Out of the blue

These notes accompany the video demonstration **Out of the blue** from *Education in Chemistry* which can be viewed at: https://rsc.li/3FkGYi6/

The same chemistry that drives the famed cobalt traffic light and the pink catalyst reaction also drives another colour-changing reaction – the blue and gold reaction. This reaction is an excellent introduction to reversible reactions because of the repeated rapid switches between shades of blue, green, yellow and red, with accompanying fizzing and precipitation.

Level

This demonstration is ideally suited to lessons on reversible reactions and/or transition metal chemistry for learners aged 14–16.

Equipment

- 30 cm^3 of 1 M potassium sodium tartrate solution beaker
- 100 cm^3 of 3% (10 vol) hydrogen peroxide solution
- 1 cm^3 of 0.5 M copper(II) sulfate solution
- Kettle and large beaker (eg 1 L) to make a water bath
- Magnetic stirrer and stirrer bar
- 250 cm^3 beaker (preferably tall form) for the reaction
- Boiling tube for heating an initial portion of the hydrogen peroxide solution
- Thermometer (with a range of 0–100°C)
- White tile

Preparation

Make up 100 cm^3 of fresh 10 vol hydrogen peroxide (10 vol solutions do not keep well because the decomposition inhibitor is less effective when diluted).

Place 30 cm^3 of 1 M potassium sodium tartrate in a 250 cm^3 beaker (to make this fresh from the tetrahydrate salt dissolve 8.46 g of solid in 30 cm^3 of water). Add 15 cm^3 of 10 vol hydrogen peroxide to a boiling tube and place both the beaker and the boiling tube in a 1 L beaker. Keep the remaining hydrogen peroxide ready at room temperature. Add a thermometer to the tartrate solution and add hot water from a kettle to the 1 L beaker to bring the solutions to 50–60°C in time for the experiment.

Safety and disposal notes

- Wear eye protection.
- Hydrogen peroxide can cause serious eye damage. CLEAPSS members should refer to RB045 (bit.ly/46MzwYE) before diluting 100 vol (30%) hydrogen peroxide.
- Copper (II) sulfate is harmful if swallowed and can cause serious eye damage. Avoid contact with skin.
- Dilute all solutions with plenty of water and dispose of all diluted solutions in a foul-water drain.

In front of the class

Wear eye protection. Place a white tile on a magnetic stirrer, place the stirrer bar in the 250 cm^3 beaker of potassium sodium tartrate solution and add the 15 cm^3 of heated hydrogen peroxide from the boiling tube and begin stirring. Monitor the temperature. The reaction is initiated by the addition of approx 1 cm^3 of 0.5 M copper sulfate(VI). This is best done when the solution reaches 50°C.

The colour of the copper sulfate(VI) would be expected to be near-colourless when diluted to this extent by adding into the tartrate/peroxide mixture. Instead a deep blue colour is observed as copper(II) tartrate complex is formed. Lots of bubbles of oxygen and carbon dioxide are released and after ≈10 seconds the solution changes from blue to an opaque, golden-orange-yellow coloured precipitate. The temperature will rise rapidly at this point to ≈65°C. On addition of 10 cm^3 of room temperature 10 vol hydrogen peroxide, the blue colour will return before the reaction repeats and cycles back to the orange precipitate. Add further aliquots of hydrogen peroxide to cycle the reaction until the tartrate, or your audience, becomes exhausted!

The reaction takes longer to repeat if you allow the temperature to drop, but this can be compensated for by adding the peroxide quickly enough after the precipitate finishes forming to maintain the temperature at 60–70°C throughout the experiment. Avoid allowing the temperature to rise too much because this inhibits the cycling of the reaction.

Teaching goal

When executed well, the cobalt variation of this reaction (rsc.li/3S5OK77) demonstrates catalytic effects superbly, with differently coloured complexes formed during the reaction before the original colour returns. However, this copper variation consumes only a small proportion of the tartrate ions each time, so it makes for a visually appealing demonstration of the reversibility of reactions and demonstrates aspects of transition metal chemistry (changes of colour, variable oxidation states, complex formation and catalytic behaviour).

On addition of the copper, the solution goes from near-colourless to blue as intensely coloured copper–tartrate complex ion forms. After a short latency period, the copper acts as a catalyst for the decomposition of peroxide (the two can react without the presence of tartrate), and in the oxidation of tartrate. Eventually, the ratio of [tartrate]:[H_2O_2] becomes high enough and the Cu(II) complex becomes a reactant and is reduced to the orange precipitate. The orange precipitate looks like the copper(I) oxide formed in a positive Benedict's test but is more likely to be a copper(I)–peroxo–tartrate complex of Cu_2O.

When more peroxide is added the ratio flips back again and reoxidises the Cu(I) to Cu(II), which causes the chain of reactions to start over, this time from a slightly higher pH. The reason the reaction tends to slow over time would seem on first glance to be explained by the reduction in tartrate concentration, but higher temperatures and higher pH also inhibit formation of the precipitate (one reason it's not recommended to go too much higher than 70°C).