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AN APPROACH IN SUPPORTING UNIVERSITY CHEMISTRY TEACHING

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ABSTRACT: Some new learning materials for First year University students following a course in Chemistry are described. The new materials were paper-based and were called Chemorganiser in that the key aim of the Chemorganisers was to prepare (or organise) the mind for learning. They were designed to provide bridges between what the learner already knows and what is to be learned. They were designed to help the learner organise and retrieve material which has already been learned. They also sought to teach by filling the gaps and clearing areas of misconception. They were used with a large undergraduate class and the effects of their use on learning are discussed in detail. Considerable evidence indicates that they were used, appreciated and were effective in assisting students in learning, there being a special benefit for those students whose previous background in Chemistry was weak. [*Chem. Educ. Res. Pract. Eur.*: 2002, *3*, 65-75]

KEY WORDS: Support teaching materials, undergraduate chemistry, helping understanding, weak students.

INTRODUCTION

In Scottish Universities, an undergraduate course takes four years and, in keeping with the Scottish tradition of curriculum width, students typically follow three courses in their first year of study. Although they have indicated their preferred subject for their degree, they can change this choice in the light of their reaction to the three courses undertaken in year one or even later. In Chemistry, about 800 students undertake the first year course in Glasgow. Some are planning to pursue chemistry as their degree subject while many others take chemistry as an essential support subject for other courses. There are also those who take chemistry merely to complete their first year curriculum.

Two classes are offered: Chemistry-1 (for up to around 600 students) and General Chemistry (up to around 200 students). The work described here applies only to the General Chemistry Class.

In the General Chemistry class, students tend to be studying chemistry because they are required to, in order to support another subject of study. Their commitment levels are frequently low and their background knowledge of chemistry can be very varied. Indeed, some students on this course have no formal chemistry qualifications at all, their entry to university being based on qualifications on other subjects. The wide diversity of entry qualifications in chemistry makes the task of the lecturing team difficult and demanding.

Students in level 1 Chemistry courses would normally be expected to have gained a pass in Higher Grade Chemistry from school, part of the examination system operated in all Scottish schools under the Scottish Qualifications Authority. In the General Chemistry class, about 50% of the students each year have not studied chemistry to a level to gain a pass in this examination. Thus, there was a real need to bridge the gap between their knowledge base and what was to follow.

During the academic year 1997-98, various surveys of General Chemistry student difficulties revealed the key areas where students were not coping well (Sirhan, 2000). This was carried out by scrutinising examination scripts as well as by asking the students about their areas of difficulty by means of a questionnaire. Clearly, there were several areas where the General Chemistry students were experiencing problems. To meet the needs of these students, new teaching materials were devised in order to help the students, especially those with poor background knowledge of chemistry. Monitoring was continued to assess the impact of these new materials and, in particular, their impact on the less well qualified students was explored in some detail.

This paper seeks to describe the new materials and the basis for their construction as well as offering some evidence about their impact. The work was part of a wider programme of research, some of which has been discussed elsewhere (Sirhan *et al*., 1999; Sirhan and Reid, 2001).

INTRODUCING THE CHEMORGANISER

The new materials were described as "Chemorganisers", the name being chosen to reflect their purpose in preparing (or organising) the mind for learning. The Chemorganisers were designed to provide bridges between what the learner already knew and what was to be learned. They were designed to help the learner organise and retrieve material which has already been learned. They also sought to teach by filling the gaps and clearing areas of misconception, based particularly on ideas proposed by Ausubel (1968) and developed by Johnstone (1993). In addition, the information processing model (Johnstone and El-Banna, 1986) was influential in considering the design of the materials. In developing the materials, only topics shown to cause difficulty were covered.

Some sixty Chemorganisers were developed, covering those topics which had previously been found to cause difficulties for students. Practical considerations led to a paper-based format, with each Chemorganiser being designed to fit on to one A4 page in landscape orientation, making it easier for the students to see all the parts of the presentation at one time. The style, language and terminology were made consistent with the way individual lecturers presented the topics. Extensive use of variable typescript formats and shading was introduced to aid ease of use and to emphasise key points.

Each Chemorganiser started by introducing the topic or presenting the problem, followed by a list of the background information which the student would need (entitled: "Before You Start"). The aim here was to focus sharply on the necessary themes and ideas which were important in making sense of the topic, allowing students to recall, as far as possible, previous knowledge. Then, the topic was explained, often using an example, a general strategy was outlined and students were given opportunities to try out their skills, with answers provided. Although each Chemorganiser covered a single topic or idea, links between Chemorganisers were provided so that students could move from one to another logically or could move back to a previous one to clarify underlying ideas.

The aim of the Chemorganisers was to bridge the gap about what they knew and what was to follow in the lecture course. Each Chemorganiser sought to make a single theme accessible by bringing together key ideas, examples and principles in a focussed way. The general format is shown in Figure 1, with some examples of the Chemorganisers given in the Appendix.

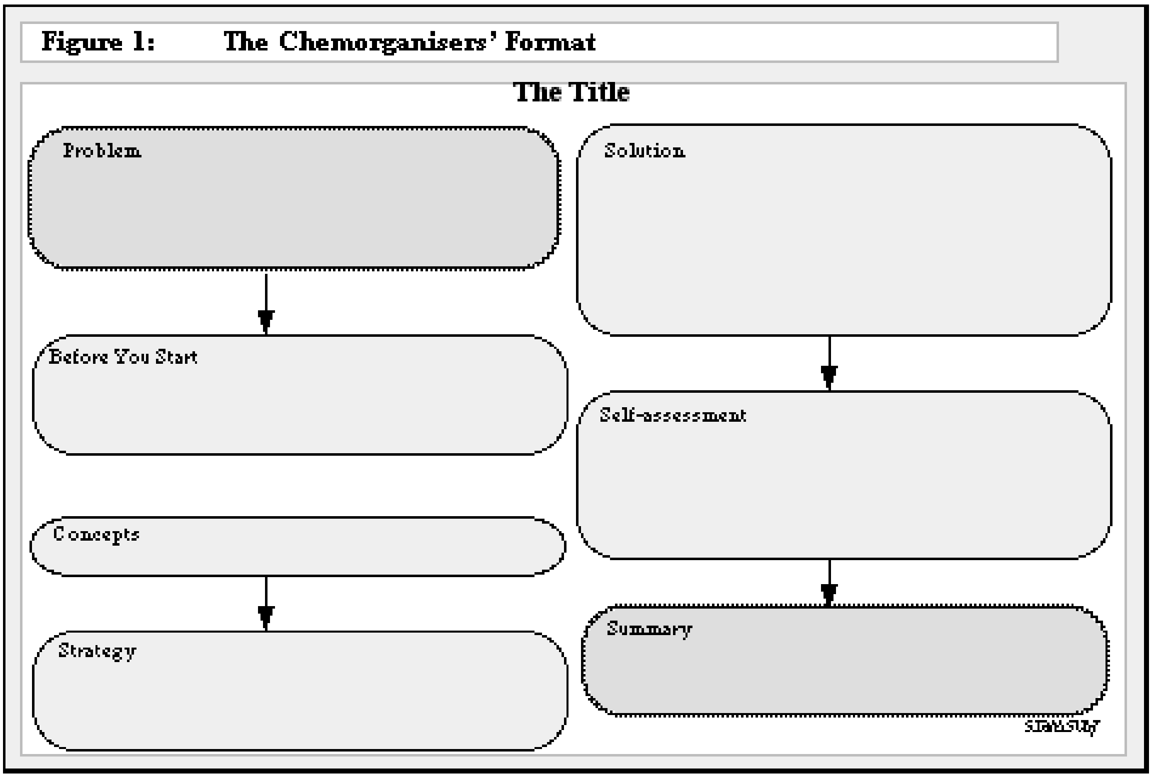

FIGURE 1. *The chemorganisers' format.*

How the Chemorganisers were used

Twelve of the Chemorganisers (mainly those laying down background mathematics) were used in introductory teaching sessions during academic year 1998-99. Each chemorganiser was used as the basis for teaching background material, followed by discussion as the students worked through the material and attempted the self-assessment questions. The atmosphere was unthreatening, involved no assessment and allowed students to be involved in cooperative learning.

However, most of the Chemorganisers (covering topics in inorganic, organic and physical chemistry) were provided for use at the beginning of each block of lectures. There was no pressure on students to take them, to use them, or to use them in a specific way. They were merely made available to students to take if they wished and to be used in whatever way they found most helpful.

THE OUTCOMES FROM USE

A range of observations was made in order to see the effect of the Chemorganisers on student learning. Examination and test scripts were scrutinised and performance was analysed. Surveys of perceived student difficulties were carried out. Questionnaires were used to assess student reaction to the Chemorganisers while interviews were conducted with a small sample. Each of these is discussed in turn.

Examination and test results

In looking at student performance in formal examinations, the class was divided into two groupings according to qualifications in Chemistry gained before university entry. Those with "Upper Qualifications" are those who had achieved a pass at 'C' or better in

Chemistry at Higher Grade in the Scottish Certificate of Education while the "Lower Qualifications" were those entry qualifications in chemistry were less than the 'C' pass at the Higher Grade. [The Higher Grade is the school qualifying examination for entry to Higher Education and a 'C' pass is the accepted 'pass' level]. University Chemistry courses at level 1 tend to assume the knowledge and experience attained by those who have passed Higher Chemistry at school. Thus, the "Upper" Group should have been able to cope with the lecture course while the "Lower" Group might be expected to experience problems.

It has been shown elsewhere (Sirhan *et al*., 1999; Sirhan and Reid, 2001) that the evidence from the examinations data clearly seems to suggest that the Chemorganisers were bringing a specific benefit to the less well qualified group. Table 1 illustrates this. Thus, it appears that the chemorganisers were having the desired effect in bridging the knowledge gap for those who were inadequately qualified on entry.

TABLE 1. *Average examination marks.*

Year	*N*	Average examination marks (%)			
		Whole class	Upper group	Lower group	Difference between groups*
1995/96	169	43.0	46.9	38.7	8.2 (S)
1996/97	163	44.6	48.2	41.9	6.3 (S)
1997/98	229	44.1	46.7	41.3	5.4 (S)
1998/99	192	48.4	49.7	47.7	2.0 (NS)

* S: Statistically significant difference; NS: Statistically non-significant difference.

Class test results were also encouraging. In looking at 18 topics where Chemorganisers were available, there was a marked overall improvement in performance (averaging at around 20%) while, in another 10 topics where Chemorganisers were not used, there was a marginal deterioration in performance (averaging at 4%). Although in no way rigorous, this pattern supports the general impact of the Chemorganisers in supporting learning effectively.

Finally, examination scripts were studied in detail and it was encouraging to note evidence of specific approaches in the Chemorganisers re-appearing in examination scripts showing very clearly that students had been applying ideas established in the Chemorganisers.

Self perception questionnaires

Students were invited to complete questionnaires showing their perceptions of areas of difficulty. In session 1997-98 (before the use of the chemorganisers), 165 students from the General Chemistry class (return rate 72%) completed the questionnaire. Given a list of topics, students were asked to allocate the various topics into three categories: (i) Easy - understood it without difficulty; (ii) Moderate - had difficulties but understand it now; (iii) Difficult - still do not understand it. Exactly the same questionnaire was used for session 1998-99 with the General Chemistry class (when Chemorganisers were in use), the response rate being 79% (152 students). The results are shown in Figure 2. It is clear that the perceived difficulty for many of the topics has fallen while, for some topics, it has actually risen. Without exception, all topics where Chemorganisers were available show a fall in perceived difficulty.

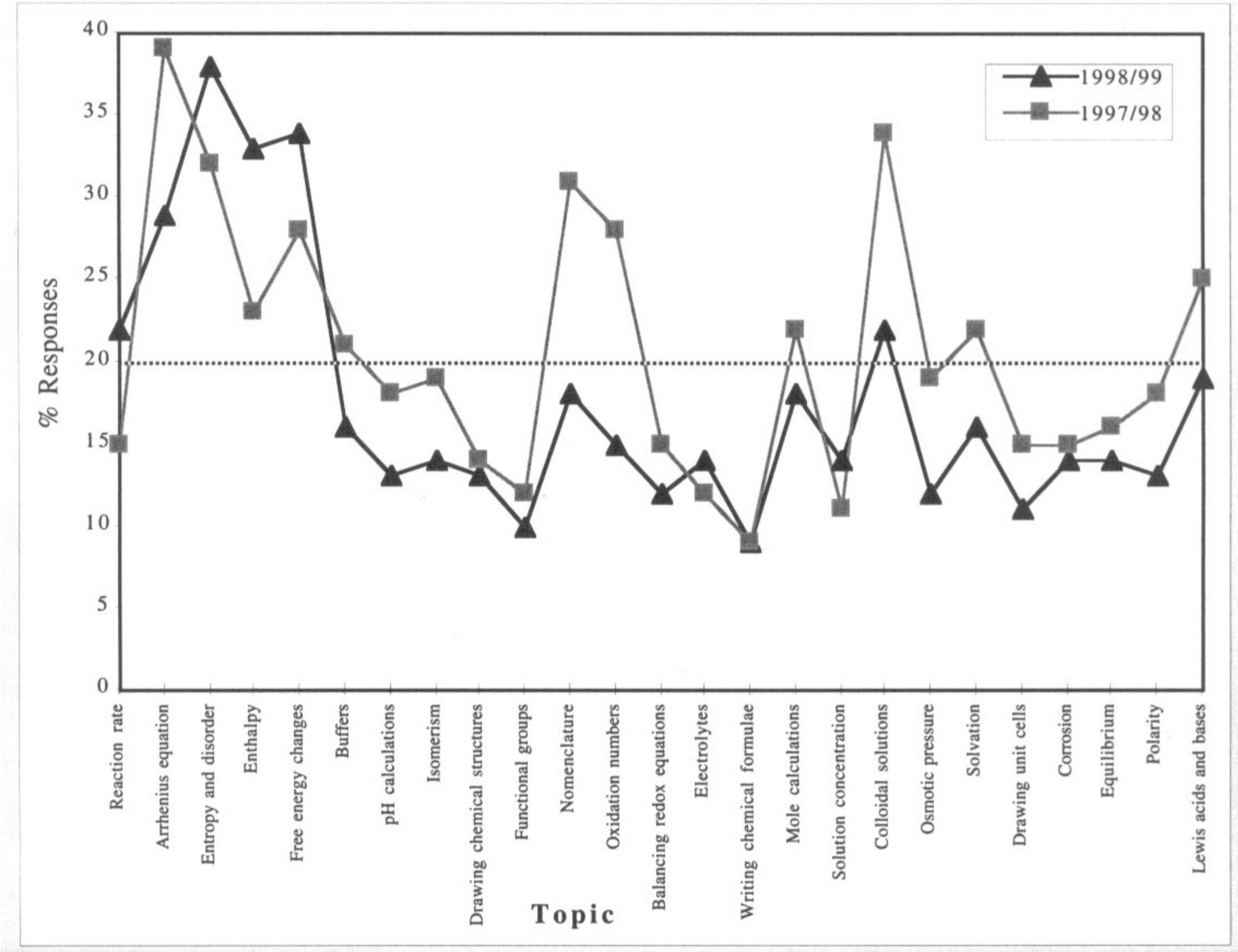

FIGURE 2. *% responses of general chemistry students (topics still difficult).*

Student questionnaires

It was also possible to apply a questionnaire which looked at the use of the Chemorganisers which covered topics which were included in one class test. The questionnaire focussed on the benefit of having and using the Chemorganisers before answering the questions in one of the class tests (test-4, which was held at the end of term-2). For each topic, students were invited to indicate which best described their experience of the Chemorganisers: (i) Used, essential to understand the topic; (ii) Used, helpful to understand the topic; (iii) Used, not very helpful to understand the topic; (iv) Did not use.

A total of 100 General Chemistry students responded to the questionnaire (a return rate of 64%). Overall, about 80% of General Chemistry students used the Chemorganisers, of whom 87% said they found them useful. A space was provided at the foot of the questionnaire for free responses which were analysed to see if there was a pattern of response which might give hints about the problems and the deficiencies in this teaching and learning approach. 71 students' general comments were identified and students said that hey found the Chemorganisers essential and helpful. Indeed, they asked for more of them! Almost all comments were strongly positive. From this group, 14 students (chosen as a cross section of the class) were interviewed in depth to explore their experiences further.

Interviews

Interviewing the General Chemistry students was a good opportunity to gather information about the effectiveness of the Chemorganisers in their own words. It gave useful insights into the way General Chemistry students felt about the Chemorganisers, and provided some evidence about the questionnaire validity. Other insights were also gained such as students' study habits and their attitudes towards chemistry.

The interviews were carried out during the last two weeks of the final term (May, 1999). By this time, all the Chemorganisers had been handed out to students, and the overall picture of the course was clear for them. Interviews lasted for about 30 minutes. The interview covered three main areas: students' study habits, attitudes towards chemistry, and their experiences with the Chemorganisers. A checklist was designed to record students' responses. Only the responses that relate to the Chemorganisers are discussed here. When the students were asked about their experience with the Chemorganisers, their responses were very positive and the idea of the Chemorganisers appealed to them. Critical comments were conspicuous by their absence. Typical comments were:

- *"I find Chemorganisers very clear and precise. They guide me through a problem step by step".*
- *"They are very helpful, like working with a friend".*
- *"Gives more confidence in learning".*
- *"Summary of what done, foundation to build on".*
- *"Helps to focus my study on a particular area of chemistry".*
- *".... important as a summary of the ideas that must be retained".*
- *"Feel a sense of achievement when you realise you can do the problem".*

They believed that introducing a brief theoretical background gave them the confidence and the familiarity to react positively with the topics. They said that the Chemorganisers allowed them the opportunity not offered elsewhere to practice individual questions. This was unexpected in that the course had a set text book which was full of examples and questions. Overall, the interviews confirmed the pattern emerging from the Chemorganisers' questionnaire, where the Chemorganisers were found to be widely used and students found them helpful.

CONCLUSIONS

It has to be remembered that the General Chemistry course is mainly made up of students who have made a conscious decision not to continue chemistry studies beyond that initial university year. Of even greater importance is that about half the class had inadequate previous chemistry experience. The backgrounds and future aspirations of such students tend to generate negative attitudes to chemistry and their ability to study it.

The Chemorganisers were designed to meet specific needs discussed elsewhere (Sirhan *et al*., 1999; Sirhan & Reid, 2001). They clearly brought benefit to the students and to their examination performance (especially the less well qualified) as well as being widely appreciated. Yet, in the content covered by them, they appeared to be in no way novel and they might be seen as *just another way* of presenting the same information.

Perhaps what the Chemorganisers might be doing was to make that information easily accessible. The material was designed for a particular audience, seeking to make the transition for those with a poor background in chemistry to the material of the lecture course. In the Chemorganisers, the information was extracted and collated: it was disembedded from the information presented in a text book to allow the students to focus on single ideas. It was hoped that students would use the Chemorganisers *before* starting each lecture course but there is no certainty that this happened although questionnaires indicated that some used them in this way.

For students with an inadequate background in chemistry and poor levels of motivation and commitment, the selection of information, the linking of that information to previous information and the single focus of each Chemorganiser may all be very important in enabling the students to reach greater success in their university course. With the changing patterns of access to university courses, this may become an increasing need in the years to come.

NOTE: Samples of the *Chemorganisers* can be obtained from either author.

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APPENDIX: SAMPLES OF 'CHEMORGANISERS'

In the following pages, four Chemorganisers are shown to illustrate their style and format.

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Chemorganiser

How to assign Oxidation Numbers to Atoms or Ions

It is often useful to follow chemical reactions by looking at changes in the oxidation numbers of the atoms in each compound during the reaction. Oxidation numbers also play an important role in the systematic nomenclature of chemical compounds.

Problem

Determine the oxidation number of the underlined atoms in the following:

(a) $\underline{S}_8$ (b) $(\underline{As}O_3)^{-3}$ (c) $K\underline{Mn}O_4$ (d) $K_2Cr_2O_7$

Before you start

- The oxidation number (also known as oxidation state) of an atom is the charge that atom would have had if the compound was composed of ions.
- Valency is oxidation number with no sign.
- There are some guidelines in assigning oxidation states (numbers) to atoms in a compound compound or ionic species.

	Oxidation state	Examples	Exceptions
Group 1A (Li, Na, K...)	+1	**LiCl, NaF**	....
Group IIA (Be, Ca, Mg...)	+2	**Be**Cl_2, **Ca**SO_4	....
Group IIIA (Al, B, Ga...)	+3	**Al**Cl_3, **B**F_3	....
Oxygen	-2	Na_2**O**, H_2**O**	peroxides like H_2O_2
Hydrogen	+1	**H**$_2$S, **H**Cl	hydridies like NaH
All elements	zero per atom	**Na** is zero	....
Mono-atomic ions	charge on the ion	**Ca**$^{2+}$ is +2	....

- The **sum** of the oxidation numbers in a **neutral compound** is **zero.**

  eg. In H_2O 2(+1) + (-2) = 0

- The **sum** of the oxidation numbers in a **polyatomic ion** is equal to its **charge**.

  e.g. In $(SO_4)^{2-}$ (+6) + 4(-2) = -2

Concepts

Oxidation state, group, mono-atomic ion, polyatomic ion, charge.

Strategy

(1) Look at each element and find the appropriate rule.
(2) Let x = the oxidation state of the unknown atom
(3) For a neutral compound the sum of the oxidation states is equal to zero
(4) For a polyatomic ion the sum of the oxidation states is equal to the charge on the ion

Solution

(a) For S in S_8 the answer is 0. (Rule 7)

(b) For As in (As O$_3$)$^{3-}$

(x) + 3(-2) = -3
x + (-6) = -3
x = +3 (the oxidation state of **Arsenic** atom in the ion)

(c) For Mn in K Mn O$_4$

1(+1) + 1(x) + 4(-2) = 0
1 = x + (-8) = 0
x = +7 (the oxidation state of **Manganese** atom in the ion)

(d) For Cr in Na$_2$ Cr$_2$ O$_7$

2(+1) + 2(x) + 7(-2) = 0
2 + 2x + 9(-14) = 0
x = +6 (the oxidation state of **Chromium** atom in the ion)

Self assessment

Determine the oxidation state of the underlined atoms in the following:

(a) $H_2\underline{S}O_4$ (b) $K_2\underline{Mn}O_4$ (c) $K\underline{Cl}O_3$
(d) $\underline{S}O_2$ (e) $Mg_3\underline{N}_2$ (f) $Ca_3(\underline{P}O_4)_2$
(g) $Ba\underline{Cr}O_4$ (h) $\underline{I}O_4^-$ (i) $\underline{V}O^+$

Summary

- All Group I elements are + 1
- All Group II elements are + 2
- All Group VII (Halogens) elements are - 1 when ionic
- All compounds have a sum oxidation state of zero
- All elemental substances are zero

Answers: +6 , +6 , +5 , +4, -3, +5, +6, +7, +4

Chemorganiser

Balancing Chemical Equations (Redox)

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way

Problem

Balance the redox equation between copper metal and nitric acid (HNO_3) to give copper ions (Cu^{2+}) and nitric oxide (NO).

Before you start

- A balanced equation has equal numbers of each type of atom on each side of the equation.
- Oxidation-reduction reactions involve the transfer of electrons from one atom to another. *(You cannot have oxidation without reduction)*
- Oxidation is electron loss *(the oxidation state of an atom becomes larger)*
- Reduction is electron gain *(the oxidation state of an atom becomes smaller)*

Concepts

Balanced chemical equation, reduction, oxidation, electron, half reaction

Strategy

(1) Write the half equations:

For the oxidation, electron loss (oxidation state of an atom becomes larger)

eg. $Cu \rightarrow Cu^{2+}$ (oxidation state of Cu atom moves from 0 to +2)

For the reduction, electron gain (oxidation state of an atom becomes smaller)

eg. $NO_3^- \rightarrow NO$ (oxidation state of N atom moves from +5 to +2)

(2) Balance all elements (except O and H) on each half equation

(3) Balance the oxygens using H_2O

(4) Balance the hydrogens using H^+

(5) Balance the charge using electrons (e^-)

(6) Balance the number of electrons gained and lost by multiplying each half equation so that the number of electrons in both is the same.

(7) Add both half equations together

(8) In basic medium (alkali), for each H^+ add OH^- to both sides of the equation.

Solution

(1) Write the half equations

$$Cu \rightarrow Cu^{2+}$$
$$NO_3^- \rightarrow NO$$

(2) Balance by inspection all elements (except H and O)

$$Cu \rightarrow Cu^{2+}$$
$$NO_3^- \rightarrow NO + 2H_2O$$

(3) Balance the oxygens by using H_2O

$$Cu \rightarrow Cu^{2+}$$
$$NO_3^- \rightarrow NO + 2H_2O$$

(4) Balance the hydrogens by using H^+

$$Cu \rightarrow Cu^{2+}$$
$$NO_3^- + 4H^+ \rightarrow NO + 2H_2O$$

(5) Balance the charges by using electrons (e^-)

$$Cu \rightarrow Cu^{2+} + 2e^-$$
$$NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$$

(6) Balance the number of electrons gained and lost by multiplying each half equation (multiplying each species in the first equation by 3 gives 6 electrons and multiplying each species in the second equation by 2 also gives six electrons)

$$3Cu \rightarrow 3Cu^{2+} + 6e^-$$
$$2NO_3^- + 8H^+ + 6e^- \rightarrow 2NO + 4H_2O$$

(7) Add both half reactions together (note the electrons 'disappear')

$$3Cu + 2NO_3^- + 8H^+ \rightarrow 3Cu^{2+} + 2NO + 4H_2O$$

Self assessment

Write balanced equations for the following reactions:

(a) The reaction of permanganate ion (MnO_4^-) with bromide ion (Br^-) in acidic solution for form Mn^{2+} ion and bromine (Br_2);

(b) The oxidation of Cr^{3+} ions by hydrogen peroxide (H_2O_2) in alkaline solution to give chromate ions (CrO_4^{2-}). In this reaction, the hydrogen peroxide is converted to water.

Answers

$$2MnO_4^- + 10Br^- + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 5Br_2$$
$$2Cr^{3+} + 3H_2O_2 + 10OH^- \rightarrow 2CrO_4^{2-} + 8H_2O$$

Chemorganiser

pH Calculations

One of the most frequent uses for common logarithms in chemistry is in working pH problems.

Problem

(a) What is the pH of a solution whose hydrogen ion concentration is 0.015 M ?

(b) If the pH of a solution is - 3.80, what is its hydrogen ion concentration?

Before you start

* The pH is defined as - log [H^+], where [H^+] is the hydrogen ion concentration of a solution. H^+ concentration [H^+] is measured in moles per litres.

Concepts

pH, solution, concentration, common logarithm, log, antilog, [H^+] .

Strategy

(a) **To determine the pH**, use your scientific calculator : find the **log** key.

(1) Input the number 0.015 by typing in the numbers on the keyboard

(2) Depress the **log** key

(3) Read the display and take the negative value: pH = - log [H^+]

(b) **To determine [H^+]**, take the antilog of the pH value (3.80), sign changed.

In your scientific calculator you will find a **10^x** key.

(1) Input the number - 3.80 by typing in the numbers on the keyboard

(2) Depress the **shift** or **INV** key then depress the 10x key

(3) Read the display

Solution

(a) $pH = -\log [H^+] = -\log 0.015 = -(-1.824) = 1.824$

(b) $pH = -\log [H^+] = 3.80$

therefore $\log [H^+] = -3.80$

$[H^+] = \text{antilog}(-3.80) = 1.59 \times 10^{-4}$

Self assessment

(a) What is the pH of the following solutions:

(i) 0.1 M HNO_3

(ii) 0.5 M NaOH?

(iii) 0.1 M H_2SO_4

(iv) 0.002 M KOH

(b) If the pH of a solution is 7, what is its hydrogen ion concentration?

Summary

* The pH is defined as - log [H^+], where [H^+] is the hydrogen ion concentration of a solution.
* **pH = - log [H^+]**

Answer: 1, 0.3, 0.7, 2.7, 1×10^{-7}.

Chemorganiser

Calculating ΔG° from ΔH° and ΔS°

Problem

Calculate ΔG° for the reaction at 298K

	SO_2 (g)	+	1/2 O_2 (g)	→	SO_3 (g)
If ΔH_f° in kJ mol-1 are:	-297		0		-395
S° in J K-1 mol-1 are:	248		205		256

Before you start

* Reactions take place in the direction that allows ***overall*** entropy to increase (Second Law of Thermodynamics).
* If ΔH for a reaction is negative (an exothermic reaction), this provides heat energy to the surroundings, allowing the entropy of the surroundings to increase.

  If ΔS for a reaction is positive, then the entropy of the reaction system increases.

  Combining these two ideas gives us the equation:

  ΔG° (free energy change of the reaction) = ΔH° (enthalpy change of the reaction) - $T\Delta S^\circ$ (entropy change of the reaction)

* If the free energy change of the reaction (ΔG°) has:

  A *negative* value, this means that products are favoured - the reaction equilibrium lies the right hand side. It is said that the reaction is *spontaneous*.
  (this has nothing to do with the speed of the reaction)

  A *positive* value, this means that the reactants are favoured - the reaction equilibrium lies the left hand side. It is said that the reaction is *not spontaneous*.

Concepts

Free energy, enthalpy change, entropy change, spontaneous, exothermic reaction endothermic reaction, equilibrium

Strategy

* Calculate ΔH° and ΔS° for the reaction
* Substitute the values in the equation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

Remember

ΔH° and ΔS° need to be expressed in the same unit of energy.

The temperature should be in the Kelvin scale.

Solution

* To calculate ΔH°

  ΔH_f°: SO_2 (g) 1 x (-297) + 1/2 O_2 (g) 1/2 x (0) = - 297 → SO_3 (g) 1 x (-395) = -395

  ΔH_f° (reactants) ΔH_f° (products)

  ΔH° for the overall reaction = ΔH_f° (products) - ΔH_f° (reactants)

  ΔH° = -395 - [(-297)] = - 395 + 297 = - 98 kJ = **98000 J**

* To calculate ΔS°

  S°: SO_2 (g) 1 x (248) + 1/2 O_2 (g) 1/2 x (205) = 350.5 → SO_3 (g) 1 x (256) = 256

  S° (reactants) S° (products)

  ΔS° for the overall reaction = S° (products) - S° (reactants)

  ΔS° = 256 - 350.5 = **- 94.5 J K-1 mol-1**

* To calculate ΔG°

  ΔG° = ΔH° - $T\Delta S^\circ$
  = (- 98000) J - (298 K) x (- 94.5) JK-1
  = (- 98000) - (- 28161)
  = - 69839 J = **- 69.8 kJ mol-1**

Self Assessment

(a) For the reaction: O_3 (g) + O (g) → 2 O_2 (g)
ΔH° (reaction) = -392 kJ mol-1 and ΔS° (reaction) = 10 J K-1 mol-1.
Calculate ΔG° (reaction) at 25 °C. Is the reaction is spontaneous ?

Use the data given in the table below to solve the following questions.

(b) Calculate ΔG° at 298 K for the reaction: CH_4 (g) + 2 O_2 (g) → CO_2 (g) + 2 H_2O (g)

(c) Calculate ΔH°, ΔS°, and ΔG° for the reaction at 298 K:
2CH_3OH (l) + 3 O_2 (g) → 2 CO_2 (g) + 4 H_2O (l)

	CH_4 (g)	O_2 (g)	CO_2 (g)	H_2O (g)	CH_3OH (l)	H_2O (l)
ΔH_f° (in kJmol-1)	-75	0	-394	-242	-237	-286
S° (in J mol-1 K-1)	186	205	214	189	127	70

Answers: (a) -395 kJ mol-1, yes (b) -802 kJ mol-1 (c) -1458 kJ mol-1, -161 J K-1 mol-1, -1410 kJ mol-1