1)

# ATP

- The nucleotide, adenosine triphosphate (ATP), has a crucial role to play in making energy available for
- metabolic reactions in all living organisms.
- Short term energy source for cellular activity.
- In animal cells this nucleotide is synthesised in the mitochondria of the cell.



# ATP

- The molecule consists of three phosphate groups linked in a short chain and covalently bonded to the hydroxyl group of a sugar, ribose.

- The last part of the molecule is adenine, an organic base.

- The breakdown of ATP is an **exothermic** reaction and this released energy is used by enzymes to power the catalysed reactions.

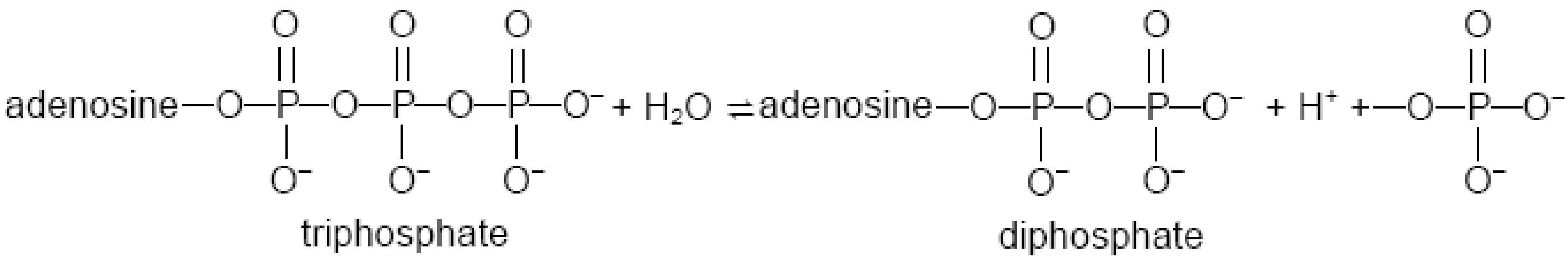
- ATP is hydrolysed to ADP (adenosine diphosphate) and an inorganic phosphate ion ($P_i$)

# ATP

- There is a net gain of energy when the products are formed.

- The release of the end phosphate group is favoured by the **repulsion** between the **negatively charged O** atoms on the **adjacent phosphate groups**

$$ATP + H_2O \rightleftharpoons ADP + P_i \qquad \Delta H = -30\ \text{kJ mol}^{-1}$$



# ATP

- **Synthesis** of **ATP** - energetically **endothermic** and this is where the energy available from the oxidation of food is needed (eg. respiration).

- Plants can make ATP from ADP and phosphate ions using energy from sunlight (photosynthesis)

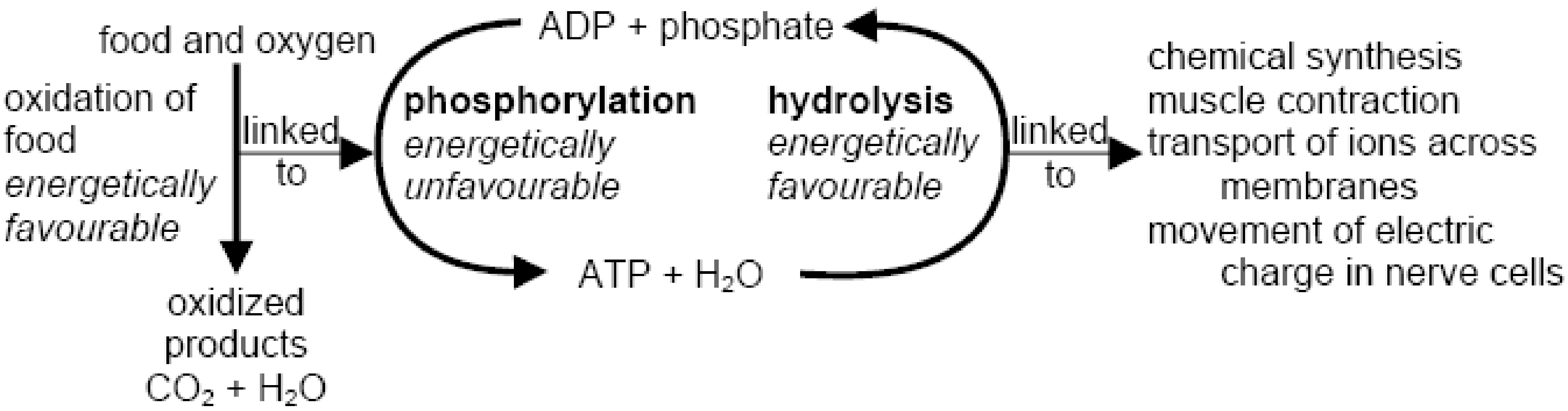



*Figure 1.46 – the role of ATP in metabolism*

# ATP

- If cellular metabolic activity is to be controlled then spontaneous reactions (hydrolysis of ATP) must not occur in the absence of enzymes.

- Although the **hydrolysis of ATP to ADP** is energetically favourable, the **activation energy** for the reaction is **high**.

- This means that spontaneous hydrolysis of ATP without the presence of an enzyme does not occur.

# Metals in Biological Systems

## (1) Iron and the haem proteins

- The $Fe^{2+}$ ions that bind oxygen to the haemoglobin.

- Each haem group can bind one oxygen molecule, and each of the four haem groups binds oxygen simultaneously, so the overall reaction is:

| Hb | + | $4O_2$ | $\rightleftharpoons$ | $HbO_8$ |
|---|---|---|---|---|
| haemoglobin | | oxygen | | oxyhaemoglobin |

- $Fe^{2+}$ ions act as the centres of complex ions; the **ligands** being the **haem group**, the protein chain, and the attached oxygen molecule

- The **binding** of the oxygen is **reversible** so that it can be ‘delivered’ to the tissues of the body where it is required.

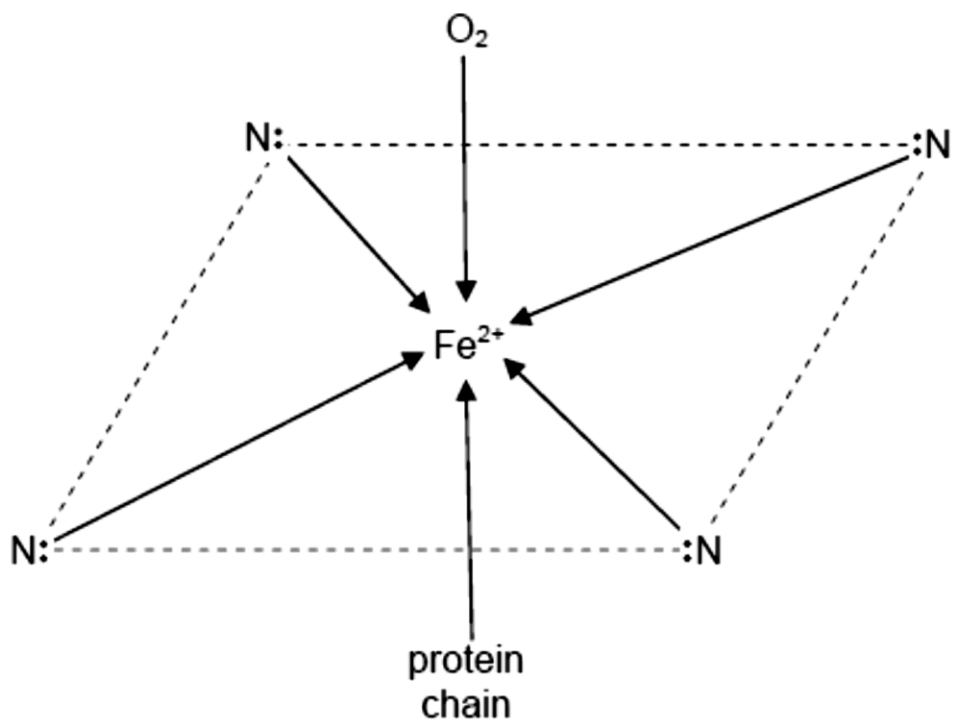



*Figure 1.47 – the complex ion in haemoglobin*

- Oxygen ligand can be replaced by another ligand that binds more strongly.

- In carbon monoxide poisoning the CO molecules replace the oxygen in oxyhaemoglobin.

- Haem is also involved in the functioning of other proteins such as the **cytochromes** present in the mitochondria.

- These proteins are responsible for the production of ATP in the final stage of the respiration process.

- Redox processes **involving electron transfer** are crucial at this stage and the ability of the **$Fe^{2+}$ ions to form $Fe^{3+}$ ions relatively easily**, and vice versa, is important here

# (2) Zinc as an enzyme cofactor

- Carbonic anhydrase, present in our red blood cells, it is responsible for the removal of carbon dioxide from the blood, producing hydrogen carbonate ions.

- Key to the activity of this enzyme is the zinc ion (**$Zn^{2+}$**) present in the **active site** of the enzyme.

- The zinc is bound to the enzyme as part of a complex using nitrogen atoms on the protein chain.

- Water is also bound to the zinc ion. Since the zinc ion has a high charge density it assists the breakdown of this water molecule into an $H^+$ and an $OH^-$ ion.

- The hydroxide ion act as an nucleophile and attack the carbon dioxide molecule → the hydrogen carbonate ion is released from the active site.

- → a further water molecule binds to the zinc and the catalytic cycle begins again.

$$CO_2 + OH^- \rightarrow HCO_3^-$$

# Sodium and potassium ion transfer across cell membranes

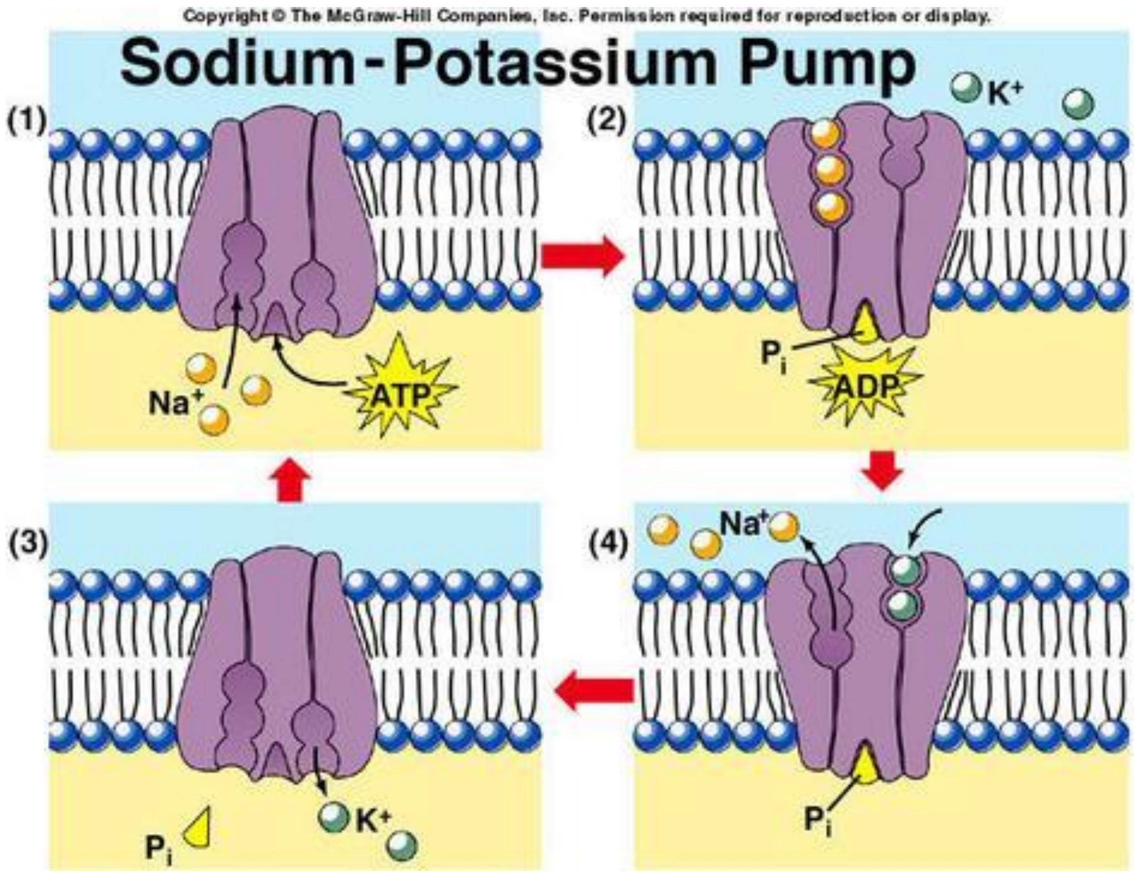
- Within cells : [$Na^+$ ] is lower, [$K^+$ ] is higher, than the surrounding liquid outside.

- When a nerve is stimulated sodium ions pour into the nerve cell.

- When this ‘signal’ has passed the $Na^+$ and $K^+$ ion concentrations have to be restored to normal.
- The sodium being transported out of the cell once again.

- The energy needed for this active transport come from the hydrolysis of ATP (enzyme for this reaction $Na^+$, $K^+$ -ATPase or ‘sodium-potassium pump’)

- These enzyme molecules sit across the membrane with parts of the protein exposed on the outer and inner surfaces.



(1) three $Na^+$ ions and an ATP molecule bind to the inner protein surface of the enzyme.

(2) ATP is hydrolysed, with the Pi binding to the protein.

- Enzyme changes shape so that the $Na^+$ ions move to the outside surface

(3) Two $K^+$ ions attach after $Na^+$ released.

(4) Two $K^+$ ions released into the cell.

- When another ATP binds, process is repeated.

# The potassium specific channel

- There are also specific water and ion channels in cell membranes.
- their selectivity is dependent on the hydration and size of the ions concerned.
- the aqueous $K^+$ ions ($K^+(aq)$) must lose their hydration shells before they can pass through the channel → linking instead to oxygen atoms in certain R groups of the protein.
- The selectivity of the channel depends on the distances between the oxygen atoms in the protein side-chains and the $K^+$ ions.
- The smaller $Na^+$ ions will not ‘fit’ the channels as the distances are too great for the complex to form.

# The potassium specific channel

- The enthalpy required to lose the hydration shell around the ions is compensated for by that given out when the new association is formed with the protein.

- The $K^+$ ions pass through the channel and then reassociate with water on the other side.

- The selectivity of the channel depends on the distances between the oxygen atoms in the protein side-chains and the $K^+$ ions.

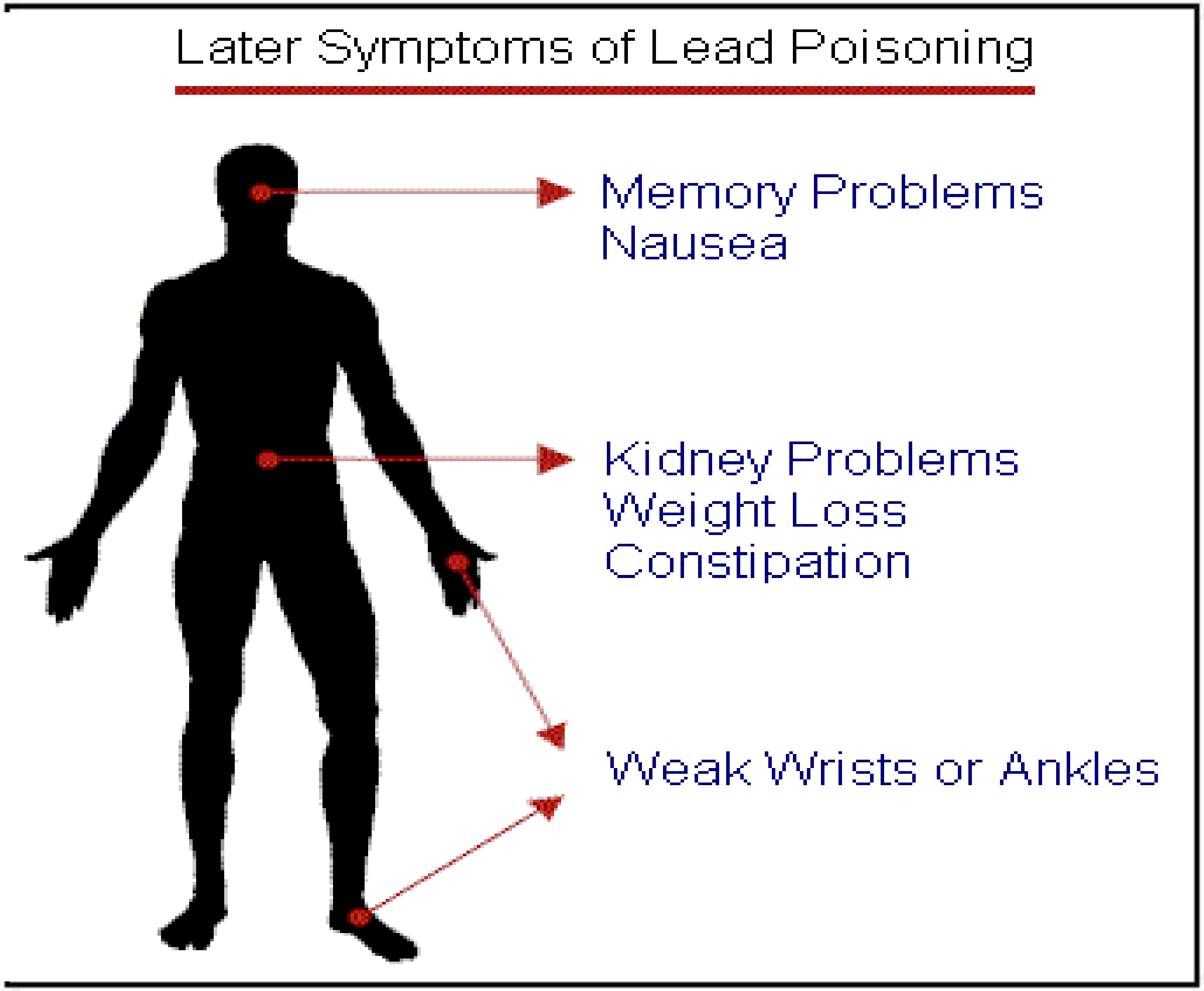
- The smaller $Na^+$ ions will not ‘fit’ the channels as the distances are too great for the complex to form.

# Toxic trace metals in the environment

- **Lead** and **mercury** interfere with enzyme function by **disrupting** the **disulphide bridges** involved in protein tertiary structure.

- The presence of certain **salts** disrupt **Van der Waals' forces** between non-polar side-chains that gives rise to the protein tertiary structure.

- Ions such as **$Li^{+}$, $Mg^{2+}$, and $Ca^{2+}$,** together with heavy metal ions such as **lead** or **mercury**, have all been shown to interfere with **Van der Waals' interactions**.


Later Symptoms of Lead Poisoning
Memory Problems
Nausea
Kidney Problems
Weight Loss
Constipation
Weak Wrists or Ankles

# Toxic trace metals in the environment

- Mercury contamination is perhaps the most notorious case of heavy metal poisoning.

- **Mercury** can enter the **food chain** by a number of routes:

  – in **waste water** discharged into rivers from factories that use mercury compounds in their processes,

  – mercury compounds have been used as **fungicides** and these can be washed off crops into the soil,

  – mercury compounds have been used to **treat timber** and again they can be washed into rivers and streams,

# Toxic trace metals in the environment

- **Mercury cathode cell** is one which is used in the large scale **production of sodium hydroxide** – again any leakage of mercury is dangerous as micro-organisms can convert mercury salts into organomercury compounds e.g. methylmercury salts, and these can be ingested by water-borne organisms.

- Effects of mercury toxicity : **loss of muscle co-ordination and mental function.**