OXFORD CAMBRIDGE AND RSA EXAMINATIONS

ADVANCED SUBSIDIARY GCE

F332/ADVANCE NOTICE

CHEMISTRY B (SALTERS)

Chemistry of Natural Resources: Advance Notice article

THURSDAY 14 JANUARY 2010: Morning

DURATION: 1 hour 45 minutes

For issue on or after:

17 NOVEMBER 2009

SUITABLE FOR VISUALLY IMPAIRED CANDIDATES

READ INSTRUCTIONS OVERLEAF

DC (LEO/SW) MEP10045 22936/2

NOTES FOR GUIDANCE (CANDIDATES)

1 **This leaflet contains an article which is needed in preparation for a question in the externally assessed examination F332.**

2 **You will need to read the article carefully and also have covered the learning outcomes for Unit F332 (*Chemistry of Natural Resources*). The examination paper will contain questions on the article. You will be expected to apply your knowledge and understanding of the work covered in Unit F332 to answer these questions. There are 20 marks available on the paper for these questions.**

3 **You can seek advice from your teacher about the content of the article and you can discuss it with others in your class. You may also investigate the topic yourself using any resources available to you.**

4 **You will NOT be able to bring your copy of the article, or other materials, into the examination. The examination paper will contain a fresh copy of the article as an insert.**

5 **You will not have time to read this article for the first time in the examination if you are to complete the examination paper within the specified time. However, you should refer to the article when answering the questions.**

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TREATING THE PUBLIC WATER SUPPLY: WHAT IS IN YOUR WATER, AND HOW IS IT MADE SAFE TO DRINK?

Adapted from "Treating the Public Water Supply: What is in Your Water and How is it Made Safe to Drink" on Washington University, St Louis, Chemistry Department website.

SPECIES (OTHER THAN H_2O) CONTAINED IN WATER

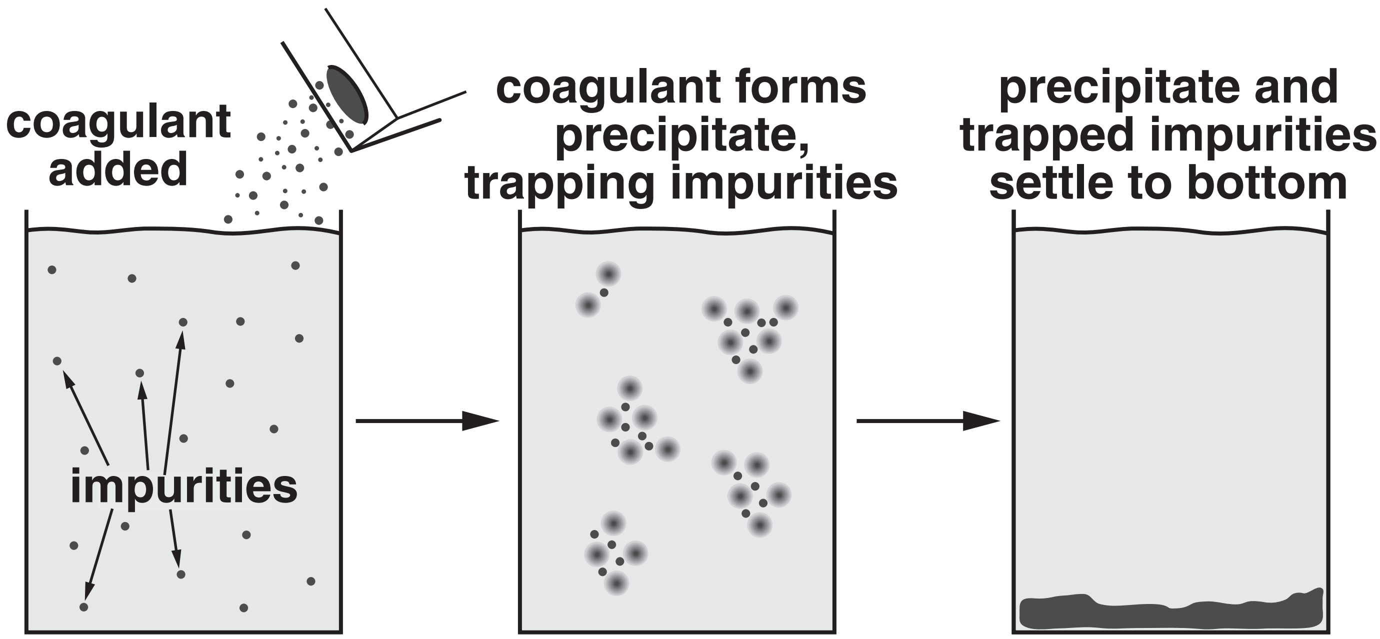
Chemical analysis of virtually any freshwater sample reveals that "water", even water that has been rigorously cleaned and treated, is really a solution containing many dissolved species. A solution is a homogeneous system (a system that is uniform throughout) containing more than one substance. A solution in which water is the solvent is known as an aqueous solution. In addition to water (the solvent), freshwater samples may include:

- ions (*e.g.*: Na^+, Ca^{2+}, F^- and HSO_4^-)
- dissolved gases (*e.g.*: O_2 and CO_2)
- other natural dissolved molecules (*e.g.*: organic by-products of decaying leaves)
- dissolved molecules from human activity (*e.g.*: industrial and agricultural wastes)

Two processes, known as flocculation and coagulation, are used to create larger particles that will settle quickly to the bottom. In flocculation, small particles with non-rigid surfaces are made to agglomerate by stirring the water (and thus bringing the particles into contact with one another so that the surfaces can become stuck together).

When the agglomeration of the particles gets large enough, the aggregate can settle in still water by sedimentation. Other suspended particles do not agglomerate well by flocculation. To remove these particles from the water, coagulation must be used. Coagulation is the process of gathering particles into a cluster or clot, often achieved by the addition of special chemicals known as coagulants. The most common coagulant used in water-treatment facilities is aluminium sulfate, $Al_2(SO_4)_3$. Other Al and Fe salts, including poly-aluminium chloride, ferric chloride, and ferric sulfate, may be used as well. These salts react with ions naturally found in the water to produce a solid precipitate of aluminium hydroxide. As this precipitate forms, other particles are caught in the solid, forming a mass that will settle to the bottom via sedimentation.

$$Al^{3+} + SO_4^{2-} + Ca^{2+} + 3HCO_3^{-} \longrightarrow Al(OH)_3 + CaSO_4 + 3CO_2$$



TREATING WATER HARDNESS

The process of removing Ca^{2+} and Mg^{2+} from the water is known as WATER SOFTENING. Two minerals, LIME, $Ca(OH)_2$ and SODA ASH, Na_2CO_3, are typically used to soften public water supplies. When lime is added to water, it dissolves to give three aqueous (solvated) ions: one Ca^{2+} ion and two OH^- ions for each unit of $Ca(OH)_2$. Likewise, soda ash dissolves to give two Na^+ ions and one CO_3^{2-} ion for each unit of Na_2CO_3 that dissolves.

A number of reactions occur to generate the insoluble precipitates $CaCO_3(s)$ and $Mg(OH)_2(s)$ from the Ca^{2+} and Mg^{2+} ions. The most important reaction for the removal of Mg^{2+} is shown below.

$$Mg^{2+}(aq) + 2OH^-(aq) \longrightarrow Mg(OH)_2(s)$$

The important reaction for the removal of Ca^{2+} ions is:

$$\underset{\text{from water}}{Ca^{2+}(aq)} + \underset{\text{from lime}}{Ca^{2+}(aq)} + \underset{\text{from soda ash}}{2CO_3^{2-}(aq)} \longrightarrow \underset{\text{precipitate}}{2CaCO_3(s)}$$

The solids generated by the water-softening precipitation reaction are then removed by sedimentation or filtration. If an excess of lime was used to precipitate magnesium ions in the water, some unused hydroxide (OH^-) ions will remain in the water after the calcium is precipitated, resulting in a high (or alkaline) pH. If necessary, the pH can be lowered by bubbling carbon dioxide gas through the water. The equations for this are given below:

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

$$H_2CO_3(aq) + OH^-(aq) \rightleftharpoons H_2O + HCO_3^-(aq)$$

HCO_3^- remaining in the water is non-toxic and does not adversely affect the flavour of the water.

REMOVING IRON AND MANGANESE

Two types of precipitation reactions may be used to remove Fe^{2+} and Mn^{2+} from the water. The most important of these reactions is OXIDATION. Using molecular oxygen (O_2) or another oxidant such as potassium permanganate, $KMnO_4$, Fe(II) is readily oxidised to Fe(III) in solution.

$$3Fe^{2+}(aq) + MnO_4^-(aq) + 2H_2O(l) \longrightarrow 3Fe^{3+}(aq) + MnO_2(s) + 4OH^-(aq)$$

If the solution is alkaline (high pH), the Fe(III) forms $Fe(OH)_3$ and precipitates. Hence, adding an oxidant to the water and raising the water's pH at the water-treatment plant forms an insoluble precipitate. The insoluble hydroxide can then be removed by sedimentation or filtration. The water-softening agents described in the "Treating Water Hardness" section on page 6 can also help to make insoluble precipitates from Fe^{2+} and Mn^{2+}.

DISINFECTION

In many water supplies, the most serious health threats are posed not by chemicals, but by infectious organisms (bacteria) in the water. Chlorine (Cl_2) is a major disinfectant that is cheap and kills most of the serious disease-causing bacteria in the water. However, chlorine is difficult to store and transport. This is because chlorine is a toxic gas at room temperature and pressure. This would mean that chlorine could diffuse across a large region, if an accident occurs during its transportation, endangering any people near the accident site. Even in small amounts, chlorine gas can cause respiratory problems. Chlorine disinfection also results in a wide variety of by-products. One class of chlorination by-products, known as trihalomethanes (THM's) are suspected carcinogens. Because of concern about these by-products in the water supply, chlorine is now kept to minimum levels, and other methods of disinfection are being used more frequently. Chloramines form more stable disinfectants and pose less risk of harmful by-products, but cost more to use. Other methods focus on removing the organisms through coagulation, sedimentation, and improved filtration.

ADSORPTION

Dissolved organic compounds in water (*e.g.* herbicides such as atrazine, and industrial waste products) can pose a significant health threat, and may affect the taste and odour of drinking water. To remove them, the process of ADSORPTION is used. Adsorption is a process in which one substance is attached to the surface of another substance. POWDERED ACTIVATED CARBON (PAC), a finely ground charcoal, is used for this process. When PAC is added to the water, the organic compounds attach to the surface of the powder granules. The granules of PAC have irregularly shaped surfaces, which gives PAC a very large surface area to attract organic compounds. It is estimated that 1 gram of PAC has a surface area of around 1000 m^2! The carbon can then be removed by filtration, taking the unwanted organic compounds with it.

ADDITION OF OTHER CHEMICALS TO THE WATER SUPPLY

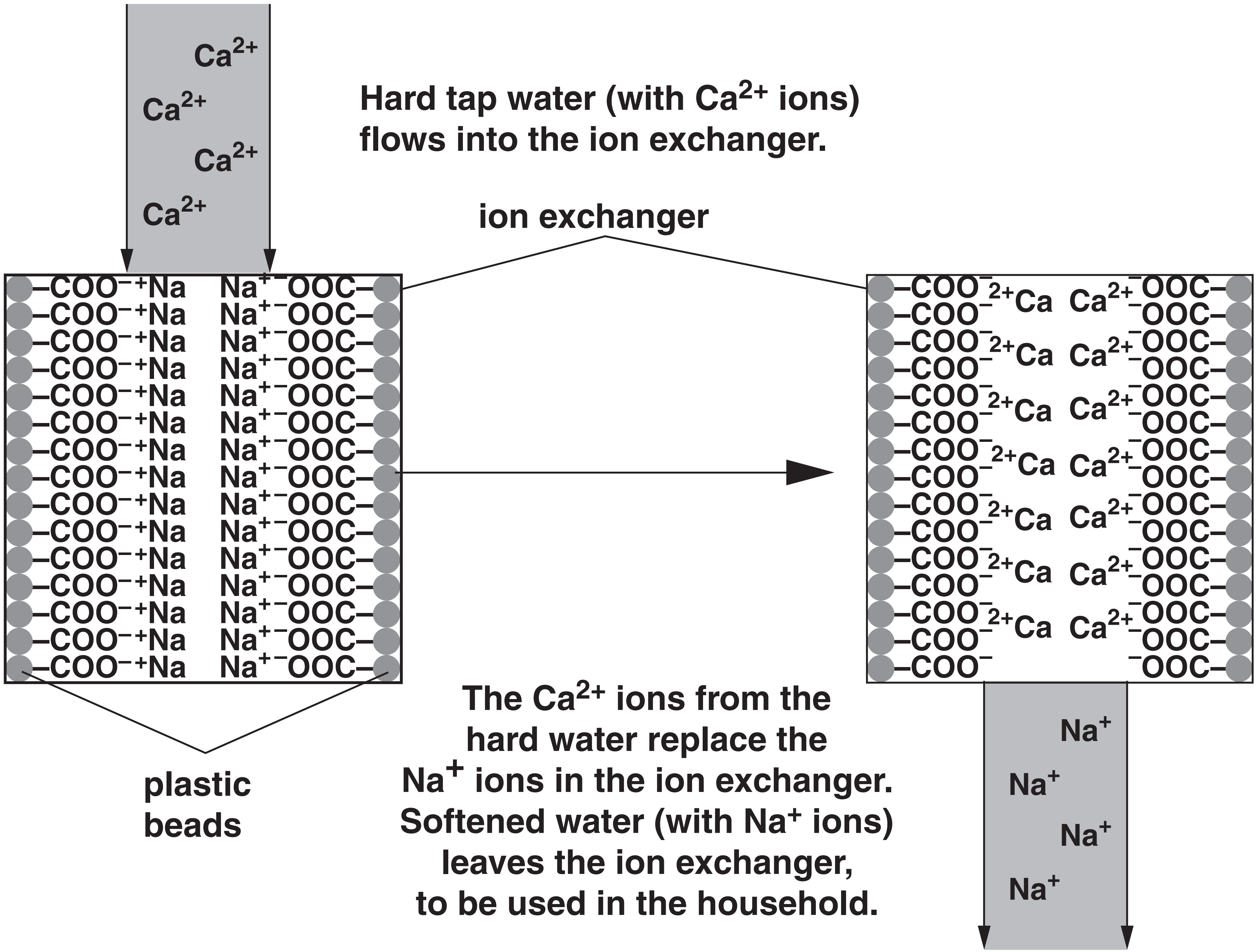
Certainly a principal objective of the water-treatment process is to remove substances from water that are harmful, or that otherwise make the water unsuitable for human use. However, another important component of the process is the addition of chemicals that make the water better for human use. For example, fluoride (F^-) is routinely added to public water supplies to protect the teeth of those who drink the water. Cities that add appropriate amounts of fluoride to their drinking-water supplies have successfully reduced the incidence of cavities among the children who inhabit those cities. The processes of screening, sedimentation, precipitation, filtration, adsorption, and disinfection work together to remove the unwanted substances from our water supply making it safe to drink and appropriate for other uses. Additions of other chemicals, such as fluoride, further enhance the quality of the water for drinking.

POINT-OF-USE WATER SOFTENERS

Household water softeners, shown as a schematic diagram on the opposite page, typically use a different process from the precipitation reaction described on page 9, known as ion exchange. Ion-exchange devices consist of a bed of plastic (polymer) beads covalently bound to anion groups, such as $-COO^-$. The negative charge of these anions is balanced by Na^+ cations attached to them. When water containing Ca^{2+} and Mg^{2+} is passed through the ion exchanger, the Ca^{2+} and Mg^{2+} ions are more attracted to the anion groups than the Na^+ ions. Hence, they replace the Na^+ ions on the beads, and so the Na^+ ions (which do not form scummy residues) go into the water in place of the Ca^{2+} and Mg^{2+}.

When hard tap water passes through the ion exchanger, the calcium ions from the tap water replace the sodium ions in the ion exchanger. Each calcium ion displaces two sodium ions during this process. the softened water, containing sodium ions in place of calcium ions, can be collected for household use.

Unfortunately, many people with high blood pressure or other health problems must restrict their intake of sodium ions. Because water softened by this type of ion exchange contains many sodium ions, people with limited sodium intakes should avoid drinking water that has been softened this way. Several new techniques for softening water without introducing sodium ions are beginning to appear on the market.


Ca2+
Ca2+
Ca2+
Ca2+
Hard tap water (with Ca2+ ions) flows into the ion exchanger.
ion exchanger
–COO⁻ ⁺Na Na⁺ ⁻OOC–
–COO⁻ 2+Ca Ca2+ ⁻OOC–
plastic beads
The Ca2+ ions from the hard water replace the Na+ ions in the ion exchanger. Softened water (with Na+ ions) leaves the ion exchanger, to be used in the household.
Na+
Na+
Na+
Na+

POINT-OF-USE ADSORPTION FILTERS

Many of the contaminants that make our drinking water unsafe or unpleasant to drink, such as lead ions (which may be leached into the water from lead pipes) or organic molecules producing offensive odours and tastes, can be removed by adsorption-filtration devices installed at the tap. These devices have filters containing powdered activated carbon, which adsorbs the offending contaminants in the water. As the water for consumption exits the device, the PAC (with the unwanted contaminants attached) is strained out of the water by the filter. Periodically, the filter must be replaced so that it does not become clogged and ineffective.

COMPLETING THE CYCLE: WHAT HAPPENS TO WATER AFTER WE USE IT?

Once water has been used, it must somehow re-enter the freshwater supply. Some of the water is evaporated (*e.g.*: if it is used to generate steam for industry, or if we drink the water and then sweat). The evaporated water eventually collects in clouds and returns to the earth via precipitation. However, most of the water that we use remains in the liquid state, and is returned to the freshwater supply directly (as run-off) or via wastewater treatment facilities.

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RECOGNISING ACHIEVEMENT