Metals and Life – Answers

Chapters 1 and 2

1  Mo is the most abundant essential transition metal in sea water. Iron is the most abundant transition metal in the Earth’s crust but not sea water. Both sodium and magnesium are abundant in sea water, however they are main-Group elements not transition metals.

2  (a) The main elements of secondary structure apparent in this structure are α-helices and loops.

(Figure based on pdb file 2qka (Zheng et al., 2007))

(b) The structure contains two asymmetric units each containing two polypeptide chains, labelled A (in blue) and C (in pink). The enzyme is thus a tetramer. (You may need to rotate the molecule to see this.)

(Figure based on pdb file 2qka (Zheng et al., 2007))
3  The Mn ions are coordinated by 3 histidyl residues (26, 74 and 163) and one aspartyl (159). (The numbers are those of the amino acid residue obtained from primary sequencing.)

(Figure based on pdb file 2qka (Zheng et al., 2007))

The histidyl residues bind via a N atom and the aspartyl via an O atom.

The bond distances are Mn–N 2.17Å (217 pm), 2.21Å (212 pm) and 2.29Å (229 pm), and Mn–O 1.92Å (192 pm).

4  As this is an enzyme the Mn is likely to have one of two roles: it may be part of the active site for catalysis itself or may be used to transfer atoms or groups to the active site.

5  (a) EXAFS can be used to provide information on the number, type and distance of atoms coordinated to the target metal atom, in this example the Mn atom. XANES can be used to provide information about the oxidation state of the Mn as well as information on the coordination environment of the metal atom.

(b) Resonance Raman spectroscopy. This technique measures vibrational frequencies for ligands attached to the metal atom that absorbs the visible light. If lines due to $O_2^-$ vibrations were observed in the Mn Raman spectrum, this would indicate that $O_2^-$ was attached to Mn.

Chapter 2

1  Histidine coordinates through a N atom, glutamate through O and cysteine and methionine through S.

2  Serine and threonine are possibilities in that they may coordinate via their oxygen lone pairs.

Glutamine and asparagine could potentially coordinate through the lone pair on the oxygen atoms but not through the N atom of the amide group. Lysine could possibly coordinate through the N lone pair. Arginine is positively charged at pH 7 and so does not form stable complexes with positive metal ions. Although tryptophan formally has a nitrogen lone pair this lone pair is not available for coordination to a metal ion as its electrons are delocalised over the side-chain, similar to an amide group.
3. If an amino acid has a $pK_a$ of 9.5 it is likely to exist in a protonated form in the absence of metal ions, as if a $pK_a$ is greater than 7 the protonated form will dominate. However in neutral aqueous solution, metal ions may displace the acidic proton of an amino acid even for an amino acid with a $pK_a$ of 9.5.

4. As Cu(I) is a soft metal ion we would expect that it would form stable complexes with soft ligands. In fact, in biochemical systems several proteins involved in electron transfer contain Cu(I) ions at the active site. In these proteins, the copper is coordinated by the sulfur atom of at least one methionyl or cysteinyl side-chain.

As Cu(II) is in a higher oxidation state, it is a harder metal ion than Cu(I), and so the ligands that stabilise the Cu(II) ion are also expected to be borderline or hard. Such ligands include the histidine, aspartate and glutamate amino acid residues.

5. Pt$^{2+}$ is a soft metal. If it were to interact with DNA it would be effectively coordinated by nitrogen atoms of a nucleobase. This would lead to disruption of the regular DNA helical structure. Structurally damaged DNA is potentially carcinogenic as we will see in Chapter 9.

Chapter 3

1. Start by defining an expression for $[\text{Fe}^{3+}]$ in terms of $K_{sp}$ and $[\text{OH}^-]$, remembering to take the stoichiometry into account.

   $K_{sp} = [\text{Fe}^{3+}][\text{OH}^-]^3$

   $[\text{Fe}^{3+}] = K_{sp}/[\text{OH}^-]^3 = 2 \times 10^{-39} \text{ mol}^4 \text{ dm}^{-12}/[\text{OH}^-]^3$

   The value of $[\text{OH}^-]$ can be calculated from the pH and the value for $K_w$, the dissociation constant for water, such that:

   $K_w = 10^{-14} \text{ mol}^2 \text{ dm}^{-6} = [\text{OH}^-][\text{H}^+]$

   At pH=5: $[\text{H}^+] = 10^{-5} \text{ mol dm}^{-3}$ and so $[\text{OH}^-] = 10^{-9} \text{ mol dm}^{-3}$

   So, $[\text{Fe}^{3+}] = 2 \times 10^{-39} \text{ mol}^4 \text{ dm}^{-12}/(10^{-9} \text{ mol dm}^{-3})^3$

   $= 2 \times 10^{-39} \text{ mol}^4 \text{ dm}^{-12}/10^{-27} \text{ mol}^3 \text{ dm}^{-9}$

   $= 2 \times 10^{-12} \text{ mol dm}^{-3}$

2. $[\text{Fe(NH}_3)_6]^{3+} < [\text{Fe(en)}_3]^{3+} < [\text{Fe(edta)}]^{-}$

   NH$_3$ is a monodentate ligand, en is a bidentate ligand forming chelate rings, edta$^{4-}$ is a hexadentate chelating ligand and is likely to form the most stable complex.

3. A is an example of a catecholate siderophore, containing catechol groups. B is an example of a hydroxamate siderophore, containing hydroxamic acid groups.

4. There are three key points that make enterobactin selective for Fe(III) and the $[\text{Fe(III)}-\text{enterobactin}]$ complex so stable.

   (i) Enterobactin is a hexadentate chelating ligand and so the stability of the complex is enhanced by the chelate effect.

   (ii) The catecholate groups coordinate to the Fe(III) (a hard acid) via O atoms (hard base).

   (iii) The enterobactin ligand is preorganised with the correct size, shape and charge for binding of Fe(III).
5 (b), (c) and (e) are correct.

**Availability of iron** Iron becomes more available at low pH (high [H⁺], low [OH⁻]) as \([\text{Fe}^{3+}] = K_{sp}/[\text{OH}^-]^3\), where \(K_{sp}\) is the solubility product of Fe(OH)₃.

**Relative stability of Fe(II) and Fe(III)** The oxidation of Fe(II) to Fe(III) is thermodynamically favourable at all values of pH. The observation that the process is much faster at high pH is down to kinetic factors.

6 (b) and (c) are correct.

Iron is believed to be taken up by roots as Fe²⁺. Plants release reducing agents and H⁺ ions near the root surface. A decrease in pH will increase the concentration of soluble iron around the root. The reducing agent will increase the relative concentration of Fe²⁺ at the root surface, aiding uptake by the plant.

In alkaline soil (high pH) additional mechanisms are needed to supplement this constitutive mechanism. Some plants aid the solubility by releasing phytosiderophores into the soil, which form stable complexes with Fe(III). The iron is taken up by the plant as the [Fe(III)–phytosiderophore] complex. Other plants increase the level of soluble iron by releasing iron–binding ligands into the soil.

Gardeners can overcome nutrient deficiency by:
- decreasing the pH of the soil;
- adding a chelator such as edta⁴⁻ to increase the level of soluble iron in the soil solution;
- adding sequestered iron (a stable Fe(III) complex).

**Chapter 4**

1 The equilibrium potential, \(V_N\), can be calculated using the form of the Nernst equation given on page 62 of *Metals and Life*.

\[
V_N = \left(\frac{RT}{zF}\right) \ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right)
\]

\[
V_N = \left\{\frac{(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298 \text{ K})}{(1)(96 485 \text{ C mol}^{-1})}\right\} \ln(10 \text{ mmol dm}^{-3}/140 \text{ mmol dm}^{-3})
\]

\[
= -0.068 \text{ V}
\]

\[
= -68 \text{ mV}
\]

2 The equilibrium potential, \(V_N\), can be calculated using the form of the Nernst equation given on page 62 of *Metals and Life*.

\[
V_N = \left(\frac{RT}{zF}\right) \ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right)
\]

Rearranging, \(\ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right) = \frac{V_N}{\left(\frac{RT}{zF}\right)}\)

\[
\ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right) = 0.060 \text{ V}/\left\{\frac{(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298 \text{ K})}{(1)(96 485 \text{ C mol}^{-1})}\right\}
\]

So, \(\ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right) = 2.336\)

and \(c_{\text{out}}/c_{\text{in}} = 10.3\)

3 The definitions can be found in Sections 4.4 and 4.5 of *Metals and Life*.

(a) **Ligand-gated ion channel** This protein forms a pore in the membrane which opens in response to the binding of a particular molecule.

(b) **Voltage-gated ion channel** This protein forms a pore in the membrane which opens in response to a change in the local membrane potential.

(c) **Symport** This protein uses the work done when one ion crosses the cell membrane to drive the transport of a second type of ion in the same direction.
(d) **Antiport** This protein uses the work done when one ion crosses the cell membrane to drive the transport of a second type of ion in the opposite direction.

(e) **Ionophore** This protein binds to an ion then transports it across the cell membrane, releasing it on the other side of membrane.

(f) **Primary ion pump** This protein uses energy provided by the hydrolysis of ATP to transport ions across the cell membrane.

4 Siderophores, such as enterobactin, can be considered to be ionophores or ion carriers as they carry the metal ion through a cell membrane by binding to a receptor on the outside of the cell membrane.

5 The effect of digitalis on cardiac performance is described on pages 76–77 of *Metals and Life*.

The inhibitory effect of digitalis causes the action of the primary Na\(^+\)/K\(^+\) ion pump to decrease. This causes the Na\(^+\) electrochemical gradient across the membrane to decrease. This in turn causes the concentration of Ca\(^{2+}\) to increase inside the cell as the function of the Na\(^+\)/Ca\(^{2+}\) antiport is decreased. The increase in the concentration of Ca\(^{2+}\) within the cell enhances cardiac performance.

6 The terms are shown in bold in Chapter 4 of *Metals and Life*.

**Endocytosis** On binding to a membrane receptor protein, a protein and the receptor break off inside the cell to form a vesicle.

**Enterocyte** A cell that lines the small intestine. Metals from digested food are transported into these cells by the divalent metal transporter, DMT1.

**Erythrocyte** A red blood cell.

**Passive diffusion** The movement of molecules from regions of high concentration to regions of lower concentration until there is an even distribution throughout the available volume.

**Phloem** Circulatory system in plants, which uses the movement of sap from cell to cell.

**Saturation** Characteristic of protein-mediated transport, at this point the rate of transport does not increase with an increase in ion concentration.

7 The information for this question can be found in Sections 4.6 and 4.7 of *Metals and Life*.

Iron from digested food is absorbed in the duodenum by the enterocyte cells that line the small intestine. Iron is transported into these cells as the Fe\(^{2+}\) ion by a protein, DMT1 (divalent metal transporter). The iron can be transported out of these cells (as Fe\(^{2+}\)) into the bloodstream by another protein, ferroportin.

Once in the bloodstream the iron is oxidised to Fe\(^{3+}\) and is transported round the body by the transport protein transferrin, as an Fe\(^{3+}\)-transferrin complex. Iron can enter the cells where it is required (eg in bone marrow) by binding of the iron-transferrin complex to specific receptors on the cell membrane. The iron is released into cytoplasm as Fe\(^{2+}\) for use or storage.
Chapter 5

1. Iron is stored in ferritin as hydrated $\text{Fe(III)}$ oxide. $\text{Fe(II)}$ ions present in the cytosol enter ferritin via the 3-fold channel which is lined with hydrophilic carboxylate groups. The inside of the ferritin is rich in carboxylate groups which coordinate with the $\text{Fe(II)}$. The iron is oxidised and the hydrated oxide grows within the core.

Iron is released from the core as the hydrated $\text{Fe(II)}$ ion through the hydrophilic 3-fold channels. The iron is believed to be reduced by molecules such as $\text{NAD}^+$ which enter via the hydrophobic 4-fold channels of ferritin or is released after compartmentalisation inside an acidic vesicle.

2. These proteins are discussed further in Chapters 3–5 of *Metals and Life*.
   (a) *DMT1* Transports divalent metal ions across the cell membrane.
   (b) *Ferroportin* An iron exporter that transports iron into the bloodstream.
   (c) *Hephaestin* A copper-dependent ferroxidase that oxidises $\text{Fe}^{2+}$ to $\text{Fe}^{3+}$.
   (d) *Transferrin* Protein that transports iron in the blood.
   (e) *Haemosiderin* One of two proteins involved in iron storage (the other is ferritin).
   (f) *Haemoglobin* The protein in red blood cells that carries iron (and oxygen) around the body.
   (g) *Enterobactin* A siderophore involved in the uptake of iron by bacteria (forms a stable chelate with $\text{Fe(III)}$).

3. (a) and (e) are correct.
   See Figure 5.5 of *Metals and Life* and the text describing this figure.

   *Siderophore synthesis* A protein called FUR binds to DNA in the presence of iron. This blocks transcription.

   *Transferrin receptor synthesis* IRPs bind to mRNA sequences in the absence of iron. This stabilises the mRNA and translation occurs leading to the production of transferrin receptors.

   *Ferritin synthesis* In the presence of iron, IRPs do not bind to mRNA. This enables translation to occur.

4. Further information on the role of these proteins can be found in Chapters 4 and 5 of *Metals and Life*.
   (a) *Metallochaperone* A protein that acquires, transports and delivers a metal ion within the cytoplasm of a cell to enzymes that need it.
   (b) *Metallothionein* A cysteine-rich storage protein present in the cytosol. These have particular affinity for soft metal ions.
   (c) *Iron regulatory protein* A protein that binds to the iron responsive elements (IREs) of ferritin and transferrin receptor mRNA regulating gene transcription/translation.
   (d) *ATP-ase* A protein that catalytically hydrolyses ATP, for example the $\text{Na}^+$/K$^+$ ion pump.
Chapter 6

1. The surface at the top of the diagram is parallel to the xy plane and cuts the z axis at 1. It is therefore the (001) plane.

2. To balance the reduction in positive charge, the following types of defect are possible.
   - Place cations of higher charge, e.g. $M^{3+}$, on $Ca^{2+}$ sites.
   - Place anions of lower charge or neutral molecules on anion sites, e.g. $CO_3^{2-}$ on $PO_4^{3-}$ sites.
   - Introduce vacancies on anion sites.
   - Add interstitial cations.

The only two defects on this list that fall into these categories are $H_2O$ on an $OH^-$ site and $Al^{3+}$ on a $Ca^{2+}$ site.

3. Dissolving $BaSO_4$ in water will produce equal numbers of $Ba^{2+}$ and $SO_4^{2-}$ ions. Thus $[Ba^{2+}][SO_4^{2-}] = [Ba^{2+}]^2 = [SO_4^{2-}]^2 = 1.10 \times 10^{-10}$ mol dm$^{-6}$.
   
   Hence $[Ba^{2+}] = \sqrt{(1.10 \times 10^{-10})} = 1.05 \times 10^{-5}$ mol dm$^{-3}$.

   The ionic strength, $I$, is given by equation 6.8 of *Metals and Life*. Since both ions are divalent, $z_i = 2$ for both. $[Ba^{2+}] = [SO_4^{2-}] = 1.05 \times 10^{-5}$ mol dm$^{-3}$.

   Hence $I = \frac{1}{2}(4 \times 1.05 \times 10^{-5} + 4 \times 1.05 \times 10^{-5}) = 4.20 \times 10^{-5}$.

4. In weakly supersaturated solutions, the Ostwald–Lussac Law predicts that the least soluble form will crystallise out.

   The least soluble mineral given is **brushite**.

5. They are all possible explanations.

   Formation of a complex in solution will reduce the concentration of $Ca^{2+}$(aq) thus reducing the degree of supersaturation and hence the rate of nucleation.

   Crystals grow more slowly on perfect surfaces than on ones with steps or kinks and so reducing the number of steps/kinks would slow crystal growth.

   Citrate bound strongly to the brushite surface would act as inhibitor.

6. Amelogenins form nanospheres which attach to specific planes of the crystal thus inhibiting growth along these planes and causing the crystals to be long and thin.

7. In limpet teeth, an array of filaments and tubules of chitin, a polysaccharide, physically restricts growth along the x and y axes and hence determines the shape of the goethite crystals. (Section 6.7.2 of *Metals and Life*.)

Chapter 7

1. The metals in the proteins play the following roles:

   - The iron in ferredoxin is an electron transfer agent. (Section 1.2 and 7.4.3)
   - The iron in haemoglobin transports oxygen. (Sections 1.2 and 3.4.3)
   - The copper in hephaestin is present at the catalytic site (the protein catalyses the oxidation of Fe(II) in the blood stream). (Section 4.6.2)
   - Zinc in zinc-finger proteins maintains the shape of the protein. (Sections 1.2 and 7.1)
In LADH, there are two Zn sites, each of which has a particular role to play in the enzyme. There is Zn\(^{2+}\) at the catalytic site for the oxidation of alcohol but there is also a zinc ion which plays a structural role.

The rate of a reaction is increased by either decreasing the activation energy, \(E_a\), or increasing the \(A\) factor. Polarising the O–H bond of ethanol makes it easier to remove H\(^+\), that is the activation energy for this step is reduced.

Keeping the NAD\(^+\) in the pocket close to the zinc will speed up the reaction by increasing the \(A\) factor but this is not a role of the zinc ion.

Formation of succinyl-CoA

\[
\text{coenzyme B}_{12} \rightarrow \text{reduced coenzyme B}_{12} + 5'-\text{deoxyadenosine}
\]

\(\text{Co}^{3+}\) octahedral \(\text{Co}^{2+}\) square pyramidal

\[
\text{methylcobalamin} \rightarrow \text{reduced methylcobalamin} + \text{methylated homocysteine}
\]

\(\text{Co}^{3+}\) octahedral \(\text{Co}^+\) square planar

In the formation of succinyl-CoA, the Co in coenzyme B\(_{12}\) is reduced from +3 to +2 by homolytic cleavage and loss of the 5'-deoxyadenosyl radical. Removal of this ligand changes the geometry from octahedral to square pyramidal.

In the production of methionine, the Co in methylcobalamin is reduced from +3 to +1 by heterolytic cleavage and loss of CH\(_3^+\). In the process the ligand opposite the methyl becomes detached from the Co giving a square planar environment.

The potential of cytochrome f should lie between those of the Rieske iron-sulfur protein and plastocyanin for efficient electron transfer.

The potential of Rieske iron-sulfur proteins are in the range \(-0.090\) V to \(0.280\) V (page 150). That of plastocyanin is \(0.375\) V (page 153). Thus, depending on which Rieske protein is involved, the potential will lie between \(-0.090\) V to \(0.280\) V and \(0.375\) V. The option that best fits is between \(0.280\) V and \(0.375\) V.

<table>
<thead>
<tr>
<th>1 → a</th>
<th>The requirements for a good electron transfer protein are given on pages 144–5 of <em>Metals and Life.</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>2 → d</td>
<td>The coordination of Cu in blue copper proteins is given on page 152 of <em>Metals and Life.</em></td>
</tr>
<tr>
<td>3 → b</td>
<td>The position of the Cu centres in azurin and copper nitrite reductase is discussed in the video sequence ‘Copper Nitrite Reductase’.</td>
</tr>
<tr>
<td>4 → c</td>
<td>The potentials of blue copper proteins are given as in the range 0.140 V to 0.700 V. The lower end of this range gives a suitable potential for reducing the Cu centre in copper nitrite reductase.</td>
</tr>
</tbody>
</table>

Chapter 8

1 When oxygen enters the lung, it diffuses through the alveoli walls into capillaries and thence into erythrocytes (red blood cells). Here it attaches to haemoglobin which transports it to other organs in the body.

In muscle, oxygen is released from haemoglobin and attaches to myoglobin where it is stored until needed.

During respiration oxygen reacts with glucose to form carbon dioxide and water. The reaction to form water is catalysed by cytochrome C oxidase (CCO).
Excess carbon dioxide produced in respiration is converted to hydrogen carbonate ions by *carbonic anhydrase*.

Oxygen is also used in other reactions. *Cytochrome P450* uses oxygen to oxidise organic molecules. The conversion of steroids to cholesterol is one example.

2 Perhaps surprisingly, the colour is not due to a transition involving orbitals on Fe. The protoporphyrin IX ring of haem is conjugated. The colour arises from a \( \pi \rightarrow \pi^* \) transition between orbitals of this conjugated system. Changing the oxidation state of the Fe alters the energy levels of protoporphyrin IX and hence the colour.

3 Valine will not hydrogen-bond to \( \text{O}_2 \). In addition it is less bulky than histidine and so would clash less with linear CO. Replacement of the distal histidine by valine would thus result in a relatively high affinity for CO.

4 Myoglobin, CCO and peroxidases all contain at least one haem group.

   Haemocyanin, despite its name, contains no haem groups and in fact has two Cu ions coordinated by amino acids at its active site.

   Chlorophyll and methylcobalamin contain rings similar to that in the haem group but there are differences in the ring and the metal ions at the centre are \( \text{Mg}^{2+} \) and \( \text{Co}^{2+} \).

5 From the experimental evidence available \( \text{N}_2 \) is thought to be reduced at the FeMo-cofactor. Other parts of the nitrogenase system are involved in this process by, for example, providing electrons but \( \text{N}_2 \) attaches to the FeMo-cofactor.

6 Statements B, D and E are correct.

   The position of the K-edge in the XANES spectrum suggests Ni is present as \( \text{Ni}^{(II)} \).

   Two histidine residues are found in the vicinity of the Ni ion and these bind via \( \text{N} \). This would account for the two \( \text{N} \) observed. The four \( \text{O} \) are likely to be glutamate or water.

   If \( S \) is not \( \frac{1}{2} \) then the complex cannot have one unpaired electron. This rules out \( \text{Ni(I)} \, d^9 \) and low spin \( \text{Ni(III)} \, d^7 \).

7 In the resting state the iron is in oxidation state III. This is then reduced to Fe(II) and the substrate RH is bound in a hydrophobic pocket in the protein backbone. Oxygen coordinates to the iron, oxidising the Fe back to Fe(III). The coordinated oxygen is reduced to hydroperoxide and then hydroxide is removed as water by addition of a proton. The highly reactive Fe(V) intermediate rapidly inserts oxygen into the R–H bond of the adjacent substrate returning the enzyme to the resting state.

   The overall reaction is:
   \[
   \text{RH(aq)} + \text{O}_2(g) + 2\text{H}^+(\text{aq}) + 2\text{e}^- = \text{ROH(aq)} + \text{H}_2\text{O(l)}
   \]

Chapter 9

1 You need a metal with a large magnetic moment, in this case \( \text{Gd}^{3+} \).

   The complex needs to be thermodynamically and kinetically stable, so that it does not get broken down to release \( \text{Gd}^{3+} \) into the body.

   High stability constant achieved by using polydentate or macrocyclic ligands (also ligand preorganisation).

   Choice of ligating atom – \( \text{Gd}^{3+} \) is hard acid and so prefers \( \text{N} \) or \( \text{O} \).

   Use of anionic ligands to encourage binding to the metal cation and also water molecules (in the external sphere).
The preparation of a complex of general formula $[\text{PtL}_4]^{n-}$:

\[
\begin{align*}
\left[ \begin{array}{c}
\text{Cl} \\
\text{Cl-Pt-Cl}
\end{array} \right]^{2-} & \xrightarrow{\text{NH}_3} \left[ \begin{array}{c}
\text{NH}_3 \\
\text{Cl-Pt-Cl}
\end{array} \right]^{2-} & \xrightarrow{\text{NO}_2^-} \left[ \begin{array}{c}
\text{NH}_3 \\
\text{Cl-Pt-NO}_2
\end{array} \right]^{2-}
\end{align*}
\]

The Pt complex shown in 1 is a trans-complex.

Trans-complexes such as 1 are unable to bridge the two guanosine residues as the 1,2-intrastrand adduct for steric reasons, as the distance between the two Cl leaving groups is too long. The bending of the DNA double helix is much less effective. In addition, the binding to high mobility proteins is less strong for trans complexes such as transplatin for example, and so the lesions are more easily repaired than in cisplatin. Trans complexes are also more readily intercepted by sulphur-containing species leading to their removal from cancer cells.

(a) Au(I) is a soft acid and forms most stable complexes with soft bases, for example S containing ligands. The ester groups aid solubility. The phosphine ligand is included to provide the complex with lipophilicity, i.e., fat solubility, to aid distribution across the cell membrane.

(b) The blood of smokers has been found to contain higher concentrations of cyanide than that of non-smokers. The cyanide ion forms a stable complex with Au(I) ($[\text{Au(CN)}_2]^-$) which is readily absorbed by red blood cells.

Reference

Acknowledgement
The figures in this document were created using data from The Protein Databank http://www.rsc.org.