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Introduction

This booklet presents learning material based on the manufacture and uses of sodium carbonate made by the Solvay (ammonia-soda) process. It is the result of a Learning Material Workshop organised by The Royal Society of Chemistry in conjunction with The Institute of Materials and The Worshipful Company of Armourers and Brasiers. The workshop was held at the Brunner Mond Company, Northwich, Cheshire.

A group of chemistry teachers spent a day at Brunner Mond and was given a presentation by the company on various aspects of the Solvay (ammonia-soda) process for the manufacture of sodium carbonate and sodium hydrogencarbonate. This was followed by a tour of the plant. The following day was spent brainstorming and drafting the material which is presented here in edited form.

The teachers involved were:

Paul Butlin, Ipswich High School;

Janice Chubb, The Dame Alice Harpur School, Bedford;

David Earnshaw, Ysgol Y Berwyn, Bala;

Keith Huggins, Aylesbury High School; and

Barry McFarland.

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The material

The booklet includes teacher's notes and material to photocopy as follows:

Part 1. Manufacturing sodium carbonate – an overview for teachers
An overview for teachers of sodium carbonate and sodium hydrogencarbonate manufacture (especially by the Solvay process) and of the uses of these products. It includes some unusual details of the process and anecdotes which could be used by teachers to enhance their own teaching.

Part 2. Making sodium carbonate
A worksheet for 11–13 year old students. It includes some simple practical work as well as an account of the Solvay process and questions on the process and raw materials.

Part 3. Manufacturing sodium carbonate
A worksheet for 14–16 year old students with an account of the Solvay process and questions on the process and raw materials.

Part 4. Manufacturing sodium carbonate by the Solvay process
An account of the Solvay process based on 1 above but with some of the detail, that which is intended specifically for teachers, removed. It is aimed at post-16 students but would also be accessible to more able pre-16 students.

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Part 5. The thermodynamics and equilibria involved in the Solvay process for the production of sodium carbonate
A worksheet for post-16 students with questions on the thermodynamics and acid-base aspects of the Solvay process and the uses of the products. It could be used independently but would ideally be used after students have read part 4.

Using the material

None of the material assumes any prior knowledge of the Solvay process. Parts 3 and 5 are entirely self-contained and require no teacher input. They are therefore suitable as homework exercises or as work to be tackled in the event of teacher absence.

The Solvay process is not a core part of current syllabuses and specifications but the aim of the worksheets is to get students to apply chemical principles in an unfamiliar context, not for them to learn details of this process.

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3. Manufacturing sodium carbonate

Answers to questions

1. Various. The list might include windows (houses, cars), bottles, jars, TV and computer screens, light bulbs, drinking glasses, mirrors.
2. Salt is present in the area. (The many names ending in -wich in the area – Northwich, Nantwich, Middlewich, for example – testify to the importance of salt; the ending -wich is derived from Anglo-Saxon.) Limestone is available close by (as is coal, from which the coke is made).
3. (*a*) Na^+ and CO_3^{2-}.
   (*b*) Na^+ from sodium chloride and CO_3^{2-} from calcium carbonate.
4. The salt extraction process has little environmental impact. All that is visible above ground are a number of small pumping stations each about the size of a garden shed. On the other hand, quarries are large, difficult to hide and may be considered an eyesore for many years after they have finished working (unless landscaped).
5. (*a*) and (*e*).
6. Ammonia is an intermediate (a catalyst might also be an acceptable term at this level) as it is neither a raw material nor a product.
7. Calcium chloride.
8. (*a*) The reaction regenerates the ammonia for re-use in reaction (*c*).
   (*b*) The price for which calcium hydroxide and ammonium chloride could be sold relative to the price for which ammonia is bought. Ammonia becomes in effect a reactant, rather than an intermediate.
9. Burning coke (an exothermic reaction) provides the heat energy to decompose the limestone (an endothermic reaction).
10. The carbon dioxide is used in the process.

4. Manufacturing sodium carbonate by the Solvay process

None required

5. The thermodynamics and equilibria involved in the Solvay process for the production of sodium carbonate

Answers to questions

1. (*a*) Yes it is.
   (*b*) + 20 kJ mol^{-1}

The value is the same as that quoted for the overall reaction.

2. Coke is an impure form of carbon produced by heating coal in the absence of air for about 18 hours. Moisture, a variety of volatile organic compounds (coal tar) and ammonia are driven out of the coal during this process.
3. -393 kJ mol^{-1}
4. +179 kJ mol^{-1}
5. 2
6. Burning coke produces carbon dioxide as the only main product. This is used in the Solvay process.
7. Far less earth has to be moved; it is safer; it has less environmental impact.
8. As we move down from the top of the tower, more reaction has taken place, more heat is given out and the temperature rises. Further down the tower, the cooling water removes much of this heat and the temperature drops again.
9. The rate of formation of the product and the temperature.

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10. $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(l) + CO_2(g)$ $\Delta H = +92\ kJ\ mol^{-1}$

11. A: $CaCO_3 \rightarrow CO_2 + CaO$ and $C + O_2 \rightarrow CO_2$
    B: $CaO + H_2O \rightarrow Ca(OH)_2$
    C: $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$
    or the equivalent word equations
    a: calcium oxide
    b: carbon dioxide
    c: sodium hydrogencarbonate
    d: calcium hydroxide

12. (a) Acid: H_2O; base: NH_3
    (b) Acid: NH_4^+; base: OH^-

13. (a) The solution will be alkaline. The carbonate ion will accept a proton from a water molecule.
    $CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + OH^-(aq)$
    leaving free OH^- ions in solution.
    (b) For the equilibrium:
    $CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + OH^-(aq)$

$$2.08 \times 10^{-4} = \frac{[HCO_3^-(aq)]_{eq}\,[OH^-(aq)]_{eq}}{[CO_3^{2-}(aq)]_{eq}}$$

At equilibrium, $[HCO_3^-(aq)]_{eq} = [OH^-(aq)]_{eq}$
and, since we are dealing with a weak base, in a 1 mol dm^{-3} solution of sodium carbonate $[CO_3^{2-}(aq)]_{eq} \approx 1\ mol\ dm^{-3}$

$$2.08 \times 10^{-4} = \frac{[OH^-(aq)]_{eq}^2}{1}$$

$[OH^-(aq)]_{eq} = 0.01443\ mol\ dm^{-3}$
More OH^- ions are formed from the equilibrium:
$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$
for which

$$2.22 \times 10^{-8} = \frac{[H_2CO_3(aq)]_{eq}\,[OH^-(aq)]_{eq}}{[HCO_3^-(aq)]_{eq}}$$

At equilibrium, $[H_2CO_3(aq)]_{eq} = [OH^-(aq)]_{eq}$
We have calculated above that $[HCO_3^-(aq)]_{eq} = 0.01443\ mol\ dm^{-3}$ and, since we are dealing with a weak base, in a 0.01443 mol dm^{-3} solution of hydrogencarbonate ions

$[HCO_3^-(aq)]_{eq} \approx 0.01443\ mol\ dm^{-3}$

$$2.22 \times 10^{-8} = \frac{[OH^-(aq)]_{eq}^2}{0.01443}$$

$[OH^-] = 1.79 \times 10^{-5}\ mol\ dm^{-3}$

So the total $[OH^-]$ from both equilibria is

$1.79 \times 10^{-5} + 0.01443 = 0.0145\ mol\ dm^{-3}$

Since

$[H^+(aq)]_{eq} \times [OH^-(aq)]_{eq} = 1.0 \times 10^{-14}\ mol^2\ dm^{-6}$

$[H^+(aq)]_{eq} \times 0.0145 = 1.0 \times 10^{-14}$

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$[H^+(aq)]_{eq} = 6.9 \times 10^{-13}$ mol dm^{-3}

pH = 12.2

14. The essential point is to select an indicator that will change sharply at the second end point. Thymol blue's red to yellow change is probably the most suitable with methyl orange as as a more familiar alternative.

    Also look for appropriate detail of making up the solution and the titration procedure itself.

    If it is desired to allow students to actually carry out a titration, a sample of sodium carbonate contaminated with a known percentage of sodium chloride could be made up.

    The analysis of this mixture could give practice in making up solutions in volumetric flasks and other aspects of volumetric analysis.