UNIT 4 PERFORMANCE TASK: CHEMICAL ANALYST FOR A DAY

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Prediction

(a) After the experimental sample is passed through a Brita water filter (or similar ion-exchange resin), the $[Ca^{2+}_{(aq)}]$ should be lower.

Materials

(b)

- Brita water filter (or similar ion-exchange resin)
- funnel
- two 250-mL beakers
- ring clamp and stand

Procedure

(c) Two identical samples of hard water are obtained. One is kept as the control; the other is passed through the Brita water filter and collected.

Analysis

(d) The chemical formula of the EDTA ion can be written as $Y^{4-}_{(aq)}$. EDTA chelates (or binds) metal ions by forming up to six attractions with the metal ion (see Figure 1): four attractions with the oxygen ends of EDTA and two with the nitrogen atoms. During the titration, EDTA, in the form $Y^{4-}_{(aq)}$ combines in a 1:1 ratio with calcium as given by the following chemical equation:

$$Y^{4-}_{(aq)} + Ca^{2+}_{(aq)} \rightleftharpoons CaY^{2-}_{(aq)}$$

EDTA is also commonly available as the disodium salt. If this version of EDTA is used, the equilibrium becomes:

$$HY^{2-}_{(aq)} + Ca^{2+}_{(aq)} \rightleftharpoons CaY_{(aq)}$$

(e)

	Tap water	Treated water
volume of 0.0100 mol/L EDTA:	4.40 mL	1.60 mL

Tap water analysis:

$$n_{EDTA_{(aq)}} = C_{EDTA_{(aq)}} \times V_{EDTA_{(aq)}}$$
$$= 0.0100 \text{ mol/L} \times 4.40 \text{ mL}$$
$$n_{EDTA_{(aq)}} = 4.40 \times 10^{-2} \text{ mol/L}$$

Treated water analysis:

$$n_{EDTA_{(aq)}} = 0.0100 \text{ mol/L} \times 1.60 \text{ mL}$$
$$n_{EDTA_{(aq)}} = 1.60 \times 10^{-2} \text{ mol/L}$$

The calcium ion concentration in tap water decreased from 4.40×10^{-2} mol/L to 1.60×10^{-2} mol/L after being passed through a Brita water filter.

Evaluation

(f) There were no obvious flaws or sources of error in the experimental design. One minor improvement would be to use a fresh supply of indicator to ensure that the colour change is as crisp as possible.

(g) The prediction is judged to be adequate because the concentration of the water sample was lower as a result of being passed through the water filter.

Synthesis

(h) Both types of titrations involve indicators that are weak acids. The endpoint of each type of titration is signalled by an equilibrium shift of the indicator. However, the colour changes involved in EDTA titrations tend to be more sluggish than acid–base titration endpoints.

(i) (This answer assumes the disodium salt of EDTA was used in the experiment.) During the titration, $H_2Y^{2-}_{(aq)}$ chelates (binds) free $Ca^{2+}_{(aq)}$ ions in solution, shifting the following equilibrium to the right:

$Ca^{2+}_{(aq)} + H_2Y^{2-}_{(aq)} \rightleftharpoons CaY^{2-}_{(aq)} + 2\ H^{+}_{(aq)}$

Performing this titration in a basic solution shifts this equilibrium to the right, ensuring that all the calcium in the sample has been complexed with EDTA. This is particularly important because calcium–EDTA complexes are weak as compared to metal–EDTA complexes.

Erichrome black T is a dark dye used to signal the endpoint of an EDTA titration. Like acid–base indicators, Erichrome black T is a weak acid (abbrev. $HIn^{2-}_{(aq)}$) which is in equilibrium with its conjugate base, In $In^{3-}_{(aq)}$:

$In^{3-}_{(aq)} + H^{+}_{(aq)} \rightleftharpoons HIn^{2-}_{(aq)}$

Initially, in the titration, there is a large excess of $Ca^{2+}_{(aq)}$. Some calcium combines with the indicator to produce a red-coloured complex, $CaIn^{-}_{(aq)}$.

$CaIn^{-}_{(aq)} + H^{+}_{(aq)} \rightleftharpoons HIn^{2-}_{(aq)} + Ca^{2+}_{(aq)}$

(red) (blue)

At the endpoint, chelation of the last trace of free $Ca^{2+}_{(aq)}$ shifts the Erichrome black T equilibrium to the right, resulting in the endpoint colour change.

(j) The sharpness of the endpoint increases with pH. However, there is an upper limit to how high the pH can be. If the pH is too high, calcium and magnesium ions begin to precipitate out of solution as $CaCO_{3(s)}$ and $Mg(OH)_{2(s)}$. As a result, a compromise of pH 10 is used for this titration. To maintain a constant pH during the titration, an ammonia/ammonium buffer solution is used. The buffering equilibrium involved is:

$NH^{+}_{4(aq)} \rightleftharpoons H^{+}_{(aq)} + NH_{3(aq)}$

Small amounts of acid ($H^{+}_{(aq)}$) produced in the flask are consumed by the forward reaction. Small excesses of base ($OH^{-}_{(aq)}$) are consumed by the reverse reaction.

(k) EDTA can be found in a large variety of consumer and pharmaceutical products:

Soaps – EDTA is sometimes added to soap to act as a water-softening agent. EDTA softens water by chelating calcium and magnesium from the water.

Canned fruits and vegetables – Metals are sometimes introduced into canned vegetables either from the soil or from harvesting or processing machinery. Metals can degrade food by catalyzing the oxidation of fat. EDTA chelates metals, preventing them from decomposing food.

Meat products – EDTA prevents the discoloration of some meat products.

Chelation therapy – EDTA is useful in the treatment of a variety of disorders, such as

- arteriosclerosis (hardening of the arteries). EDTA removes calcium deposits, making the arteries flexible again.
- metal poisoning. EDTA chelates the metal (e.g., lead), which can then be eliminated from the body in urine.
- kidney stones (which consist primarily of calcium compounds such as calcium oxalate). EDTA chelates calcium, which helps to shrink the stones.

(l) The medical use of EDTA is not without risk. Large doses of EDTA can damage the kidneys. Also, EDTA can cause a drop in the blood sugar levels. This is a particular concern for diabetics who use zinc-based insulin.

UNIT 4 SELF-QUIZ

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1. False: The equilibrium concentrations depend on the value of the equilibrium constant at any given temperature.
2. True
3. True
4. False: Catalysts lower the activation energy for both the forward and reverse reactions.
5. False: Inert gases have no effect on equilibrium concentrations.
6. False: The value of the equilibrium constant will decrease.
7. False: Calcium fluoride is more soluble.
8. True
9. False: The activation energy depends on whether the reaction is endothermic or exothermic.