Chromium, molybdenum and tungsten – teacher notes

Topic

Transition elements – colours of ions, redox reactions and variable oxidisation state.

Timing

10 mins

Description

In this unusual experiment, some features of the chemistry of three transition elements are examined. The experiment illustrates aspects of colour, precipitate formation, changes in oxidation state and equilibria – all important concepts in transition metal chemistry. Most students will already be familiar with some of the chemistry of chromium through the oxidising properties of the dichromate ion, but not that of molybdenum and tungsten – the chemistry of these two elements is very complex.

Apparatus

- Student worksheet
- Clear plastic sheet (*eg* ohp sheet).

Chemicals

Solutions contained in plastic pipettes, see our standard health and safety guidance.

- Potassium chromate 0.2 mol dm^{-3}
- Ammonium molybdate 0.05 mol dm^{-3}
- Sodium tungstate 0.2 mol dm^{-3}
- Hydrochloric acid 1 mol dm^{-3}
- Sodium hydroxide 1 mol dm^{-3}
- Iron(II) sulphate 0.2 mol dm^{-3}

Discussion

Molybdenum and tungsten
These two transition metals, in the same group as chromium, are rarely encountered in experiments at secondary level although students should be familiar with the use of tungsten metal as filaments in light bulbs. (It has the highest melting point of any metal – 3422 ± 200 °C.) Molybdenum is an essential element in animal biochemistry and occurs in the enzyme xanthine oxidase which is involved in purine–adenine and guanine metabolism. Both metals are widely used in the steel industry where they are essential in the manufacture of high-speed steels for cutting tools.
Their solution chemistry is very complex – students might be surprised by the formula of ammonium molybdate!

The procedures described here illustrate changes in oxidation state (molybdenum) and precipitation from acid solution (tungsten). The addition of a mild reducing agent (iron(II)) to a solution of molybdate produces a blue colour generally known as molybdenum blue. These are non-stoichiometric compounds, containing both oxides and hydroxides, the mean oxidation number of molybdenum being between 5 and 6. It has been suggested that Mo $_3$ atom clusters might be responsible for the blue colour.
The acidification of a solution of a tungstate produces a precipitate of tungsten(VI) oxide. Tungsten is therefore extracted from its ore (wolframite (Fe, Mn) WO_4) under alkaline conditions.

Observations

1. Students should observe that the solution of chromium (as chromate(III)) is coloured, whereas those of molybdenum and tungsten are not. Discussion could ensue on whether this is significant, bearing in mind the general characteristic of transition elements that their compounds are coloured. Molybdenum and tungsten do form coloured compounds in other oxidation states, and students should be aware of the blue copper(II) and white copper(I) salts.
2. Acidification of the yellow chromate(VI) solution produces an orange colour due to the formation of dichromate ions as the position of equilibrium is shifted:
   $2CrO_4^{2-} + 2H^+ \rightleftarrows 2HCrO_4^- \rightleftarrows Cr_2O_7^{2-} + H_2O$
   yellow intermediate orange
   The addition of alkali removes the hydrogen ions and shifts the position of equilibrium back to the left, and so the yellow colour is seen again.
3. Acidification of the molybdate(VI) solution produces a very interesting result. A white precipitate is formed at first. However, after a short while this precipitate starts to dissolve until eventually a colourless solution reforms. Molybdenum complexes are formed and, as these disproportionate, the species formed redissolve.
4. Acidification of the tungstate(VI) solution slowly produces a white precipitate of hydrated tungsten(VI) oxide, (WO^3). Whereas chromium and its compounds are soluble in acid solution, molybdenum and tungsten, and their compounds are precipitated at low pH but brought into solution at high pH. This is significant in the methods used to extract both molybdenum and tungsten from their ores.
5. The addition of iron(II) ions to chromate(VI) ions produces an orange colour. This is probably due to the effect of a change in pH. The iron(II) is oxidised to iron(III) and this, being slightly acidic, causes a shift in the position of equilibrium forming orange dichromate ions.
6. The addition of iron(II) ions – a mild reducing agent – to a molybdate solution produces a dark bluish colour sometimes known as molybdenum blue.
7. Addition of iron(II) ions to a tungstate solution produces a whitish precipitate of WO_3.

Health, safety and technical notes

Students must wear suitable eye protection – (splash proof goggles to BS EN166 3).
Potassium chromate, 0.2M KCrO4 is a carcinogen, mutagen and skin sensitiser as well as a skin/eye irritant. Explosive or vigorous-burning mixtures can be formed with Aluminum and other metals and combustible materials

Hydrochloric acid, 1 mol dm^{-3} HCl (aq), Ammonium molybdate, 0.05 mol dm^{-3} $(NH_4)_6Mo_7O_{24}4H_2O$(aq), Sodium tungstate, 0.2 mol $^{dm-3}$ $Na_2WO_4.2H_2O$ (aq) and Iron(II) sulphate, 0.2 mol dm^{-3}, $FeSO_4.7H_2O$ (aq) are of low hazard.
Sodium hydroxide solution, 1 mol dm^{-3} NaOH (aq), is corrosive.