THE USE OF PROGRAMMED LEARNING MATERIALS TO INVESTIGATE LEARNING PROCESSES IN DIFFICULT AREAS IN SCHOOL CHEMISTRY

by

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1.1. INTRODUCTION

In the past, syllabus reforms in chemistry have been a result of intuitive feelings of what was good for the pupils or on occasion, the consequence of personal whim or fancy of the reforming body. Practising teachers will testify that on many occasions, syllabuses which superficially at least seemed well balanced and logical, turned out to be a labyrinth of confusing ideas for pupils. Is not this "hunch" approach to syllabus construction directly opposed to the "Scientific Method" which the syllabuses aim to instil in the pupils ? Such changes must necessarily be preceded by careful investigation into the conceptual demands likely to be made on the child population concerned, and into the maturity barriers placed in their paths.

Disregarding such problems as inattention, lack of motivation and poor teaching methods, there must lie hidden difficulties which are conceptual in nature. It is certainly not good enough to say that pupils can be taught any topic provided they are taught for long enough using an "ideal" method of teaching. There are some concepts in chemistry which will be beyond the level of conceptual thinking that many pupils will ever reach and it is fruitless to spend uneconomic periods of time teaching these topics.

The prime function of this study was to identify the difficulties in two areas of chemistry syllabuses in Scotland -

(i) The Mole Concept at "O" Grade.

(ii) Colour and Paramagnetism in Transition Metal Complexes in the Certificate of Sixth Year Studies Chemistry.

MOLE CONCEPT

2.1. THE MOLE CONCEPT

(i) The Problems

It is eleven years since the introduction of the alternative "O" grade chemistry syllabus in Scotland[1] and difficulties have arisen regarding the teaching of certain sections of the work. A careful study of these[2] has shown that section H7[3] - "Equations and their use in chemical calculations" and sections J6 and J8 - Calculations to find the molarity of a solution, have amongst others been extremely difficult for pupils to grasp.

Ingle and Shayer[4] have surveyed the Nuffield "O" level syllabus in chemistry, which is used in England and Wales, and they classify the mole concept as stage III_B of Piaget's conceptual levels.[5] This is the stage at which abstract thinking, algebra, proportionality, use of equations etc., become possible. This is Piaget's stage of Formal Operations. At thirteen years, the age at which pupils are taught the mole concept in the Nuffield scheme, Shayer[6] estimates that the concepts involved are only capable of being understood by pupils of I.Q. greater than 125. By 15 years then, it appears that children with an I.Q. above 110 would find this within their conceptual limits (Shayer takes 110 as the minimum I.Q. necessary for Grammar School entry). The startling truth in this is that statistically, only 20% of 14 year old pupils (and 40% of all 16 year olds) will have the mental equipment necessary to cope with the concepts involved in the mole concept. In the Scottish syllabus this concept is taught in S.3. or S.4. i.e. in the second or third year of secondary education, when the pupils are between 14 and 16 years old, and the difficulty experienced by them is blatantly obvious.

(ii) Aims of this work

It is more than likely that teachers of chemistry do not fully appreciate where the difficulties lie in this concept, although they may guess at them, and it was the aim of this work to identify, both positively and objectively, the problem areas. The difficulties on the other hand may not be inherent in the topic but be artificially created by the method of teaching. Different methods of presenting the topic were tried in an effort to see if the results of one method were significantly better than another. Conceptually it may be that the topic is too difficult and that it is a problem of maturity. In this respect, pupils in S.4 and S.5 were tested and the results compared with those in S.3.

2.2. EXPERIMENTAL TECHNIQUES

In all investigations involving the analysis of educational difficulties and methods it is of prime importance that the number of variable factors, which can colour or even obscure an emergent picture or pattern, be minimised. It was with this in mind that programmed learning materials were produced to present the material, and objective testing methods[7] used to search for the difficulties.

All chemical formulae were written in a simple molecular form,[8] which excluded "monsters" like $\underbrace{2H^{+}_{(aq)} + SO_4{}^{2-}_{(aq)}}$; being used to represent sulphuric acid.

The depth of treatment and method of presentation were being controlled, and this it was hoped would exclude freak results which could be caused by over-enthusiastic "mole orientated" teachers who might spend uneconomic periods of time drilling the concept into their pupils to reach perfection in this topic. It would also, of course protect pupils who were at the other end of this scale. For each pupil therefore, the content was identical and the rate at which they consumed the information was under their control, the slower pupils not being penalised by more traditional class (mass) teaching methods.

All available published programs[9,10,11] were studied, but none being completely suitable, material was constructed which was based on a normal class lesson on this subject.

Programs (Appendix I p. 1.)

A frequent criticism of programmed learning materials is that they are both boring and exhausting to work through. Pupils in S.3 in Scottish Schools (14-15 year olds in their third year of secondary education) were taking part in this experiment and an attempt was therefore made to tailor the material to fit their needs.

The topic split naturally into 4 sections and four short programs were constructed, each being of the linear/branching type.[12,13] (See Appendix I p. 1).

Program 1 - This dealt with the fundamental definition of the mole and calculations involving moles of pure substances.

Program 2 - Equations and the mole. Calculations from simple equations e.g. thermal decompositions, without involving concentration terms.

Program 3 - The definition of a molar solution and associated dilution problems.

Program 4/5 - Calculations from equations involving
(a) solids and solutions, and
(b) two solutions, i.e. calculations often involved in simple volumetric analysis.

Also included in this basic frame work, were various methods of presenting a particular idea.

In Program 1 the pupils followed one of three pathways :-

(i) Beginning at frame 1, whereafter they were given a very simple definition of the mole :-

1 mole $\equiv$ 1 G.F.W. (Gram Formula Weight) for any element or compound.

(ii) Beginning at frame 3. A more informed approach was given in that the mole was defined as the very large (but unspecified) number of atoms or molecules which makes up the Gram Formula Weight of a substance.

(iii) Beginning at frame 4. Atoms and molecules were considered to have very small masses (atomic mass units) which could be measured by mass spectrometer. The G.F.W. of any substance was then considered to contain the same number of "particles" as the G.F.W. of any other - a mole of particles, despite the fact that the particles had different masses.

Two different approaches to the calculations involved in volumetric analysis were presented in Program 4 and 5. This is perhaps best illustrated by a simple example.

What volume of 2 M NaOH solution would completely neutralise 100 ml. of 4 M HCl solution ?

Method in Program 4[14] : -

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M HCl neutralises 1 l. of 1 M NaOH

∴ 1 l. of 4 M HCl " 1 l. of 4 M NaOH

∴ 1 l. of 4 M HCl " 2 l. of 2 M NaOH

∴ $\frac{1}{10}$ l. of 4 M HCl " x l. of 2 M NaOH

$$x = \frac{1}{10} \times 2$$

$$= \frac{1}{5} \text{ l.}$$

$$= \underline{200 \text{ ml}}$$

Method in Program 5 : -

From the balanced equation,

1 mole of NaOH will neutralise 1 mole of HCl

$\frac{1}{10}$ l. of 4 M HCl contains 0.4 moles of HCl

$\therefore$ 0.4 moles of HCl neutralise 0.4 moles of NaOH

$\therefore$ Volume of 2 M NaOH solution containing 0.4 moles of NaOH

$$= \frac{\text{number of moles}}{\text{Molarity}}$$

$$= \frac{0.4}{2}$$

$$= 0.2 \text{ l.}$$

$$= \underline{\underline{200 \text{ ml}}}$$

These different approaches were included to see if they had any significant effect on the pupils' understanding of the topic.

Before beginning these programs, all pupils had covered the following topics in their normal class work.

(a) Formula writing

(b) Calculating formula weights

(c) Balancing equations

The programs were used once and subsequently revised in the light of test results. On each occasion, each part of Program 1 was followed by 3 schools (9 in all) and the numbers split between Programs 4 and 5. Almost 300 pupils completed each test.

Tests (Appendix I p. 56)

The pupils sat a test before working through each program (pre-test) and after they had completed it (post-test).[15] The pre-tests and post-tests were in fact identical objective tests. Another group of pupils also completed the tests without the programs but having had a period of formal teaching, covering the material contained in the programs.

Each question was carefully constructed to test specific difficulties and the most plausible wrong answers were included amongst the distractors.

The results of the tests were used in three ways :-

(i) To judge the effectiveness of the programs.

(ii) To pin-point difficulties experienced by pupils.

(iii) To study the effectiveness of different teaching methods.

Each test looked for certain difficulties.

<u>Test 1</u> (accompanying Program 1)

(a) Did calculation of mole quantities present any more difficulty than the calculation of Gram Formula Weights ?

(b) Did formula writing present difficulty ?

(c) Did simple arithmetical calculations like proportionality cause problems ?

(d) How easy did they find conversion from weights of compounds back to moles <u>i.e.</u> reverse of (a) ?

<u>Test 2</u>

(a) Given balanced equations - could they calculate the number of moles of one substance required to react with another ?

(b) As (a), but with equations requiring to be balanced.

(c) As (a), but with extension to include calculation of actual weights.

(d) As (c), but of a more complicated type, involving relatively more difficult arithmetic

Test 3

(a) Was the definition of a molar solution difficult for students to understand ?

(b) Concentration and dilution problems.

Test 4 - As test 2 but involving molar solutions in calculations.

(a) Calculations involving moles of solids reacting with solutions.

(b) Calculations between two solutions i.e. calculations involved in simple volumetric analysis.

The objective nature of these tests made marking by computer possible. The pupils answered the tests on computer cards and a full analysis of the results was therefore accurately and speedily obtained. Facility values (F.V.) and discriminating powers (D.P.)[7] were obtained for each question and overall orders of merit for each complete test.

2.3. VALIDATION AND REVISION OF PROGRAMS AND TESTS

Almost 300 pupils were chosen from 9 Scottish Secondary Schools to sit the tests and use the programs. The schools were selected from various parts of Scotland and ranged from a four year Junior High School to a six year Selective City School.

Programs

Each program was pre-tested and post-tested and the improvement in mean scores from pre-test to post-test was in every case significant at the 1% level[16] (t-distribution significance test) i.e. less than 1% chance of the improvement being caused by sampling. See Appendix II pg. 7

The graphs which follow (figures 1-4) show clearly that the pupils were in general scoring better in every individual question after having worked through the programs.

Test 1 1972

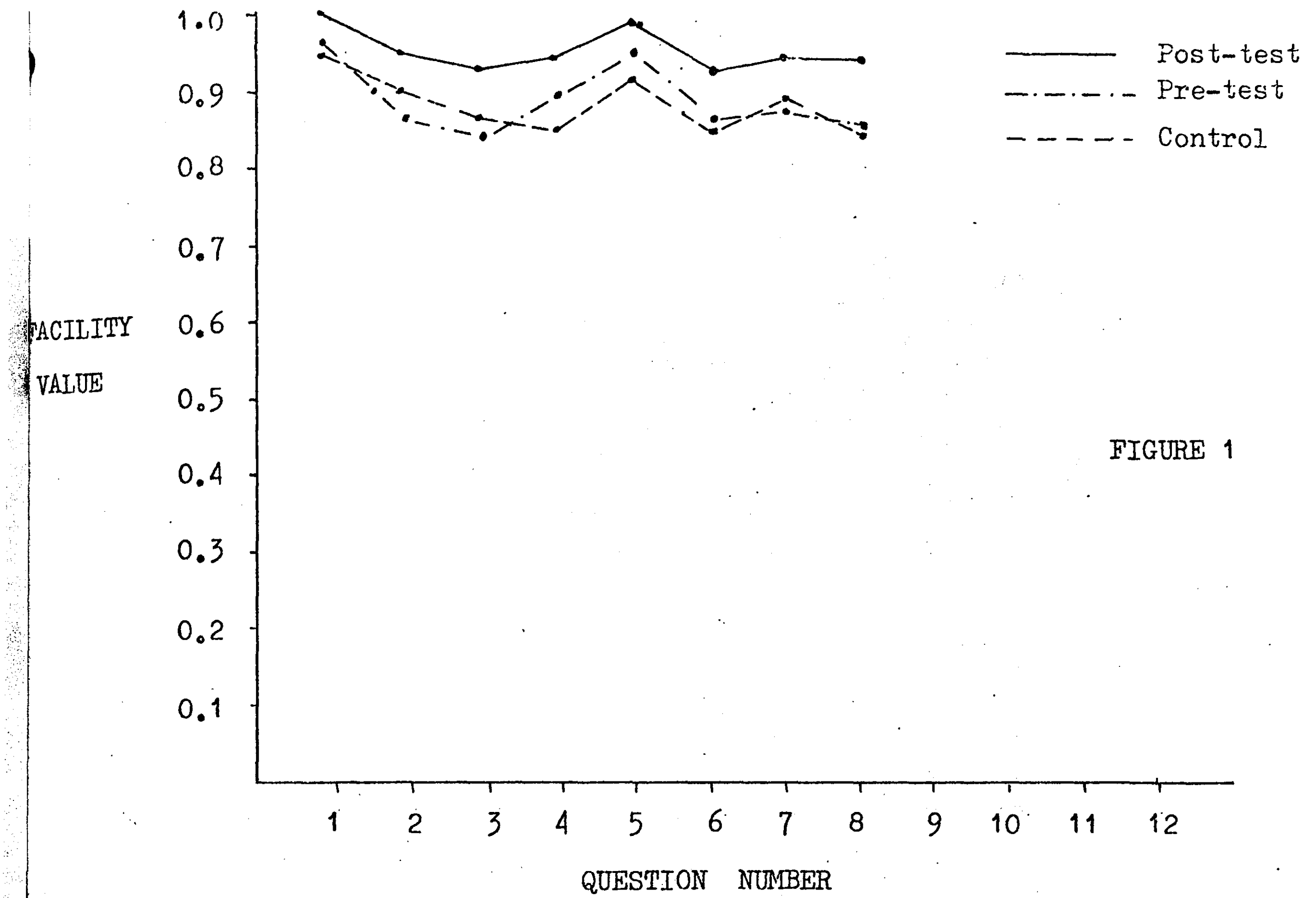


FIGURE 1

Test 2 1972

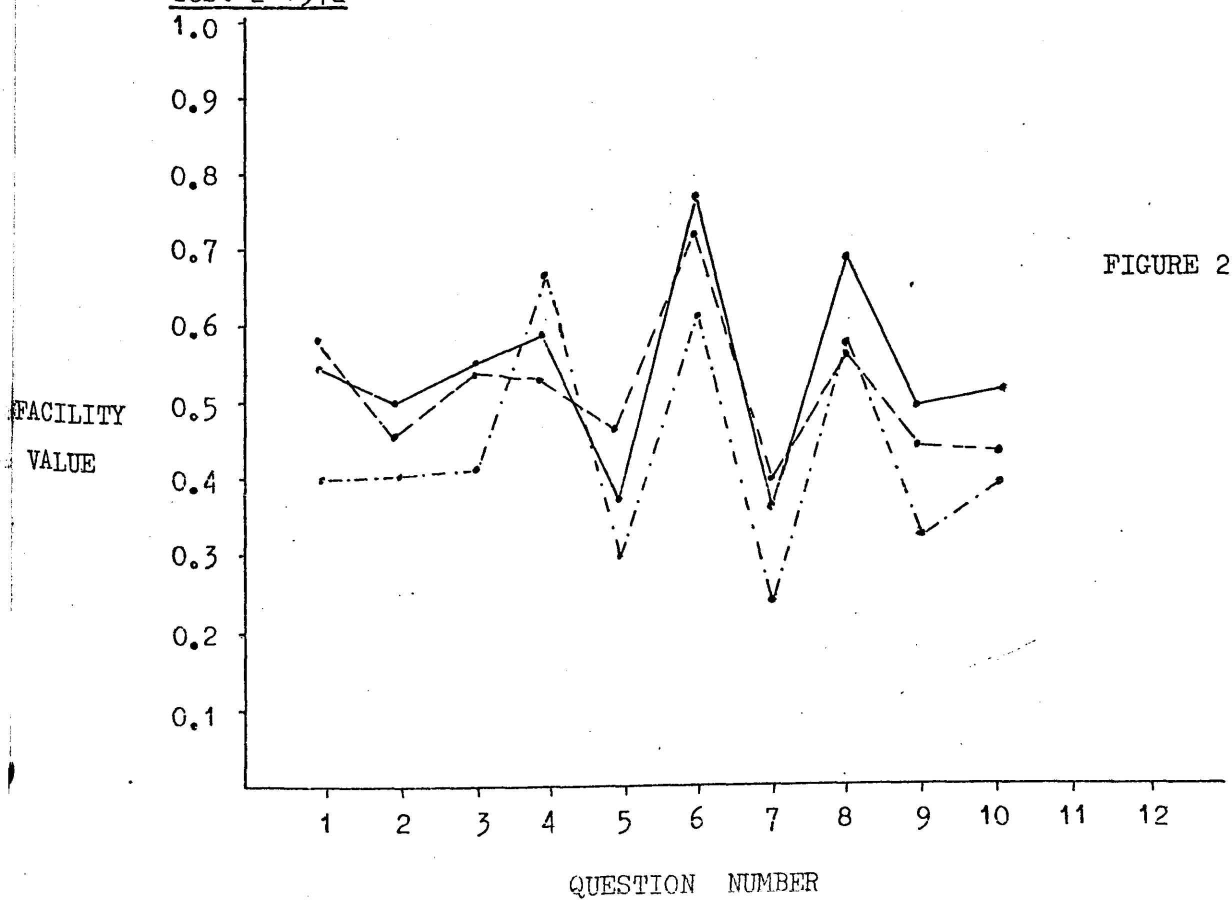


FIGURE 2

Test 3 1972

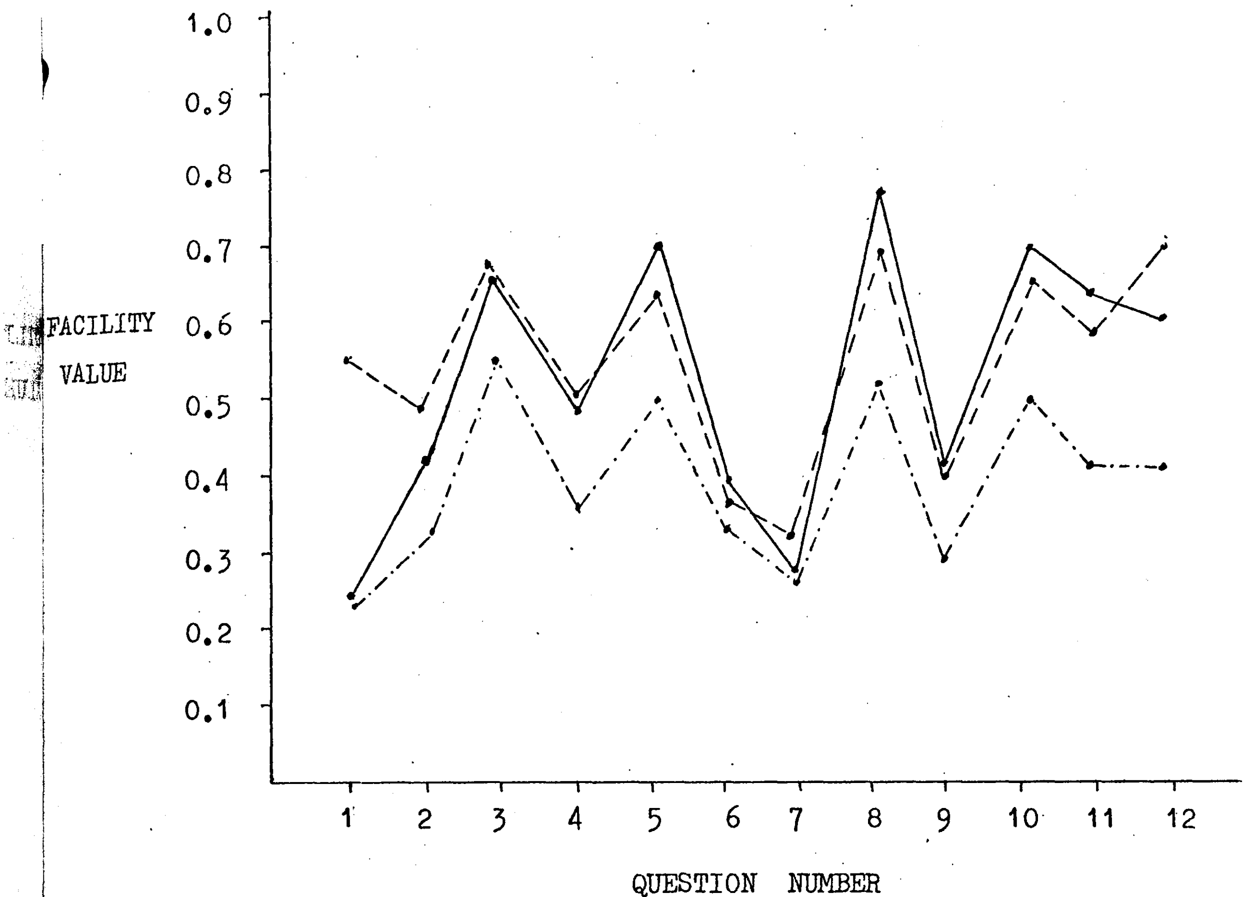


FIGURE 3

Test 4 1972

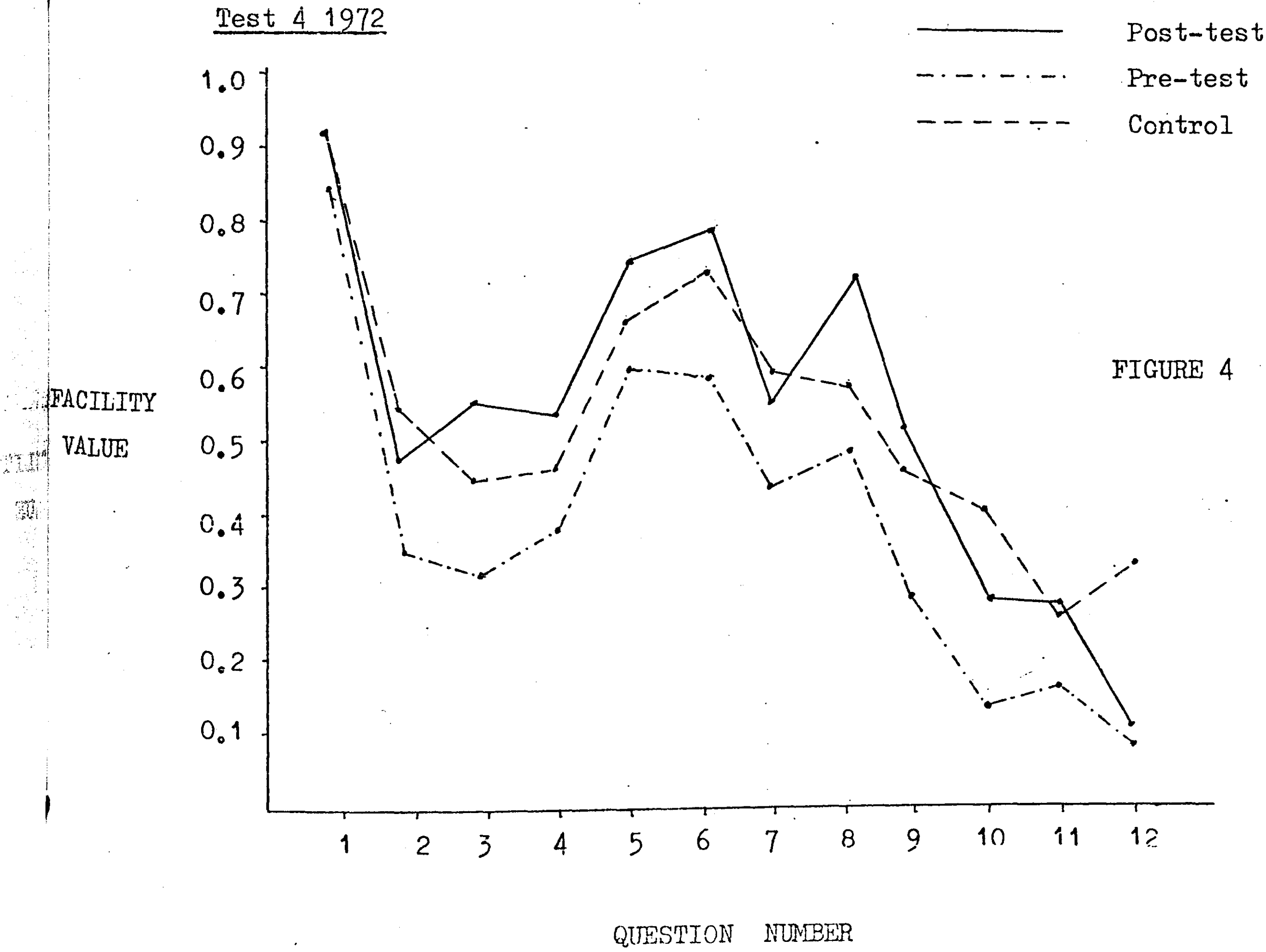


FIGURE 4

Three criteria were adopted for program revision.

(i) If the post-test score was lower than the pre-test score, or not significantly better for any one particular question then revision was called for. In Test 2, question 4, such a situation arose. In this case however the D.P. increased from 0.28 to 0.39, indicating that although the F.V. had dropped, more people who were scoring well in the test as a whole were getting the question correct. In this case, no revision was instituted.

(ii) If the control group were scoring much higher in a particular question, e.g. Test 3 question 1, which asked for the definition of a molar solution. Program 3 was revised considerably in order to alleviate this problem.

(iii) Generally low F.V.'s required further investigation. Many of the lowest F.V.'s occurred in questions which included material not taught in the programs :-

Test 2, question 5.

Given $N_2 + H_2 \longrightarrow NH_3$, how many moles of H_2 are required to react completely with 1 mole of N_2 ? It was considered that equation balancing caused the difficulty here, and the programs made no attempt to teach this. It was however a requirement for beginning the programs.

Difficulty with arithmetic caused F.V.'s to be low, and again as this was not one of the prime functions of the programs no revision was considered.

Where low F.V.'s were common to both the program group and control group it was judged that the difficulty was inherent in the question and not the program.

<u>Tests</u> : In the light of the results (Appendix II p. 5) some of the

tests were revised in order to clarify further some of the pupil difficulties which had arisen, and to remedy some ambiguities which had occurred in construction of the questions.

Test 1 was almost completely revised with only 4 of the original questions remaining. The questions had been too easy and much duplication of ideas had been included.

The number of questions in Test 2 was reduced again to avoid unnecessary duplication of material.

Tests 3 and 4 remained almost unaltered.

2.4. THE DIFFICULTIES

Over 500 pupils took part in this second series of tests and the scores on individual questions are shown on the graphs (figures 5 - 8). Again the improvement in mean scores between pre-tests and post-tests was significant at the 1% level.

The lowest facility values can be seen clearly by looking at these graphs and these indicate where the difficulties lie.

Test 1

Given the correct chemical formula, the pupils had no difficulty in calculating the Gram Formula Weight of a compound, e.g. Q.2.

What is the G.F.W. of $(NH_4)_2SO_4$?

			(Program Group - Post-test)	(Control Group)
	A.	66 g.	3%	3%
	B.	84 g.	5%	1%
	C.	114 g.	8%	10%
* (Key)	D.	132 g.	84%	85%

The transfer from Gram Formula Weights to Moles presented no difficulty, e.g. Q.4.

What is the weight of 1 mole of $(NH_4)_2SO_3$?

	A.	70 g.	4%	2%
	B.	84 g.	7%	3%
*	C.	116 g.	82%	88%
	D.	180 g.	7%	6%

These results were consistent with those in the first series.

Asking for fractions or multiples of moles added no further difficulty, e.g.

Test 1 1973

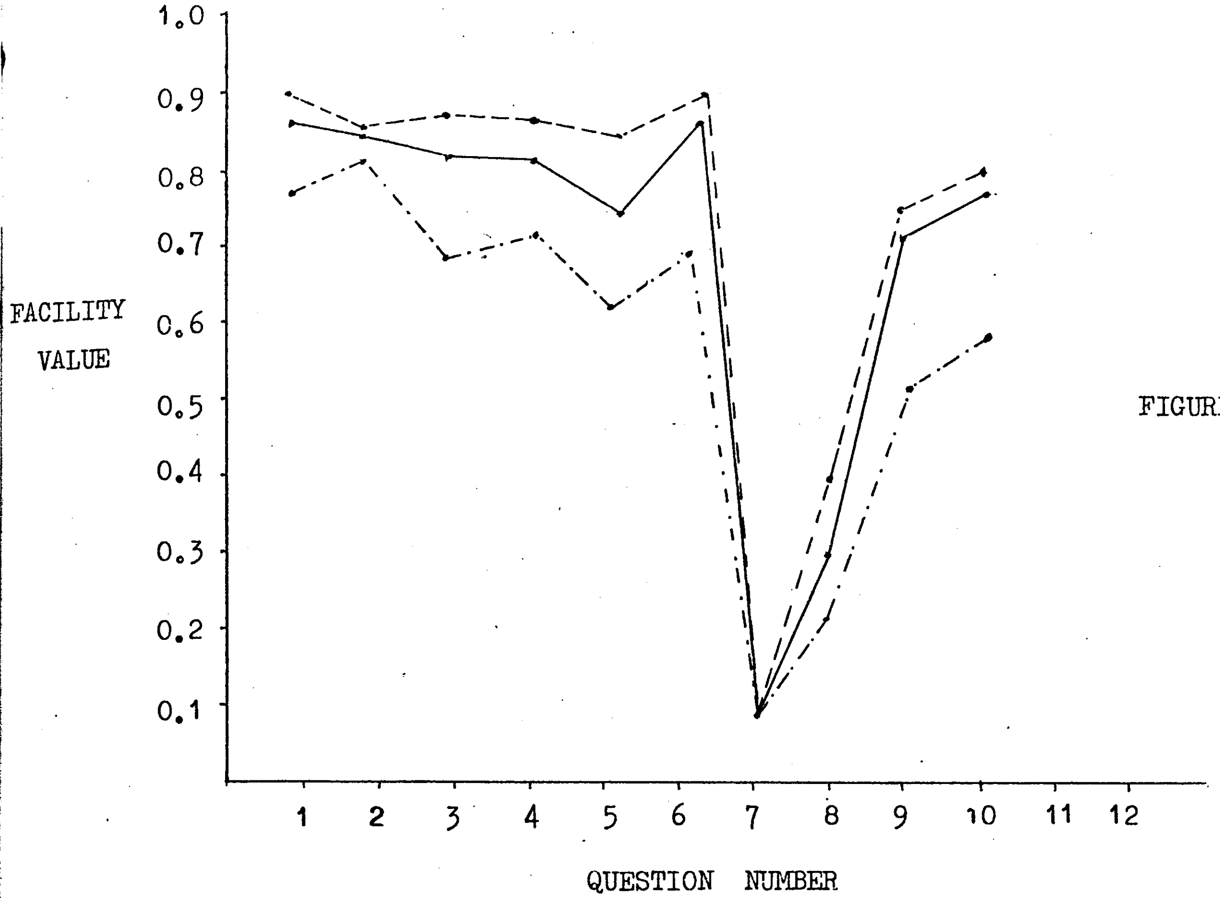


FIGURE 5

Test 2 1973

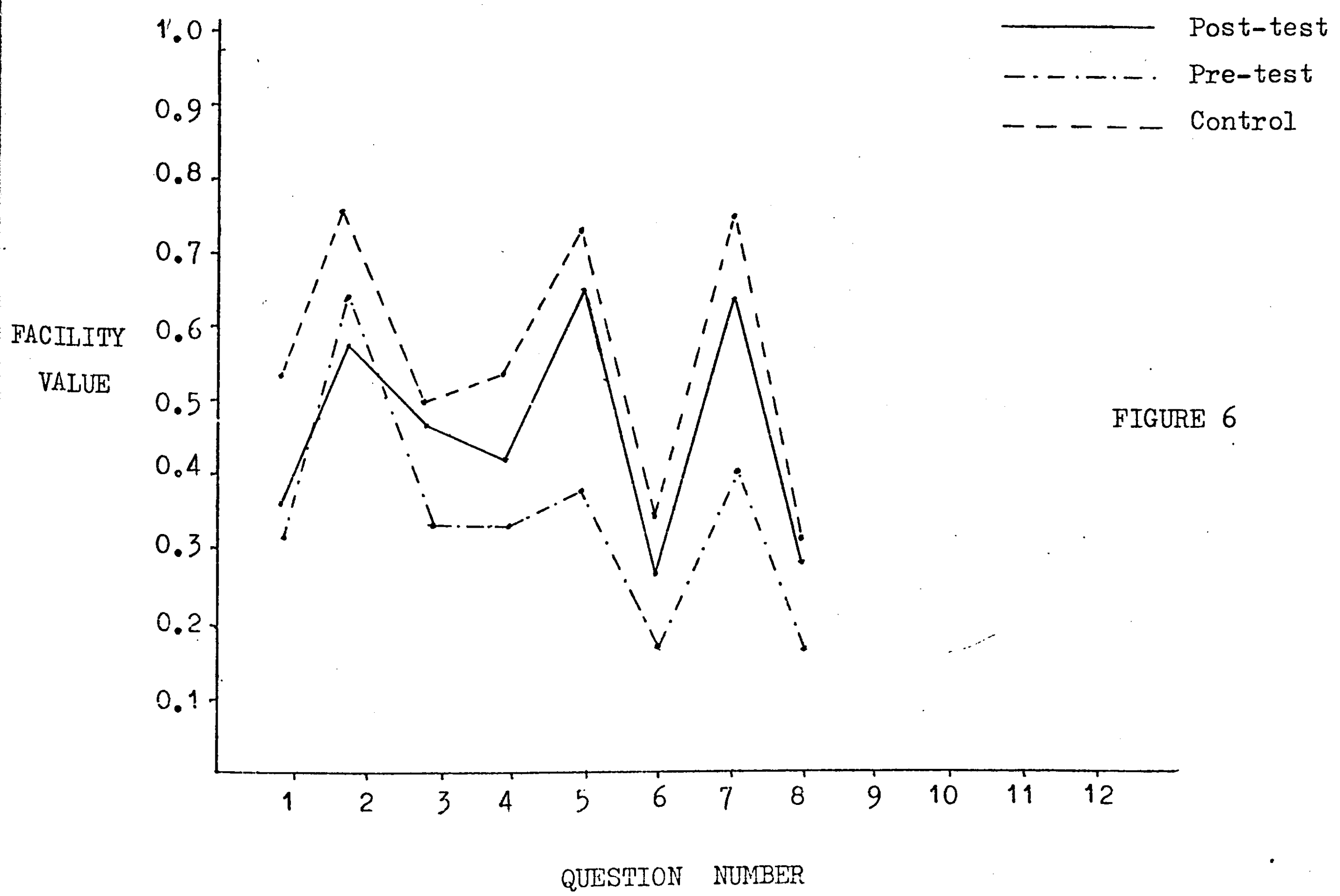


FIGURE 6

Test 3 1973

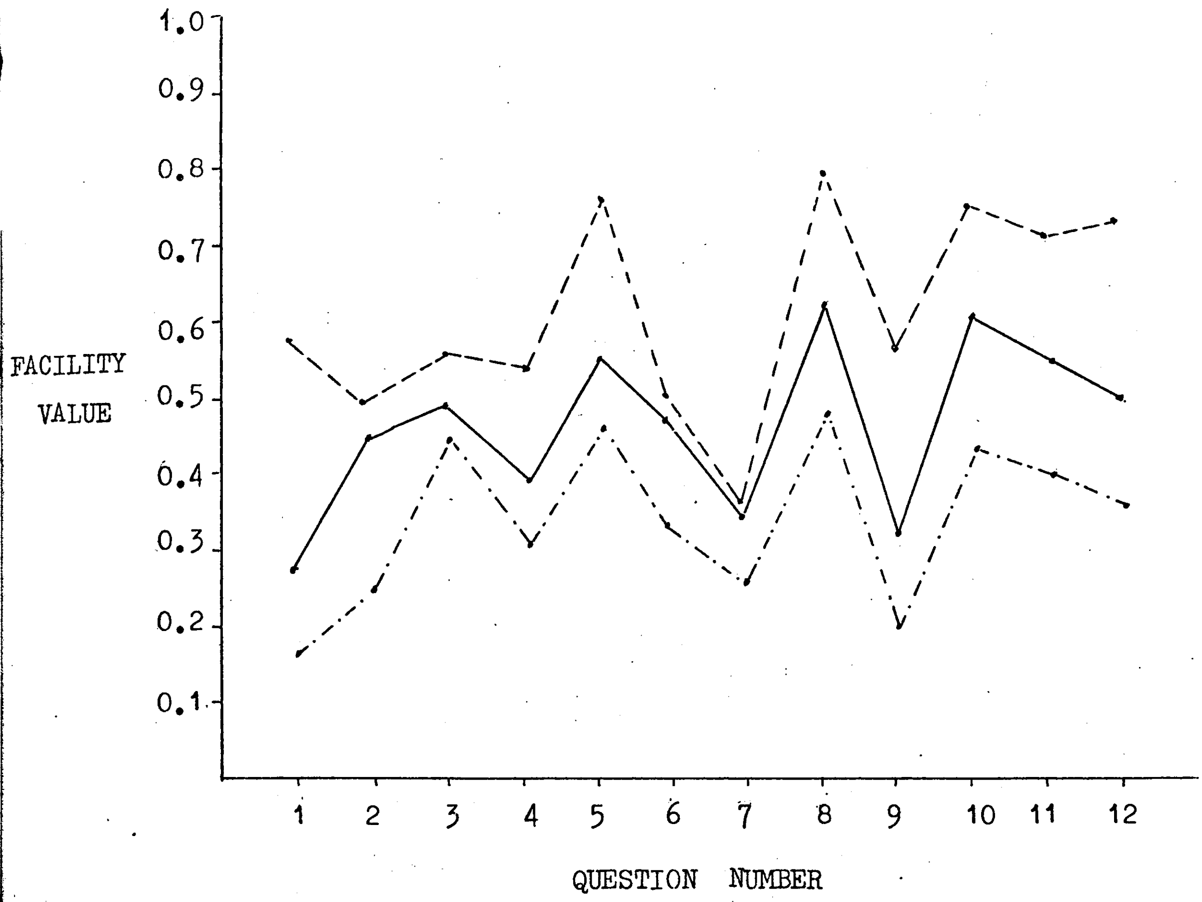


FIGURE 7

Test 4 1973

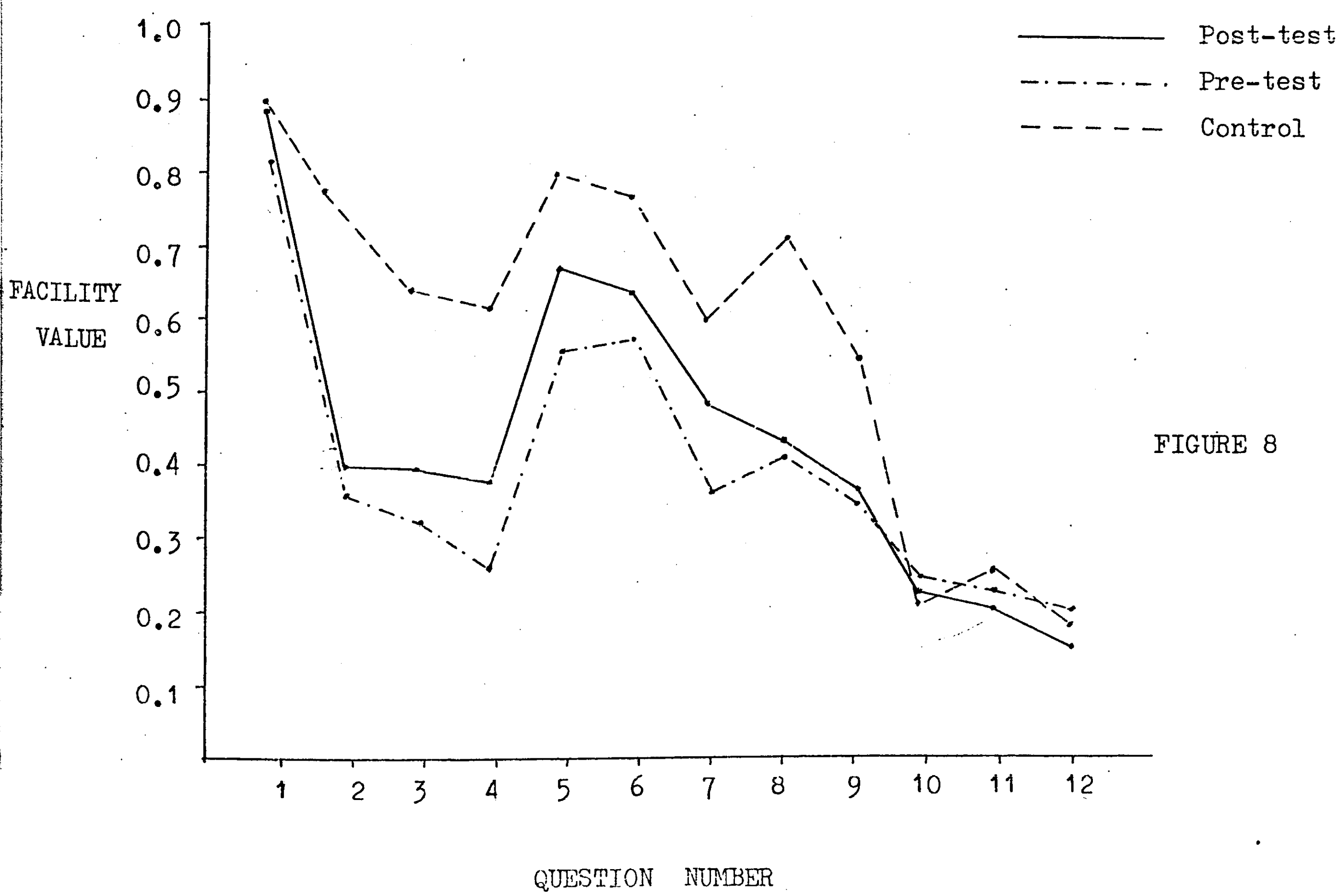


FIGURE 8

	Q.5.	74%	and	86%	chose the key.
and	Q.6.	87%	and	91%	

If the formula was not given and they were only presented with the chemical name, the facility values dropped dramatically.

Q.8. What is the weight of 0.5 moles of sodium sulphide ?

Only 29% and 39% chose the key.

Q.7. What is the weight of 2 moles of magnesium nitrate ?

Only 9% and 8% chose the key.

Formula writing therefore provided considerable difficulty, although it was not part of the concept of the mole.

The reverse process of being given the weight of a compound and being asked to calculate the number of moles present was not difficult, despite the fact that this involved the basic ideas of proportionality.

Q.10. How many moles of H_2SO_4 are contained in 196 g. of the compound ?

76% and 81% chose the key in this case.

Test 2

This test was concerned mainly with the mole and its use in calculations from chemical equations.

The first necessary step in calculating quantities from equations was to balance correctly these equations. This ability was tested in Q. 1.

The correctly balanced form of the equation

$$Al + O_2 \longrightarrow Al_2O_3 \text{ is}$$

	A.	$2Al + O_3 \longrightarrow Al_2O_3$	38	25
	B.	$Al_2 + 3O \longrightarrow Al_2O_3$	25	19
*	C.	$4Al + 3O_2 \longrightarrow 2Al_2O_3$	35%	53%
	D.	$Al_4 + 6O \longrightarrow 2Al_2O_3$	2	2

The fact that only the key contained O_2 may have "given the answer" - i.e. it could have been chosen for the wrong reason.

There was a apparently a fundamental difficulty in understanding the "odd mathematical language", peculiar to chemistry, which is used in equation balancing. Equation balancing was not "taught" in the program as it was a prerequisite of the programs. There were several questions included in these tests which were not testing material taught in the programs and it was significant that in all of these, the control group scored more highly than the program group.

Throughout this test the correct formulae were always given and there seemed little doubt that had chemical names been given rather than formulae, the scores would have been much lower.

Q.2. appeared to be very easy.

Given $2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$, how many moles of NaOH are required to react with 1 mole of H_2SO_4 ?

	A.	$\frac{1}{2}$	3	6
	B.	1	31	15
*	C.	2	58%	76%
	D.	4	8	3

This was a surprisingly low % choosing the key in such a straightforward question. A surprising number of pupils chose B, i.e. 1 mole reacting with 1 mole.

Question 3 was similar :-

How many moles of NO_2 could be obtained from 1 mole of $Pb(NO_3)_2$ if the equation for this reaction is,

$$2Pb(NO_3)_2 \longrightarrow 2PbO + 4NO_2 + O_2$$

A.	½	8	6
B.	1	18	14
* C.	2	46%	50%
D.	4	28	30

Almost 30% blindly copied down the prefix numbers.

The significance of these "prefix" numbers was not obvious to pupils, the majority tending to think that 1 mole always reacted with 1 mole. Questions 6 and 8 involved non 1:1 relationships and provided two definite "dips" in the graphs (figure 6)

The next step in such calculations was to extend the work to actual weights. Question 5 tested this and with a 1:1 relationship involved there seemed to be no difficulty, 66% and 74% choosing the key. The additional step of converting from moles to actual weights presented no difficulty, as expected from the results in the first test. Even when simple proportion was involved in a 1:1 situation (Q.7.) the results were good.

Test 3

The fundamental definition of a molar solution was not well understood by the program group in the first series of tests. Program 3 was rewritten in part to try to alleviate this difficulty - obviously it did not.

Q.1. A 1 Molar solution of hydrochloric acid (HCl) contains

A.	1 mole of HCl dissolved in 1 mole of water.	14	5
B.	1 " " " " " 1 litre " " .	56	35
* C.	1 " " " " " 1 " " solution.	28%	58%
D.	1 " " water " " 1 " " HCl.	2	2

The fine distinction between B and C was not apparent to pupils. Questions 2, 3, 6, and 7 involved complex situations in which concentration, volume and weight of solute were intermixed and as can be seen from the graphs (figure 7) , the scores were low for these questions, e.g. Q.2.

Which solution of HCl is most concentrated ?

A.	500 ml. of 2 M HCl	9	9
B.	1000 ml. of 3 M HCl	20	17
C.	300 ml. of 4 M HCl	27	25
* D.	800 ml. of 5 M HCl	44%	50%

They could not see that the volume was not important and that concentration was the number of moles (or mass) per unit of volume.

Now consider Q.6.

Which of the following solutions contains most NaCl ?

A.	500 ml. of 2 M NaCl	4	4
* B.	1000 ml. of 3 M NaCl	48%	51%
C.	250 ml. of 4 M NaCl	7	5
D.	200 ml. of 5 M NaCl	40	40

They were almost equally split between the largest volume (B) and the biggest concentration (D).

How did they tackle such problems ? Did they work out each one or look at them as a whole complex situation ?

In questions 5 and 8 such simple calculations were given in isolation.

Q.5. If 0.5 moles of NaOH are dissolved in 200 ml. of solution, what is the concentration of the solution ?

56% and 77% chose correctly.

and Q.8. How many moles of NaOH are dissolved in 500 ml. of 4 M NaOH solution ?

64% and 81% chose the key.

The difficulty in the more complex situation may well be one of not knowing where to start - not seeing any line of attack or in seeing the problem as being capable of being done in several small steps. These multi-variant situations seem to be too difficult for pupils at this stage.

Questions 10 and 11 were similar to 5 and 8 but involved weights in place of moles. Again this provided no added difficulty.

10.	61% and 76%	Choose the key
11.	56% and 72%	

Test 4

In this test, the pupils' inability to cope with concentration and difficult arithmetic was quickly shown up.

With very straightforward examples e.g. Q.1 and Q.5 they scored well, although they could be misled very easily as in Q.7. -

If $\frac{1}{2}$ l. of 1 M NaOH is neutralised by 1 l. of a solution of HCl, what is the molarity of the HCl ?

25% of each group chose 2 M instead of $\frac{1}{2}$ M.

The outstanding feature of this test was the poor results obtained in questions 10, 11, and 12, as can be seen from the graphs. The highest facility value being 0.27. In these examples the arithmetic was more complicated, the equation was not one involving a simple 1:1 relationship and on the whole the situation was rather too complex, e.g. Q.12.

If 20 ml. of 2 M H_2SO_4 neutralises 100 ml. of NaOH solution, what is the molarity of the NaOH solution ?

A.	0.04 M	25	17
B.	0.08 M	12	9
C.	0.40 M	46	55
* D.	0.80 M	16%	19%

Summary

As a result of these tests, some of the difficulties experienced by pupils in understanding this concept have been identified.

(i) Writing chemical formulae.

(ii) Balancing chemical equations.

(iii) Understanding the significance of the prefix numbers used in chemical equations.

(iv) Manipulating concentration and volume variables in problems concerning dilution etc.

(v) Coping with complex, multivariant situations.

(vi) Dealing with difficult arithmetic, or more precisely, figures which are not easily imaginable.

2.5. METHOD AND THE MOLE

The programmed materials were used to enable methods of presentation of the topics to be carefully controlled.

In the first program, three approaches were adopted for introducing the fundamental theory involved in the mole concept. This has already been outlined - 2.2 page 2 . Approximately 90 pupils followed each route, but it was not possible to match these groups initially and the significance of the results could not be verified statistically.

The third method which involved the most detailed definition of the mole produced the least improvement in Test 1.

Mean scores	P_1	P_3	P_4	Control
Pre-test 1	4.5	6.1	6.7	-
Post-test 1	6.4	7.1	6.7	7.3

P_1 identifies the group following the simplest route through Program 1. P_3 and P_4 identify the other two groups using the other routes through Program 1.

The third group (P_4) started off in this pre-test with the highest score and continued to gain the highest mean scores throughout all of the tests, with the exception of Post-test 1. The second group (P_3) were always better than the first group (P_1) except in the final test.

None of these methods produced results which were outstandingly better than the other (Appendix II p. 3) and even the control group, undoubtedly subjected to many methods of teaching, did not score highly in this test.

In another part of this topic -- "Volumetric type calculations" - two groups were chosen, each of about 140 pupils. These groups followed different teaching methods as outlined in 2.2. p. 3

Mean scores	P_4	Number in group	P_5	Number in group	Control
Pre-test 4	4.5	145	5.3	85	-
Post-test 4	4.7	140	6.3	86	7.2

P_4 and P_5 identify the two separate groups using the fourth and fifth programs. Each group sat the same pre-test and then followed their separate programs before sitting Post-test 4.

Program 5 (Group P_5 above) produced a greater improvement and it is worth noting that this program encouraged the use of a formula ($m = \frac{N}{V}$) in these calculations, with or without understanding how the formula was derived. The other group (P_4) were encouraged to use a more intuitive and understanding approach.

Neither of these methods however, produced satisfactory scores in such a test.

The method of teaching this concept therefore does not seem to be the factor which limits the pupils' ability to cope with this topic and it is probable that it is more of a conceptual problem linked to the maturity of the pupils concerned.

2.6. MATURITY FACTORS

Any investigation into maturity factors affecting a situation must by its very nature be lengthy. This was not possible in this case and the results shown below may be taken only as an indication of the maturity problem.

Test 1

	Mean	S.D.	number in group
Class III	7.3	1.9	241
IV	8.2	1.8	188
V	8.3	2.1	87

Test 2

	Mean	S.D.	number in group
Class III	4.5	1.9	241
IV	5.8	2.0	181
V	6.8	1.6	86

Test 3

	Mean	S.D.	number in group
Class III	7.2	2.9	246
IV	7.5	2.9	187
V	8.9	2.1	78

Test 4

	Mean	S.D.	number in group
Class III	7.2	2.4	151
IV	7.0	3.3	172
V	9.6	2.0	68

With only one exception the maturer the group, the better was the score. Of course the group from Class V included only the best of the Class IV group, but those in Class III were of similar ability to those in Class IV.

The recent findings of T.V. Howe[23] agree to a great extent with these results and he has concluded that the later a topic is taught to pupils the greater is the chance that they will grasp it.

It is most likely then, that the mole problem is one of conceptual difficulty and that delaying the onset of teaching this topic might improve the pupils' understanding. Along with this however must be considered the fact that those who did better in the preceding tests had been exposed to the topic for a longer period, i.e. they were more familiar with it.

As well as allowing the pupils to increase in maturity before presenting them with the concept, it seems that the concept has to mature within the pupils before comprehensive understanding is achieved. This of course presupposes that the pupils will have sufficient intellect to reach such a state of conceptual thinking - eventually - Piaget's Formal Operations Stage - as some school pupils will never reach this stage no matter how long they wait.

2.7. Discussion of Results and Suggestions for Further Work

The introductory note in the Scottish Certificate of Education Examination Board, Chemistry Ordinary and Higher Grades[3] makes reference to the syllabus - "The approach therefore is conceptual rather than factual and the relation of observed facts to fundamental principles is emphasized throughout". Also included in this publication, in a preface by the Director of the Board - "As a result of experience gained with the Alternative Chemistry syllabuses for Ordinary and Higher Grades contained in Scottish Education Department Circular 512,[1] the Board's Subject Panel has recommended that certain adjustments be made to the syllabuses".

Was the "experience gained" referred to in this statement related to the conceptual demands made upon the pupils or to the amount of factual material as mentioned in the introductory note ? The indications are that the logical syllabus has not appeared quite so coherent to pupils, and that they have been presented with ideas and concepts which are beyond their reach.

The level of understanding required in the mole concept is such that regardless of teaching method, many pupils will never fully grasp this topic by the time they reach the age of 16.

The processes of formula writing and equation balancing although abstract in nature and requiring a level of understanding appropriate to Piaget's Formal Operations Stage, can probably be mastered, at least in the short term, by drilling and repeated exposure to the problems. Consider this example,

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

In balancing this equation, why is it wrong to write 4O or O_4 instead of $2O_2$? The odd mathematical 'language' peculiar to chemistry, combined with deep seated conceptual problems such as this, make equation balancing extremely difficult for pupils to understand.

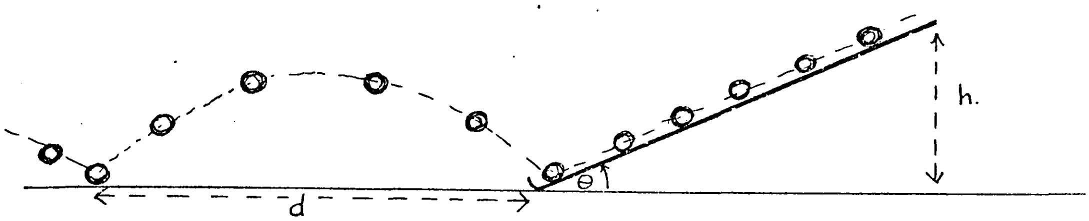
Persistent drilling could also enable pupils to master the problem of deducing mole relationships from balanced equations without necessarily understanding why they do it. The desirability of such methods is of course open to criticism.

The calculation of the mass of a mole of a compound when given correct chemical formulae is readily grasped, probably because it is very similar to the mechanical, mathematical evaluation in parts, e.g. in calculating the mass of 1 mole of H_2O.

$$
\begin{aligned}
H_2O &= 2H + O \\
&= 2 \times 1 + 16 \\
&= 18 \text{ g.}
\end{aligned}
$$

The depth of treatment of the mole concept in the Scottish "O" Grade should "float" at this shallow level and leave the problems of concentration and volumetric type calculations until the pupils reach a suitable stage of mental maturity.

The latter problems are multivariate in nature and can be compared with Piaget's problem of rolling spheres down an inclined plane.[5] The pupils are faced with the problem of discovering the factors which determine the distance (d) the ball jumps after rolling down the slope.



d depends on the angle of the runway θ

d depends on the distance up the slope ℓ.

These are observations of "concrete" behaviour interpreted in an abstract manner. Pupils with a higher level of conceptual development can however visualise a relationship between these two apparently unrelated relationships -

d depends on h alone, and that

$$h = l\sin\theta$$

It is reasoning on this higher plane - drawing conclusions from two or more related abstract relationships - that is necessary to extend the mole into use in problems involving concentration.

Mass of solute varies with volume of solution.

Mass of solute varies with concentration of solution.

The mass of solute therefore depends on both factors.

Volumetric analysis type calculations involve simple proportion and this provides similar difficulties in that two interdependent abstract relationships have to be considered. It is interesting to note however that when the figures are "simple", the student performance improves. When the numbers used in such multivariate situations are not easily imaginable or not within the concrete experience of the pupils, the problems are very great indeed.

The results of the tests carried out in this work suggest - any implication stronger than suggestion being invalid in the absence of reliable statistical evidence - that pupils do eventually "crack" this problem, and that perhaps it is only as a result of meeting these logical relationships in a large number of concrete and pseudo-concrete (visual representation and calculation) situations over 4 or 5 years, that enables the pupils to generalise between one concrete relationship and another, using verbal and mathematical reasoning as their tools and so enter Stage III of Piaget's Conceptual Levels. Not only must the pupils be mature, but the topic must mature within the pupils.

If the approach to the syllabus must be conceptual and not factual, the stages of the course should follow an order of increasing complexity, consistent with the pupil's own conceptual development. The subject matter must therefore be closely examined for areas of conceptual difficulty. Once these have been identified, the % of the pupil cohort capable of grasping the particular topic must be determined before a decision is reached as to its chronological placement in the syllabus order. The feasibility and indeed the necessity of including the topic should then be studied.

This extended form of maturity experiment would take many years to develop and meanwhile, those who struggle to teach this topic should attend to the following :-

(a) Ensure that the concept of the mole is not obscured by the problems of formula writing or equation balancing.

(b) Reduce arithmetical difficulties to a minimum.

(c) Accept the fact that for many pupils, mechanical drilling will be the only means of solving the more difficult problems associated with this concept.

2.8. APPENDIX I

PROGRAMS and TESTS

Program 1, 1973

1. The Gram Formula Weight (shortened to G.F.W.) of a compound can also be called a MOLE of the compound.

Your teacher asks you to weigh out the G.F.W. of water. He might also have asked you to weigh out one __________ of water. (Write your answer in the space provided.) ⟶ 2.

2. YOUR ANSWER - HE MIGHT ALSO HAVE ASKED YOU TO WEIGH OUT 1 MOLE OF WATER. GOOD THIS IS CORRECT. ⟶ 18.

3. The Gram Formula Weight of a compound (shortened to G.F.W.) contains a large number of molecules of the compound.

If the G.F.W. of water is measured out, will it contain only a few or many molecules ?

______________________________ (write your answer here) ⟶ 5.

4. Atoms and molecules have very small masses and special units are used to measure their mass. They are called atomic mass units (shortened to a.m.u.).

If one molecule of nitrogen has a mass of 28 a.m.u., what will be the mass of 10 nitrogen molecules ?

______________________________ (write your answer here) ⟶ 6.

5. THE G.F.W. OF WATER WILL CONTAIN MANY WATER MOLECULES - GOOD.

If we have one DOZEN eggs we have ________ eggs.

If we score a CENTURY at cricket we have scored ________ runs. ⟶ 7.

6. YOUR ANSWER - 280 a.m.u. (atomic mass units) - GOOD !

If one hydrogen molecule has a mass of 2 a.m.u., what is the mass of 10 hydrogen molecules ? ________________ ⟶ 8.

7. 1 DOZEN = 12
1 CENTURY = 100 CORRECT

The number of molecules in the G.F.W. of a compound (Gram Formula Weight) is called a MOLE.

The MOLE then is a number, just like a __________ or a ______________. ⟶ 9.

8. 10 HYDROGEN MOLECULES HAVE A MASS OF 20 a.m.u. - CORRECT.

10 molecules of hydrogen have a mass of 20 a.m.u.
10 molecules of nitrogen have a mass of 280 a.m.u.

If you had 2 g. of hydrogen molecules and 28 g. of nitrogen molecules, would there be,

(a) the same number of molecules in each pile ☐ ⟶ 10.

(b) a different number of molecules in each pile ☐ ⟶ 11.

(Put a TICK in the box you choose.)

9. THE MOLE IS A NUMBER JUST LIKE A DOZEN OR A CENTURY - CORRECT.

The G.F.W. of a compound contains one MOLE of molecules of the compound.

How many water molecules are there in the G.F.W. of water

______________ ⟶ 12.

10. 2 g. OF HYDROGEN MOLECULES WOULD CONTAIN THE SAME NUMBER OF MOLECULES AS 28 g. OF NITROGEN - VERY GOOD. ⟶ 16.

11. (b) A DIFFERENT NUMBER IN EACH PILE - SORRY, THIS IS NOT CORRECT.

Imagine that you have been given 2 bags of nails, one full of small nails, each weighing 2 g, and one full of larger nails, each weighing 28 g.

How many nails are there in (a) the small bag, it it weighs 20 g. ____
and (b) the larger bag, if it weighs 280 g. ____

⟶ 13.

12. YOUR ANSWER - THE G.F.W. OF WATER CONTAINS 1 MOLE OF WATER MOLECULES - GOOD.

The G.F.W. of any compound contains one mole of molecules.

The G.F.W. of nitrogen is 28 g. How many nitrogen molecules does it contain ? ______________ ⟶ 14.

13. (a) NUMBER IN SMALL BAG = 10 } CORRECT
(b) NUMBER IN LARGE BAG = 10 }

Even although the bags have different weight, they still contain the same number of nails.

If you have 20 kg. of small nails and 280 kg. of large nails in bags, would you have the same, or a different number in each bag ? ____________ ⟶ 15.

14. 28 g. OF NITROGEN CONTAINS ONE MOLE OF NITROGEN MOLECULES - GOOD

⟶ 18.

15. THERE WOULD BE THE SAME NUMBER OF NAILS IN EACH BAG.

1 kg. = 1000 g.

Therefore No. of small nails $= \frac{20 \times 1000}{2}$ No. of large $= \frac{280 \times 1000}{28}$

$= 10,000$ $= 10,000$

Will 2 g. of hydrogen contain the same, or a different number of molecules from 28 g. of nitrogen ? ____________ ⟶ 10.

16. The G.F.W. of Hydrogen = 2 g.
The G.F.W. of Nitrogen = 28 g.

Are there the same number of molecules in the G.F.W. of Hydrogen (2 g.) as there are in the G.F.W. of Nitrogen (28 g.) ? ______ ⟶ 20.

17. YOU CHOSE (a) THE G.F.W. OF WATER = 16 g. THIS IS NOT CORRECT.

G.F.W. of H_2O = 2 x 1 (for the hydrogen atoms)
+ 16 (for the oxygen atom)
= 2 + 16 = 18 g. ⟶ 22.

18. Which of the following is the correct G.F.W. for water (H_2O) ? (Atomic Weights are given on the final page of this program.)

(a) 16 g. ☐ (Put a tick ⟶ 17.
(b) 17 g. ☐ in the box ⟶ 19.
(c) 18 g. ☐ you choose.) ⟶ 21.

19.(b) THE G.F.W. OF H_2O = 17 g. - NO !

G.F.W. = 2 x 1 (for the hydrogen atoms)
+ 16 (for the oxygen atom)
= 2 + 16 = 18 g. ⟶ 22.

20. YES, THERE ARE THE SAME NUMBER OF MOLECULES IN THE G.F.W. OF HYDROGEN AS THERE ARE IN THE G.F.W. OF NITROGEN.

The G.F.W. of any compound contains the same number of molecules as the G.F.W. of any other compound.

If the G.F.W. of HCl = 36.5 g. and the G.F.W. of HNO_3 = 63 g., does 36.5 g. of HCl contain the same number of molecules as 63 g. of HNO_3 ? ____________ → 23.

21.(c) THE G.F.W. OF H_2O = 18 g. - VERY GOOD → 22.

22. What is the G.F.W. of Ammonia (NH_3) ?

(a) 16 g. ☐ → 24.
(b) 17 g. ☐ → 27.
(c) 45 g. ☐ → 28.

23. YES, 36.5 g. OF HCl WILL CONTAIN THE SAME NUMBER OF MOLECULES AS 63 g. OF HNO_3, SINCE THE G.F.W. of any compound contains the same number of molecules as the G.F.W. of any other compound.

The <u>number</u> of molecules in the G.F.W. of a compound is called a <u>MOLE</u>.

How many molecules are there in the G.F.W. of water ? __________ → 25.

24.(a) THE G.F.W. OF NH_3 = 16 g. THIS IS WRONG.

You cannot calculate the G.F.W. of a compound. Return this program to your teacher and sit quietly.

25. YOUR ANSWER - THE G.F.W. OF WATER CONTAINS ONE <u>MOLE</u> OF MOLECULES - CORRECT. The G.F.W. of any compound contains one mole of molecules.

What is the name given to the number of molecules in the G.F.W. of a compound ? ____________ → 26.

26. 1 MOLE - VERY GOOD. → 18.

27. THE G.F.W. OF NH_3 = 17 g. QUITE CORRECT.

$$G.F.W. = 14 + 3 \times 1$$
$$= 17\ g.$$

Now, if your teacher asks you to weigh out

(a) The G.F.W. of NaCl

(b) 1 Mole of NaCl

What weight of NaCl would you have in each case ?

(a) ________________ (b) ________________ ⟶ 29.

28.(c) THE G.F.W. OF NH_3 = 45 g. THIS IS NOT CORRECT.

You do not know how to calculate the G.F.W. of a compound. Return this program to your teacher and sit quietly.

29.(a) THE G.F.W. OF NaCl = 58.5 g. (23 + 35.5) } i.e. 1 MOLE
(b) 1 MOLE OF NaCl = 58.5 g.

YOU WOULD WEIGH OUT THE SAME AMOUNT IN EACH CASE.

To find the weight of one mole of a compound you simply calculate the ________________ of the compound. ⟶ 30.

30. G.F.W. - GOOD. 1. G.F.W. = 1 MOLE

If one mole of H_2SO_4 (sulphuric acid) = 98 g., what is the G.F.W. of sulphuric acid ? ________________ ⟶ 31.

31. THE G.F.W. OF H_2SO_4 = 98 g. CORRECT. This is the same as 1 mole of H_2SO_4.

What is the weight of $\frac{1}{2}$ of a mole of H_2SO_4 ? ⟶ 32.

32. $\frac{1}{2}$ MOLE OF H_2SO_4 = 49 g. $(\frac{98}{2})$ VERY GOOD.

How many moles of water are there in 36 g. of water ? ________ ⟶ 33.

33. THERE ARE 2 MOLES OF WATER IN 36 g. Easy isn't it, because 1 mole of water weighs 18 g. and 2 moles will be 2 x 18 g.

Can you match up the following lists of data ?

(The first one is done for you.)

(A)	1 MOLE H_2O		34 g.
(B)	$\frac{1}{2}$ MOLE CO_2		32 g.
(C)	1 MOLE H_2S	A	18 g.
(D)	1 MOLE CaO		56 g.
(E)	2 MOLES CH_4		22 g.
(F)	1 MOLE $CaCO_3$		100 g.

⟶ 34.

34. WAS YOUR ANSWER CEADBF - GOOD

How many moles of CO_2 are contained in 11 g. of the gas ? ______ ⟶ 35.

35. 0.25 MOLES - GOOD

1 mole of CO_2 weighs 44 g.

0.25 moles of CO_2 weigh 11 g.

END OF PROGRAM

Atomic Weights

H	= 1	Na	= 23
C	= 12	S	= 32
N	= 14	Cl	= 35.5
O	= 16	Ca	= 40

Program 2, 1973

1. When calcium carbonate (chalk) is heated, it decomposes, forming calcium oxide and carbon dioxide.

$$\text{Calcium Carbonate} \xrightarrow{\text{heat}} \text{Calcium Oxide} + \text{Carbon Dioxide}$$

$$\text{or} \quad CaCO_3 \longrightarrow CaO + CO_2$$

$$100 \text{ g.} \longrightarrow 56 \text{ g.} + ?$$

On heating 100 g. of $CaCO_3$, it is found that 56 g. of CaO is produced. How much CO_2 would also be produced ?

(a) 44 g. ☐

(b) It is impossible to tell ☐

(Put a tick in the box you choose.)

(a) → 2.
(b) → 3.

2. (a) 44 g. - CORRECT.

You obviously know that the weight of products formed during a reaction = weight of starting substances.

$$CaCO_3 \longrightarrow CaO + CO_2$$

$$100 \text{ g.} \qquad \underbrace{56 \text{ g} + 44 \text{ g}}_{100}$$

What is the weight of (a) 1 mole of $CaCO_3$ ________ g.

(b) 1 mole of CaO ________ g.

(c) 1 mole of CO_2 ________ g.

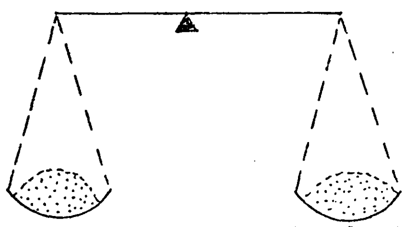
(NOTE : - Atomic Weights are provided at the end of this program.)

→ 4.

3. (b) IT IS IMPOSSIBLE TO TELL. - NO ! You have forgotten an important law of nature, i.e. "Matter cannot be created or destroyed".

So ! $CaCO_3 \longrightarrow CaO + CO_2$

100 g. 56 g. + _____ ?



Starting Materials = Products

→ 2.

4. 1 MOLE OF $CaCO_3$ WEIGHS 100 g.
1 MOLE OF CaO WEIGHS 56 g.
1 MOLE OF CO_2 WEIGHS 44 g.
} CORRECT !

How many moles of CO_2 are produced by heating 1 mole of $CaCO_3$?

$CaCO_3 \longrightarrow$	CaO	+ CO_2
100 g.	56 g.	44 g.
1 mole	1 mole	______ ?

→ 5.

5. 1 MOLE - GOOD. SINCE 1 MOLE OF CO_2 WEIGHS 44 g.

$CaCO_3 \longrightarrow$	CaO	+ CO_2
1 mole	1 mole	1 mole

How many moles of CO_2 would be produced by heating $\frac{1}{2}$ mole of $CaCO_3$

(a) $\frac{1}{2}$ mole ☐ → 7.
(b) $\frac{1}{4}$ mole ☐ → 6.

6. (b) $\frac{1}{4}$ MOLE - THINK AGAIN !

$CaCO_3 \longrightarrow$	CaO	+ CO_2
1 mole	1 mole	1 mole
$\frac{1}{2}$ mole	$\frac{1}{2}$ mole	_______ ?

→ 7.

7. (a) $\frac{1}{2}$ MOLE - GOOD.

$CaCO_3 \longrightarrow$	CaO	+ CO_2
$\frac{1}{2}$ mole	$\frac{1}{2}$ mole	$\frac{1}{2}$ mole

Now, in order to calculate the number of moles of products formed in a reaction, A BALANCED EQUATION MUST BE WRITTEN.

Balance this equation :-

$$HgO \longrightarrow Hg + O_2$$

(Mercury Oxide $\xrightarrow{\text{Heat}}$ Mercury + Oxygen)

→ 8.

8. $2HgO \longrightarrow 2Hg + O_2$. CORRECT.

If we begin with 1 mole of HgO, how many moles of Hg will be produced ______________ ?

→ 9.

9. 1 MOLE OF Hg - GOOD. $2HgO \longrightarrow 2Hg + O_2$

2 moles	2 moles	1 mole
1 mole	1 mole	$\frac{1}{2}$ mole

When hydrogen gas is passed over hot copper oxide, copper metal and steam are produced, $CuO + H_2 \quad Cu + H_2O$

Starting with 1 mole of CuO, how many moles of Cu will be produced __________ ? → 10.

10. 1 MOLE OF COPPER - GOOD, (but did you check that this equation was balanced).

If we start with 1 mole of CuO, what <u>weight</u> of Cu metal will be formed _________ ? → 11.

11. 64 g. OF COPPER (1 MOLE) - VERY GOOD.

$CuO + H_2 \longrightarrow Cu + H_2O$

1 mole	1 mole	1 mole	1 mole
		64 g.	

When heated, zinc reacts with sulphur, to produce zinc sulphide :- $Zn + S \longrightarrow ZnS$.

Starting with 2 moles of Zn, how many moles of sulphur would be required for all the Zn to be used up ? ________ → 12.

12. 2 MOLES OF SULPHUR - CORRECT. Since the equation is balanced,

$Zn + S \longrightarrow ZnS$

1 mole	1 mole	1 mole
2 moles	2 moles	2 moles

2 moles of Zn weigh _____ g. and would react completely with ________ g. of sulphur. → 13.

13. 130 g. OF Zn WOULD REACT WITH 64 g. OF SULPHUR.

Hot sodium reacts with chlorine gas to form sodium chloride.

$2Na + Cl_2 \longrightarrow 2NaCl$

How many moles of Na are required to react with 1 mole of Cl_2 ? _________ → 14.

14. 2 MOLES OF Na - CORRECT !

Aluminium reacts with sulphur producing aluminium sulphide,

$$2Al + 3S \longrightarrow Al_2S_3$$

How many moles of Al are required to react with 3 moles of S.?

______ → 15.

15. 2 MOLES - GOOD.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

What weight of Sulphuric Acid (H_2SO_4) will react with 65 g. of Zn ? ______ → 16.

(Hint ! - How many moles of H_2SO_4 react with 1 mole of Zn ?)

16. 98 g. - 1 MOLE OF H_2SO_4 - GOOD

Zn	+	H_2SO_4	→	$ZnSO_4$	+	H_2
1 mole		1 mole		1 mole		1 mole
65 g.		98 g.				

What weight of HCl (hydrochloric acid) would react completely with 24 g. of Mg ?

$$Mg + HCl \longrightarrow MgCl_2 + H_2$$

(a) 36.5 g. ☐ → 17.

(b) 73 g. ☐ → 18.

17. (a) 36.5 g. - NO ! You did not balance the equation.

Mg	+	$\underline{\underline{2}}HCl$	→	$MgCl_2$	+	H_2
1 mole		2 moles		1 mole		1 mole
24 g.		______				

→ 18.

18. (b) 73 g. - CORRECT.

Mg	+	$\underline{\underline{2}}HCl$	→	$MgCl_2$	+	H_2
1 mole		2 moles		1 mole		1 mole
24 g.		73 g.				

Chalk ($CaCO_3$) reacts with HCl as follows,

$$CaCO_3 + HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

What weight of HCl would react completely with 100 g. of $CaCO_3$?

(a) 36.5 g. ☐ → 19.

(b) 73 g. ☐ → 20.

(c) 146 g. ☐ → 21.

19. (a) 36.5 g. - SORRY. You <u>did not balance the equation</u> !

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

1 mole 2 moles

100 g. ______ g. ?

⟶ 20.

20. (b) 73 g. - CORRECT.

What weight of CO_2 would be produced by heating 100 g. of chalk

$$CaCO_3 \longrightarrow CaO + CO_2$$

100 g. ______ g.

⟶ 22.

21. (c) 146 g. - WRONG ! Are you guessing or can't balance equations.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

1 mole 2 moles

100 g. ______ g.

⟶ 20.

22. 44 g. - GOOD. $CaCO_3 \longrightarrow CaO + CO_2$

1 mole 1 mole

100 g. 44 g.

What weight of CO_2 would be produced by heating 25 g. of $CaCO_3$?

(a) 156 g. ☐ ⟶ 23.

(b) 11 g. ☐ ⟶ 25.

23. (a) 156 g. - SORRY, THIS IS NOT CORRECT.

If 100 g. of $CaCO_3$ give off 44 g. of CO_2 when heated then, will 25 g. of $CaCO_3$ give off more or less CO_2 ______

⟶ 24.

24. LESS - OF COURSE ! Now, $CaCO_3 \longrightarrow CaO + CO_2$

100 g. produces 44 g.

25 g. produces ___ g. ?

⟶ 25.

25. 11 g. - VERY GOOD. $(\frac{25}{100} \times 44)$

What weight of sulphur is required to react completely with 32.5 g. of zinc ? $Zn + S \longrightarrow ZnS$

1 mole 1 mole 1 mole

65 g. 32 g.

32.5 g. ______ g.

⟶ 26.

26. 16 g. - CORRECT $(\frac{32.5}{65} \times 32)$

Now look at this reaction, $Mg + Cl_2 \longrightarrow MgCl_2$

What weight of Cl_2 will react with 12 g. of magnesium ?

(a) 71 g. $\longrightarrow$ 27.

(b) 35.5 g. $\longrightarrow$ 28.

27. (a) 71 g. - SORRY, THIS IS NOT CORRECT.

Using the balanced equation $Mg + Cl_2 \longrightarrow MgCl_2$

Mg	Cl_2
1 mole	1 mole
24 g.	71 g.
12 g.	___ g. ?

$\longrightarrow$ 28.

28. 35.5 g. - CORRECT $(\frac{12}{24} \times 71)$

What weight of Calcium will react with 36.5 g. of HCl (hydrochloric acid) ? $Ca + HCl \longrightarrow CaCl_2 + H_2$

(a) 40 g. ☐ $\longrightarrow$ 29.

(b) 20 g. ☐ $\longrightarrow$ 30.

29. (a) 40 g. - NO. Did you balance the equation ?

$Ca + \underline{\underline{2}}HCl \longrightarrow CaCl_2 + H_2$

Ca	2HCl
1 mole	2 moles
40 g.	73 g.
___ g. ?	36.5 g.

$\longrightarrow$ 30.

30. (b) 20 g. - CORRECT $(\frac{36.5}{73} \times 40)$.

END OF PROGRAM

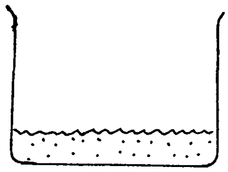
Atomic Weights

H = 1		S = 32	
C = 12		Cl = 35.5	
O = 16		Ca = 40	
Mg = 24		Cu = 64	
		Zn = 65	

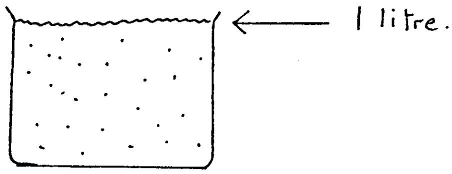
Program 3, 1973

1. Most chemical reactions occur in solution and the idea of the Mole has been adapted to deal with this.

If we dissolve 1 mole of Sodium hydroxide (NaOH), 40 g., in some water,



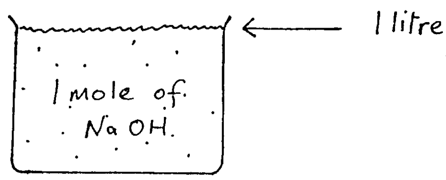
and then add more water until the volume of the solution is 1 litre.



How many moles of NaOH will this solution contain ?

______________ (write your answer here) → 2.

2. 1 MOLE - GOOD.



If one litre of a solution contains one mole of a substance dissolved in it, the concentration of the solution is __________ per litre. → 3.

3. 1 MOLE PER LITRE - YES !

If one litre of salt solution contains 1 mole of NaCl then the concentration is said to be 1 mole per litre (1 mole/litre) A solution whose concentration is 1 mole per litre can also be called a MOLAR solution.

How many moles of HCl are dissolved in 1 litre of MOLAR HCl solution ? __________ → 4.

4. 1 MOLE - CORRECT. A molar solution of HCl contains 1 mole of HCl per litre of solution.

If a solution has a concentration of 1 mole per litre, it can also be called a __________ solution. → 5.

5. MOLAR SOLUTION - YES !

To make a molar solution of NaOH we dissolve 1 mole of NaOH (40 g.) in water and add water until the volume of the solution is ________ → 6.

6. 1 LITRE - GOOD

What is a molar solution ? ________________________ → 7.

7. A SOLUTION, 1 LITRE OF WHICH CONTAINS 1 MOLE OF DISSOLVED SUBSTANCE.

If 1 litre of NaOH solution contains 5 moles of dissolved NaCH then, the concentration is 5 moles per litre.

5 Moles per litre can also be written as 5 ____________ → 9.

8. SORRY - Consider this example :- If you added 50 ml. of alcohol to 50 ml. of water, what would you expect the final volume to be ? - 100 ml. You would get a surprise, because the final volume would in fact be about 98 ml. - ask your science teacher to show you this if you don't believe it.

So, when you dissolve a substance in 1 l. of water the volume of solution changes and you must make up the volume to 1 l. → 1.

9. 5 MOLAR - CORRECT !

How many moles of H_2SO_4 are contained in 1 l. of 3 molar H_2SO_4 solution ? __________ → 10.

10. 3 MOLES - YES ! Since 3 molar = 3 moles/l.

Which of the following set of instructions would make up correctly, 1 l. of 4 molar NaOH ?

(a) Dissolve 4 moles of NaOH in 1 l. of water ________ → 8.

(b) Dissolve 4 moles of NaOH in water and then add some more water until the volume is 1 l. ________ → 13.

(c) Dissolve 4 moles of NaOH in 1 mole of water ________ → 11.

(d) Dissolve 1 mole of NaOH in 4 moles of water ________ → 12.

11. NO ! = Return to the 1st frame as you seem to have misunderstood the meaning of a molar solution.

12. SORRY ! – You do not understand how to make up a molar solution – return to frame 1.

13. (b) YES !

Which of the following solutions contains most NaOH ?

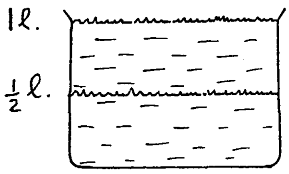
(a) 1 litre of ½ molar NaOH

(b) 1 litre of 1 molar NaOH

(c) 1 litre of 2 molar NaOH

__________ → 14.

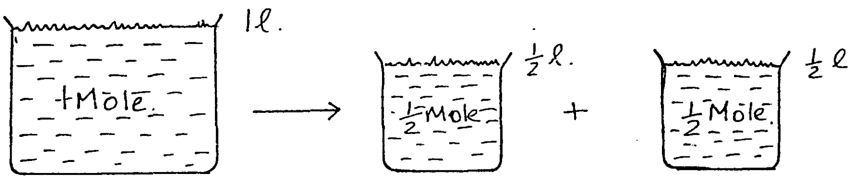
14. (c) 2 MOLAR NaOH – CORRECT. It contains 2 moles of NaOH in 1 litre of solution.



1 litre of 1 Molar NaOH contains 1 mole of NaOH.

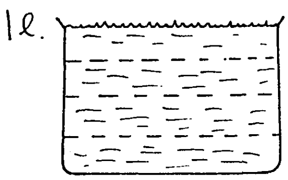
½ litre of 1 Molar NaOH contains ______ moles of NaOH → 15.

15. ½ MOLE – GOOD !



How many moles of NaOH are contained in 100 ml (1/10 litre) of 1 Molar NaOH solution ? __________ → 16.

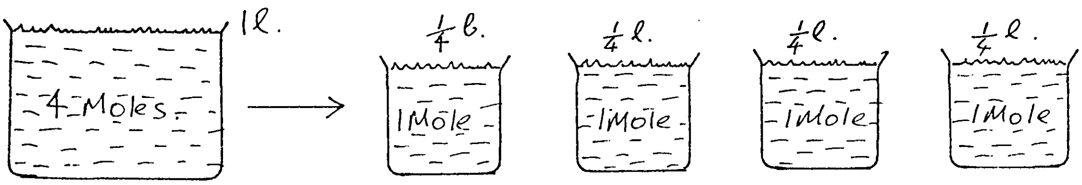
16. 1/10 MOLE – GOOD



1 litre of 4 Molar NaOH contains 4 moles of NaOH.

250 ml. (1/4 litre) of 4 molar NaOH contains ________ moles of NaOH → 17.

17. 1 MOLE – VERY GOOD !



How many moles of HCl are contained in 500 ml. of 2 molar HCl solution ? __________ → 18.

18. 1 MOLE. Since 1 l. of 2 M. HCl solution contains 2 moles of HCl and 500 ml. of 2 M. HCl solution contains 1 mole of HCl.

(NOTE - 1 M. is short for 1 Molar and 2 M. is short for 2 Molar etc.)

How many moles of NaCl are contained in 3 litres of 0.5 M. NaCl solution ?

(a) 0.5 → 19.

(b) 1.5 → 20.

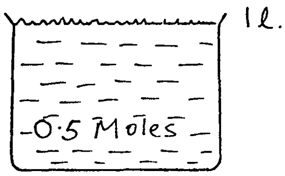
(c) 3 → 21.

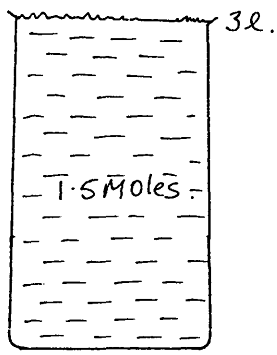
19. 0.5 MOLES - NO !

1 litre of 0.5 M. contains 0.5 moles
therefore 3 litres of 0.5 M. contains ________

Now return to frame 18 and try again.

20. 1.5 MOLES OF NaCl - YES.





In 1 litre of 2 M. NaOH :

(a) How many moles of NaOH are dissolved ? ________

(b) What weight of NaOH is dissolved ________

(All atomic weights are given at the end of the program) → 22.

21. 3 MOLES - NO !

1 litre of 0.5 M. contains 0.5 moles
3 litres of 0.5 M. contains ________

Now return to frame 18 and try again.

22. (a) 2 MOLES } CORRECT
(b) 80 g. (2 x 40 g.) }

1 litre of 2 M. NaOH contains 80 g. of NaOH.

What is the concentration of this solution, in g. per litre

________ → 23.

23. 80 g. PER LITRE - YES

Given 500 ml. ($\frac{1}{2}$ l.) of 2 M. HCl solution

(a) How many moles of HCl does it contain ? ________

(b) What weight of HCl does it contain ? ________ → 24.

24. (a) 1 MOLE OF HCl

(b) 36.5 g. OF HCl

Which of the following solutions contains most H_2SO_4 ?

(a) 200 ml. of 5 M. H_2SO_4 → 25.

(b) 500 ml. of 3 M. H_2SO_4 → 26.

(c) 800 ml. of 1 M. H_2SO_4 → 27.

25. (a) SORRY !

1 litre of 5 M. H_2SO_4 contains 5 moles
therefore 200 ml. (1/5 l.) of 5 M. H_2SO_4 contains 1 Mole.

Now return to frame 24 and try again.

26. (b) - CORRECT

500 ml. of 3 M. H_2SO_4 contains 1.5 moles.

You have finished the program.

27. (c) - NO !

1000 ml. of 1 M. H_2SO_4 contains 1 mole
800 ml. of 1 M. H_2SO_4 contains 0.8 moles.

Return to frame 24 and try again.

END OF PROGRAM

Atomic Weights

H	=	1	Na	=	23
O	=	16	Cl	=	35.5

Program 4, 1973

1. Magnesium metal reacts with sulphuric acid forming magnesium sulphate and hydrogen gas.

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of H_2SO_4 are required to react with 1 mole of Mg ? ______________ (Write your answer in the space provided.) ⟶ 2.

2. 1 MOLE - YES

$$\begin{array}{ccccccc} Mg & + & H_2SO_4 & \longrightarrow & MgSO_4 & + & H_2 \\ \text{1 mole} & & \text{1 mole} & & \text{1 mole} & & \text{1 mole} \end{array}$$

What is the weight of 1 mole of H_2SO_4 ? ______________ ⟶ 3.

(Atomic Weights are given at the end of this program.)

3. 98 g. - GOOD (2 + 32 + 64)

H_2SO_4 is however a liquid and it is easier to measure out a volume than a weight.

If 1 mole of H_2SO_4 is contained in 1 litre of solution, what is the molarity of this solution ? ______________ ⟶ 4.

4. 1 MOLAR (OR 1 MOLE PER LITRE)

$$\begin{array}{ccccccc} & Mg & + & H_2SO_4 & \longrightarrow & MgSO_4 & + H_2 \\ & \text{1 mole} & & \text{1 mole} & & & \\ \text{or} & \text{1 mole} & & \text{1 l. of 1 molar} & & & \end{array}$$

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ?

(a) 1 ☐ ⟶ 6.

(b) 2 ☐ ⟶ 7.

(Tick the box you think correct.)

5. 1 l. - Since 1 l. of 2 M. H_2SO_4 contains 2 moles of H_2SO_4 dissolved in it.

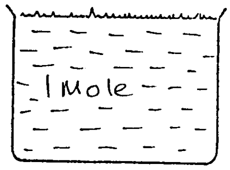
You may remember neutralising acids with alkalis in your first year, e.g. adding sodium hydroxide (alkali) to hydrochloric acid (HCl).

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

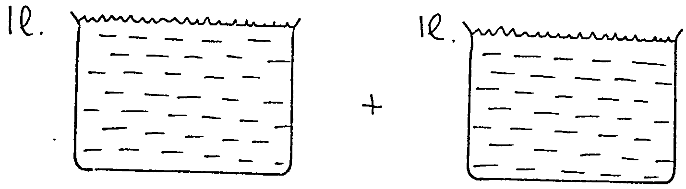
How many moles of HCl neutralise 1 mole of NaOH ? ______________ ⟶ 9.

6. (a) 1 MOLE - SORRY, this is not correct.

1 l. of 1 M. H_2SO_4 contains 1 mole of H_2SO_4

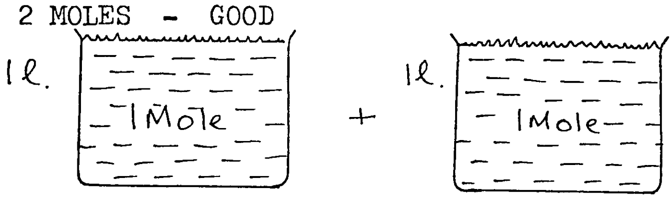


2 l. of 1 M. H_2SO_4 contains ____________



⟶ 8.

7. 2 MOLES - GOOD



$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 moles   2 moles

or 2 moles   2 l. of 1 M.

What volume of 2 M. H_2SO_4 would react with 2 moles of Mg ? ________ ⟶ 5.

8. 2 MOLES - YES

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 l. of 1 M.

?   2 moles

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ? ________ ⟶ 7.

9. 1 MOLE - YES

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 mole   1 mole   1 mole   1 mole

1 l. of 1 M. HCl contains 1 mole of HCl.

What volume of 1 M. NaOH would neutralise 1 l. of 1 M. HCl ? ____________

⟶ 10.

10. 1 LITRE - GOOD

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 mole   1 mole   1 mole   1 mole

1 l. of 1M. 1 l. of 1M.

What volume of 1 M. NaOH would react with 500 ml. (½ l.) of 1 M. HCl ? ______________ ⟶ 11.

11. 500 ml. - YES. 500 ml. of 1 M HCl contains ½ mole of HCl <u>and</u> 500 ml. of 1 M. NaOH contains ½ mole of NaOH.

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

500 ml. of 1 M.   500 ml. of 1 M.

½ mole   ½ mole

What volume of 1 M. NaOH would react with 250 ml (l.) of 1 M. HCl ? ______________ ⟶ 12.

12. 250 ml of 1 M. HCl - GOOD

If 100 ml. of 1 M. HCl is neutralised by 50 ml. of NaOH solution, what is the molarity of the NaOH solution ?

(a) ½ M. ⟶ 13.

(b) 2 M. ⟶ 14.

13. (a) ½ M. - NO !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 mole   1 mole

Therefore 1 l. of 1 M. 1 l. of 1 M.
Therefore 100 ml. of 1 M. 50 ml. of ______? ⟶ 14.

14. (b) 2 M. - YES

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 100 ml. of 1M. 100 ml. of 1 M.

Therefore 100 ml. of 1M. 50 ml. of x M.

$$x = \frac{100 \times 1}{50}$$ (2 on top multiplied and divided by one on bottom line)

$$= \underline{2\ M.}$$

If 200 ml. of 2 M. HCl is neutralised by 400 ml. of NaOH solution, what is the molarity of the NaOH ? ______________ ⟶ 15.

15. 1 MOLAR - YES !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 200 ml. of 2 M. 200 ml. of 2 M. $x = \frac{200 \times 2}{400}$

Therefore 200 ml. of 2 M. 400 ml. of x M. $= \underline{1\ M.}$

What volume of 2 M. HCL would neutralise 20 ml. of 4 M. NaOH solution ?

(a) 40 ml. ☐ ⟶ 17.

(b) 80 ml. ☐ ⟶ 18.

16. 2 MOLES - CORRECT. (Did you balance the equation ?)

$$\underline{\underline{2}}NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 moles 1 mole

Therefore 2 l. of 1 M. __________ ? ⟶ 19.

17. (a) 40 ml. - CORRECT !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 20 ml. of 4 M. 20 ml. of 4 M. $x = \frac{20 \times 4}{2}$

Therefore 20 ml. of 4 M. x ml. of 2 M. $= \underline{40\ ml.}$

Now, when NaOH neutralises sulphuric acid (H_2SO_4), how many moles of NaOH are required to neutralise 1 mole of H_2SO_4 ?

$$NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$$ ⟶ 16.

18. 80 ml. - NO !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 20 ml. of 4 M. 20 ml. of 4 M. (Multiply two on top and divide by the one on bottom.)

Therefore 20 ml. of 4 M. x ml. of 2 M.

$$x = \frac{20 \times 4}{2}$$

= ______ ? ⟶ 17.

19. 1 l. of 1 M. - VERY GOOD !

What volume of 2 M. NaOH will be required to neutralise 50 ml. of 1 M. H_2SO_4 ?

(a) 25 ml. ☐ → 20.

(b) 50 ml. ☐ → 21.

20. (a) 25 ml. of 2 M. NaOH - SORRY, THIS IS NOT CORRECT.

$$\underset{1\ \text{mole}}{H_2SO_4} + \underset{2\ \text{moles}}{2NaOH} \longrightarrow Na_2SO_4 + 2H_2O$$

Therefore 1 l. of 1 M. 2 l. of 1 M.

Therefore 50 ml. of 1 M. 100 ml. of 1 M. $x = \frac{100 \times 1}{2}$

Therefore 50 ml. of 1 M. x ml. of 2 M.

= ________ → 21.

21. (b) 50 ml. of 2 M. NaOH - CORRECT

$$\underset{1\ \text{mole}}{H_2SO_4} + \underset{2\ \text{moles}}{2NaOH} \longrightarrow Na_2SO_4 + 2H_2O$$

Therefore 1 l. of 1 M. 2 l. of 1 M.

Therefore 50 ml. of 1 M. 100 ml. of 1 M. $x = \frac{100 \times 1}{2}$

Therefore 50 ml. of 1 M. x ml. of 2 M.

= 50 ml.

END OF PROGRAM

Atomic Weights

H = 1

S = 32

O = 16

Program 5. 1973

1. Magnesium metal reacts with sulphuric acid forming magnesium sulphate and hydrogen gas.

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of H_2SO_4 are required to react with 1 mole of Mg ? ______________ (Write your answer in the space provided.) ⟶ 2.

2. 1 MOLE - YES

$$\begin{matrix} Mg & + & H_2SO_4 & \longrightarrow & MgSO_4 & + & H_2 \\ \text{1 mole} & & \text{1 mole} & & \text{1 mole} & & \text{1 mole} \end{matrix}$$

What is the weight of 1 mole of H_2SO_4 ? ______________ ⟶ 3.

(Atomic Weights are given at the end of the program)

3. 98 g. - GOOD (2 + 32 + 64)

H_2SO_4 is however a liquid and it is easier to measure out a volume than a weight.

If 1 mole of H_2SO_4 is contained in 1 litre of a solution, what is the molarity of this solution ? ______________ ⟶ 4.

4. 1 MOLAR (OR 1 MOLE PER LITRE)

$$\begin{matrix} & Mg & + & H_2SO_4 & \longrightarrow & MgSO_4 & + & H_2 \\ & \text{1 mole} & & \text{1 mole} & & & & \\ \text{or} & \text{1 mole} & & \text{1 l. of 1 molar} & & & & \end{matrix}$$

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ?

(a) 1 ☐ ⟶ 6.

(b) 2 ☐ ⟶ 7.

(Tick the box you think correct.)

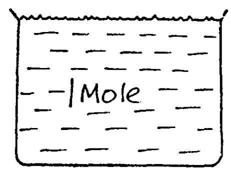
5. 1 l. - Since 1 l. of 2 M. H_2SO_4 contains 2 moles of H_2SO_4 dissolved in it.

You may remember neutralising acids with alkalis in your first year e.g. adding sodium hydroxide (alkali) to hydrochloric acid (HCl).

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

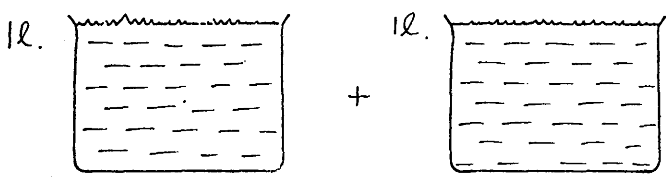
How many moles of HCl neutralise 1 mole of NaOH ? ________ ⟶ 9.

6. (a) 1 MOLE - SORRY, this is not correct.



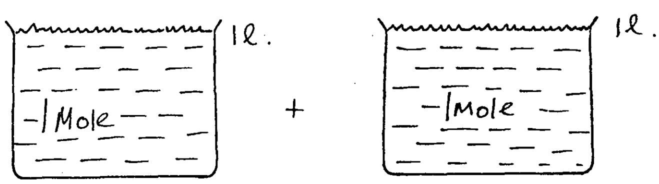
1 l. of 1 M. H_2SO_4 contains 1 mole of H_2SO_4

2 l. of 1 M. H_2SO_4 contains ________



⟶ 8.

7. 2 MOLES - GOOD



$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

	2 moles	2 moles
or	2 moles	2 l. of 1 M.

What volume of 2 M. H_2SO_4 would react with 2 moles of Mg ? ________ ⟶ 5.

8. 2 MOLES - YES

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

	2 l. of 1 M.	
?	2 moles	

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ? ________ ⟶ 7.

9. 1 MOLE - GOOD

1 litre of 1 M. HCl contains 1 mole of HCl dissolved in it. How many moles of NaOH would react with 1 l. of 1 M. HCl ?

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

______ ? 1 l. of 1 M.

⟶ 10.

10. 1 MOLE - YES

How many moles of NaOH are contained in 1 l. of 1 M. NaOH ? __________

⟶ 11.

11. 1 MOLE - CORRECT.

What volume of 1 M. NaOH will react with 1 l. of 1 M. HCl ?

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. ______ ?

⟶ 12.

12. 1 l. of 1 M. NaOH - YES. Did you do it this way ?

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. HCl
contains 1 mole of HCl
and 1 mole of HCl reacts with 1 mole of NaOH

What volume of 1 M. NaOH contains 1 mole of NaOH ? - 1 l.

Now, what volume of 1 M. NaOH would react with 500 ml. of 1 M. HCl ? __________

⟶ 13.

13. 500 ml. of 1 M. HCl - VERY GOOD

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1M. HCl contains
1 mole of HCl.
∴ $\frac{1}{2}$ l. (500 ml.) of
1 M. HCl contains
$\frac{1}{2}$ mole of HCl

and $\frac{1}{2}$ mole of HCl reacts with $\frac{1}{2}$ mole of NaOH

What volume of 1 M. NaOH will contain $\frac{1}{2}$ mole of NaOH ? - $\frac{1}{2}$ l.

Now, what volume of 1 M. NaOH will neutralise 250 ml. ($\frac{1}{4}$ l.) of 1 M. HCl ? __________

⟶ 14.

14. 250 ml. ($\frac{1}{4}$ l.) of 1 M. NaOH - CORRECT

If 100 ml. of 1 M. HCl is neutralised by 50 ml. of NaOH solution, what is the molarity of the NaOH solution ?

(a) $\frac{1}{2}$ M. ☐ ⟶ 16.
(b) 2 M. ☐ ⟶ 17.

15. 1 M. - YES

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

200 ml. of 2 M. contains 2/5 moles of HCl (use N = M x V = 2 x 2/10)
<u>and</u> 2/5 moles of HCl reacts with 2/5 moles of NaOH

<u>So</u> 400 ml. of the NaOH solution contains 2/5 moles. ($M = \frac{N}{V} = \frac{2}{5} \div \frac{4}{10}$)
1000 ml. " " " " " 1 mole.

Solution is <u>1 M.</u> NaOH

What volume of 2 M. HCl would neutralise 20 ml. of 4 M. NaOH ?

(a) 40 ml. ☐ ⟶ 18.
(b) 80 ml. ☐ ⟶ 19.

16. (a) $\frac{1}{2}$ M. - SORRY, THIS IS NOT CORRECT !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

100 ml. of 1 M. contains 1/10 mole
<u>and</u> 1/10 mole of HCl reacts with 1/10 mole of NaOH.

50 ml. of NaOH solution must contain 1/10 mole
1000 ml. " " " " " 2 moles

So, molarity of this NaOH solution is ____________ M. ⟶ 17.

17. (b) 2 M. - CORRECT

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

100 ml. of 1 M. contains 1/10 mole
<u>and</u> 1/10 mole of HCl neutralises 1/10 mole of NaOH

50 ml. of this NaOH solution must contain 1/10 mole
1000 ml. " " " " " " 2 moles

Molarity = 2 M.

If 200 ml. of 2 M. HCl is neutralised by 400 ml. of NaOH solution, what is the molarity of the NaOH solution ? ____________ ⟶ 15.

NOTE The following formula may help you

$$\text{Number of moles} = \text{Molarity} \times \text{Volume (in litres)}$$

or $N = M \times V$

or $V = \frac{N}{M}$

or $M = \frac{N}{V}$

18. (a) 40 ml. - CORRECT

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

20 ml. of 4 M. contains 4/50 moles ($N = M \times V = 4 \times 1/50$)
and 4/50 moles of NaOH neutralise 4/50 moles of HCl.

1000 ml. of 2 M. HCl contains 2 moles
x ml. of " " " 4/50 moles. ($V = \frac{N}{M} = \frac{4}{50} \div 2$)

$$x = \frac{1000}{2} \times \frac{4}{50} = 40 \text{ ml.}$$

When NaOH neutralises sulphuric acid (H_2SO_4), how many moles of NaOH are required to react with 1 mole of H_2SO_4 ?

$$NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$$ ____________ ⟶ 20.

19. (b) 80 ml. - WRONG !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

20 ml. of 4 M. contains 4/50 moles. ($N = M \times V = 4 \times 1/50$)
and 4/50 moles neutralises4/50 moles of HCl.

1000 ml. of 2 M. HCl contains 2 moles.
x ml. " " " " 4/50 moles of HCl ($V = \frac{N}{M} = \frac{4}{50} \div 2$)

$$x = \frac{1000}{2} \times \frac{4}{50} =$$ ____________ ⟶ 18.

20. 2 MOLES - YES ! (Did you balance the equation ?)

$$\underline{2}NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 moles 1 mole

What volume of 1 M. H_2SO_4 will neutralise 2 l. of 2 M. NaOH ? ____________ ⟶ 21.

21. 2 l. of 1 M. H_2SO_4 - YES !

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 l. of 1 M. contains 2 moles
and 2 moles of NaOH neutralises 1 mole of H_2SO_4

1000 ml. of 1 M. H_2SO_4 contains 1 mole.

What volume of 2 M. NaOH will neutralise 50 ml. of 1 M. H_2SO_4 ?

(a) 25 ml. ☐ → 22.

(b) 50 ml. ☐ → 23.

22. (a) 25 ml. NO !

$$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

50 ml of 1 M. contains 1/20 mole. $(N = M \times V = 1 \times 1/20)$
and 1/20 mole of H_2SO_4 neutralises 2 x 1/20 moles of NaOH.

1000 ml. of 2 M. NaOH contains 2 moles of NaOH
x ml. " " " " 2/20 moles of NaOH $(V = \frac{N}{M} = \frac{2}{20} \div 2)$

$$x = \frac{1000}{2} \times \frac{2}{20} = \_\_\_\_\_\_\_\_\_\_$$ → 23.

23. (b) 50 ml. - CORRECT.

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

50 ml. of 1 M. contains 1/20 of a mole.
and 1/20 moles neutralises 2/20 moles of NaOH.

1000 ml. of 2 M. NaOH contains 2 moles of NaOH
x ml. " " " " 2/20 moles of NaOH

$$x = \frac{1000}{2} \times \frac{2}{20}$$

$$= \underline{\underline{50\ ml.}}$$

END OF PROGRAM

Program 1, 1972

1. The Gram Formula Weight (shortened to G.F.W.) of a compound can also be called a MOLE of the compound.

Your teacher asks you to weigh out the G.F.W. of water. He might also have asked you to weigh out one ____________ of water. (Write your answer in the space provided.) → 2.

2. YOUR ANSWER - HE MIGHT ALSO HAVE ASKED YOU TO WEIGH OUT 1 MOLE OF WATER. GOOD THIS IS CORRECT. → 18.

3. The Gram Formula Weight of a compound (shortened to G.F.W.) contains a large number of molecules of the compound.

If the G.F.W. of water is measured out, will it contain only a few or many water molecules ?
______________________________ (write your answer here) → 5.

4. Atoms and molecules have very small masses and special units are used to measure their mass. They are called atomic mass units (shortened to a.m.u.).

If one molecule of nitrogen has a mass of 28 a.m.u., what will be the mass of 10 nitrogen molecules ?
______________________________ (write your answer here) → 6.

5. THE G.F.W. OF WATER WILL CONTAIN MANY WATER MOLECULES - GOOD.

If we have one DOZEN eggs we have ________ eggs.

If we score a CENTURY at cricket we have scored _______ runs. → 7.

6. YOUR ANSWER - 280 a.m.u. (atomic mass units) - GOOD !

If one hydrogen molecule has a mass of 2 a.m.u., what is the mass of 10 hydrogen molecules ? ________________ → 8.

7. 1 DOZEN = 12 }
1 CENTURY = 100 } CORRECT

The number of molecules in the G.F.W. of compound (Gram Formula Weight) is called a MOLE.

The MOLE then is a number, just like a ____________ or a ________________________ . → 9.

8. 10 HYDROGEN MOLECULES HAVE A MASS OF 20 a.m.u. - CORRECT.

10 molecules of hydrogen have a mass of 20 a.m.u.
10 molecules of nitrogen have a mass of 280 a.m.u.

If you had 2 g. of hydrogen molecules and 28 g. of nitrogen molecules, would there be,

(a) the same number of molecules in each pile ☐ → 10.
(b) a different number of molecules in each pile ☐ → 11.

(Put a TICK in the box you choose.)

9. THE MOLE IS A NUMBER JUST LIKE A DOZEN OR A CENTURY - CORRECT.

The G.F.W. of a compound contains one MOLE of molecules of the compound.

How many water molecules are there in the G.F.W. of water ?

________________ → 12.

10. 2 g. OF HYDROGEN MOLECULES WOULD CONTAIN THE SAME NUMBER OF MOLECULES AS 28 g. OF NITROGEN - VERY GOOD. → 16.

11. (b) A DIFFERENT NUMBER IN EACH PILE - SORRY, THIS IS NOT CORRECT.

Imagine that you have been given 2 bags of nails, one full of small nails, each weighing 2 g. and one full of larger nails, each weighing 28 g.

How many nails are there in (a) the small bag, if it weighs 20 g. _____
and (b) the larger bag, if it weighs 280 g. _____
→ 13.

12. YOUR ANSWER - THE G.F.W. OF WATER CONTAINS 1 MOLE OF WATER MOLECULES - GOOD.

The G.F.W. of any compound contains one mole of molecules.

The G.F.W. of nitrogen is 28 g. How many nitrogen molecules does it contain ? ________________ → 14.

13. (a) NUMBER IN SMALL BAG = 10
(b) NUMBER IN LARGE BAG = 10 } CORRECT

Even although the bags have different weights, they still contain the same number of nails.

If you have 20 kg. of small nails and 280 kg. of large nails in bags, would you have the same, or a different number in each bag ?

________________ → 15.

14. 28 g. OF NITROGEN CONTAINS ONE MOLE OF NITROGEN MOLECULES - GOOD → 18.

15. THERE WOULD BE THE SAME NUMBER OF NAILS IN EACH BAG.

1 kg. = 1000 g.

Therefore number of small nails $= \frac{20 \times 1000}{2} = 10,000$

number of large nails $= \frac{280 \times 1000}{28} = 10,000$

Will 2 g. of hydrogen contain the same, or a different number of molecules from 28 g. of nitrogen ? ________________ → 10.

16. The G.F.W. of Hydrogen = 2 g.
The G.F.W. of Nitrogen = 28 g.

Are there the same number of molecules in the G.F.W. of Hydrogen (2 g.) as there are in the G.F.W. of Nitrogen (28 g.) ? ________ → 20.

17. YOU CHOSE (a) THE G.F.W. OF WATER = 16 g. THIS IS NOT CORRECT.

G.F.W. of H_2O = 2 x 1 (for the hydrogen atoms)
+ 16 (for the oxygen atom)
= 2 + 16 = 18 g. → 22.

18. Which of the following is the correct G.F.W. for water (H_2O) ? (Atomic Weights are given on the final page of this program.)

(a)	16 g.	☐	(Put a tick	→ 17.
(b)	17 g.	☐	in the box	→ 19.
(c)	18 g.	☐	you choose.)	→ 21.

19. (b) THE G.F.W. OF H_2O = 17 g. - NO !

G.F.W. = 2 x 1 (for the hydrogen atoms
+ 16 (for the oxygen atom)
= 2 + 16 = 18 g. → 22.

20. YES, THERE ARE THE SAME NUMBER OF MOLECULES IN THE G.F.W. OF HYDROGEN AS THERE ARE IN THE G.F.W. OF NITROGEN.

The G.F.W. of any compound contains the same number of molecules as the G.F.W. of any other compound.

If the G.F.W. of HCl = 36.5 g. and the G.F.W. of HNO_3 = 63 g., does 36.5 g. of HCl contain the same number of molecules as 63 g. of HNO_3 ? ________________ → 23.

21. (c) THE G.F.W. OF H_2O = 18 g. - VERY GOOD. ⟶ 22.

22. What is the G.F.W. of Ammonia (NH_3) ?

(a) 16 g. ☐ ⟶ 24.

(b) 17 g. ☐ ⟶ 27.

(c) 45 g. ☐ ⟶ 28.

23. YES, 36.5 g. OF HCl WILL CONTAIN THE SAME NUMBER OF MOLECULES AS 63 g. OF HNO_3, SINCE THE G.F.W. of any compound contains the same number of molecules as the G.F.W. of any other compound.

The number of molecules in the G.F.W. of a compound is called a MOLE.

How many molecules are there in the G.F.W. of water ? ________ ⟶ 25.

24. (a) THE G.F.W. OF NH_3 = 16 g. THIS IS WRONG.

You cannot calculate the G.F.W. of a compound. Return this program to your teacher and sit quietly.

25. YOUR ANSWER - THE G.F.W. OF WATER CONTAINS ONE MOLE OF MOLECULES - CORRECT. The G.F.W. of any compound contains one mole of molecules.

What is the name given to the number of molecules in the G.F.W. of a compound ? ________ ⟶ 26.

26. 1 MOLE - VERY GOOD. ⟶ 18.

27. The G.F.W. of NH_3 = 17 g. QUITE CORRECT.

G.F.W. = 14 + 3 x 1

= 17 g.

Now if your teacher asks you to weigh out

(a) The G.F.W. of NaCl

(b) 1 Mole of NaCl

What weight of NaCl would you have in each case ?

(a) ________ (b) ________ ⟶ 29.

28. (c) THE G.F.W. OF NH_3 = 45 g. THIS IS NOT CORRECT.

You do not know how to calculate the G.F.W. of a compound. Return this program to your teacher and sit quietly.

29. (a) THE G.F.W. OF NaCl = 58.5 g. (23 + 35.5) } i.e. 1 MOLE

(b) 1 MOLE OF NaCl = 58.5 g.

YOU WOULD WEIGH OUT THE SAME AMOUNT IN EACH CASE.

To find the weight of one mole of a compound you simply calculate the ________________ of the compound. ⟶ 30.

30. G.F.W. - GOOD. 1 G.F.W. = 1 MOLE

If one mole of H_2SO_4 (sulphuric acid) = 98 g., what is the G.F.W. of sulphuric acid ? ________________ ⟶ 31.

31. THE G.F.W. OF H_2SO_4 = 98 g. CORRECT. This is the same as 1 mole of H_2SO_4.

What is the weight of $\frac{1}{2}$ of a mole of H_2SO_4 ? ________________ ⟶ 32.

32. $\frac{1}{2}$ MOLE OF H_2SO_4 = 49 g. $(\frac{98}{2})$ VERY GOOD.

How many moles of water are there in 36 g. of water ? __________ ⟶ 33.

33. THERE ARE 2 MOLES OF WATER IN 36 g. Easy isn't it, because 1 mole of water weighs 18 g. and 2 moles will be 2 x 18 g.

Can you match up the following lists of data ? (The first one is done for you.)

(A)	1 MOLE H_2O		34 g.
(B)	$\frac{1}{2}$ MOLE CO_2		32 g.
(C)	1 MOLE H_2S	A	18 g.
(D)	1 MOLE CaO		56 g.
(E)	2 MOLES CH_4		22 g.
(F)	1 MOLE $CaCO_3$		100 g.

END OF PROGRAM

Finish Time =

Time Taken =

Atomic Weights

C = 12	H = 1	Na = 23	S = 32
N = 14	O = 16	Cl = 35.5	Ca = 40

Program 2, 1972

1. When calcium carbonate (chalk) is heated, it decomposes, forming calcium oxide and carbon dioxide.

Calcium Carbonate $\xrightarrow{\text{heat}}$ Calcium Oxide + Carbon Dioxide

or $CaCO_3 \longrightarrow CaO + CO_2$

100 g. $\longrightarrow$ 56 g. + ?

On heating 100 g. of $CaCO_3$, it is found that 56 g. of CaO is produced. How much CO_2 would also be produced ?

(a) 44 g. ☐ (Put a tick in the box you choose.) ⟶ 2.

(b) it is impossible to tell ☐ ⟶ 3.

2. (a) 44 g. - CORRECT.

You obviously know that the weight of products formed during a reaction = weight of starting substances.

$$CaCO_3 \longrightarrow CaO + CO_2$$

$$100\text{ g.} \qquad \underbrace{56\text{ g.} + 44\text{ g.}}_{100}$$

What is the weight of (a) 1 mole of $CaCO_3$ ________ g.

(b) 1 mole of CaO ________ g.

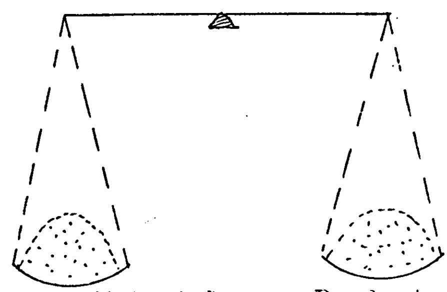
(c) 1 mole of CO_2 ________ g.

(NOTE : - Atomic Weights are provided at the end of this program.) ⟶ 4.

3. (b) IT IS IMPOSSIBLE TO TELL. - NO ! You have forgotten an important law of nature, i.e. "Matter cannot be created or destroyed".

So ! $CaCO_3 \longrightarrow CaO + CO_2$

100 g. $\longrightarrow$ 56 g. + ____ ?



Starting Materials = Products

⟶ 2.

4. 1 MOLE OF $CaCO_3$ WEIGHS 100 g.
1 MOLE OF CaO WEIGHS 56 g. } CORRECT !
1 MOLE OF CO_2 WEIGHS 44 g.

How many moles of CO_2 are produced by heating 1 mole of $CaCO_3$?

$CaCO_3 \longrightarrow$	CaO +	CO_2
100 g.	56 g.	44 g.
1 mole	1 mole	______ ?

⟶ 5.

5. 1 MOLE - GOOD. SINCE 1 MOLE OF CO_2 WEIGHS 44 g.

$CaCO_3 \longrightarrow$	CaO +	CO_2
1 mole	1 mole	1 mole

How many moles of CO_2 would be produced by heating $\frac{1}{2}$ mole of $CaCO_3$?

(a) $\frac{1}{2}$ mole ☐ ⟶ 7.
(b) $\frac{1}{4}$ mole ☐ ⟶ 6.

6. (b) $\frac{1}{4}$ MOLE - THINK AGAIN !

$CaCO_3 \longrightarrow$	CaO +	CO_2
1 mole	1 mole	1 mole
$\frac{1}{2}$ mole	$\frac{1}{2}$ mole	________

⟶ 7.

7. (a) $\frac{1}{2}$ MOLE - GOOD.

$CaCO_3 \longrightarrow$	CaO +	CO_2
$\frac{1}{2}$ mole	$\frac{1}{2}$ mole	$\frac{1}{2}$ mole

Now, in order to calculate the number of moles of products formed in a reaction, <u>A BALANCED EQUATION MUST BE WRITTEN</u>.

Balance this equation : -

$$HgO \longrightarrow Hg \qquad O_2$$

(Mercury Oxide $\xrightarrow[\text{Heat}]{}$ Mercury + Oxygen) ⟶ 8.

8. $2HgO \rightarrow 2Hg + O_2$. CORRECT.

If we begin with 1 mole of HgO, how many moles of Hg will be produced ____________ ? ⟶ 9.

9. 1 MOLE OF Hg - GOOD.

$$2HgO \longrightarrow 2Hg + O_2$$

2 moles	2 moles	1 mole
1 mole	1 mole	½ mole

When hydrogen gas is passed over hot copper oxide, copper metal and steam are produced,

$$CuO + H_2 \longrightarrow Cu + H_2O$$

Starting with 1 mole of CuO, how many moles of Cu will be produced ____________ ? ⟶ 10.

10. 1 MOLE OF COPPER - GOOD, (but did you check that this equation was balanced).

If we start with 1 mole of CuO, what weight of Cu metal will be formed ____________ ? ⟶ 11.

11. 64 g. OF COPPER (1 MOLE) - VERY GOOD.

$$CuO + H_2 \longrightarrow Cu + H_2O$$

1 mole	1 mole	1 mole	1 mole
		64 g.	

When heated, zinc reacts with sulphur, to produce zinc sulphide :-

$$Zn + S \longrightarrow ZnS.$$

Starting with 2 moles of Zn, how many moles of sulphur would be required for all the Zn to be used up ? ____________ ⟶ 12.

12. 2 MOLES OF SULPHUR - CORRECT. Since the equation is balanced,

$$Zn + S \longrightarrow ZnS$$

1 mole	1 mole	1 mole
2 moles	2 moles	2 moles

2 moles of Zn weigh ________ g. and would react completely with ________ g. of sulphur. ⟶ 13.

13. 130 g. OF Zn WOULD REACT WITH 64 g. of SULPHUR.

Hot magnesium reacts with chlorine gas to form magnesium chloride.

$$Mg + Cl_2 \longrightarrow MgCl_2.$$

What weight of Mg will react with 71 g. of Cl_2 ? ________ g. ⟶ 14.

[Hint ! (1) Balance the equation
(2) How many moles of Mg react with 1 mole of Cl_2 ?]

14. 24 g. VERY GOOD INDEED.

$$Mg + Cl_2 \longrightarrow MgCl_2$$

Mg	Cl_2	$MgCl_2$
1 mole	1 mole	1 mole
24 g.	71 g.	

What weight of $MgCl_2$ would be produced starting from 24 g. of Mg and 71 g. of Cl_2 ? ________ → 15.

15. 95 g. OF $MgCl_2$ - 1 MOLE YES.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

What weight of sulphuric acid (H_2SO_4) would be required to react with 65 g. of Zn ? ________ g. → 16.

16. 98 g. - 1 MOLE OF H_2SO_4 - GOOD.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

Zn	H_2SO_4	$ZnSO_4$	H_2
1 mole	1 mole	1 mole	1 mole
65 g.	98 g.		

What weight of HCl (hydrochloric acid) would react completely with 24 g. of Mg ?

$$Mg + HCl \longrightarrow MgCl_2 + H_2$$

(a) 36.5 g. ☐ → 17.

(b) 73 g. ☐ → 18.

17. (a) 36.5 g. - NO ! You did not balance the equation.

$$Mg + \underline{\underline{2}}HCl \longrightarrow MgCl_2 + H_2$$

Mg	2HCl	$MgCl_2$	H_2
1 mole	2 moles	1 mole	1 mole
24 g.	________ ?		

→ 18.

18. (b) 73 g. - CORRECT

$$Mg + \underline{\underline{2}}HCl \longrightarrow MgCl_2 + H_2$$

Mg	2HCl	$MgCl_2$	H_2
1 mole	2 moles	1 mole	1 mole
24 g.	73 g.		

Chalk ($CaCO_3$) reacts with HCl as follows;

$$CaCO_3 + HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

What weight of HCl would react completely with 100 g. of $CaCO_3$?

(a) 36.5 g. → 19.

(b) 73 g. → 20.

(c) 146 g. → 21.

19. (a) 36.5 g. - SORRY. You did not balance the equation !

$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$

1 mole 2 moles

100 g. ______ g ? $\longrightarrow$ 20.

20. (b) 73 g. - CORRECT.

What weight of CO_2 would be produced by heating 100 g. of chalk

$CaCO_3 \longrightarrow CaO + CO_2$

100 g. ______ g. $\longrightarrow$ 22.

21. (c) 146 g. - WRONG ! Are you guessing or can't you balance equations ?

$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$

1 mole 2 moles

100 g. ______ g. $\longrightarrow$ 20.

22. 44 g. - GOOD. $CaCO_3 \longrightarrow CaO + CO_2$

1 mole 1 mole

100 g. 44 g.

What weight of CO_2 would be produced by heating 25 g. of $CaCO_3$?

(a) 156 g. ☐ $\longrightarrow$ 23.

(b) 11 g. ☐ $\longrightarrow$ 25.

23. (a) 156 g. - SORRY, THIS IS NOT CORRECT.

If 100 g. of $CaCO_3$ give off 44 g. of CO_2 when heated then, will 25 g. of $CaCO_3$ give off more or less CO_2 ? ______ $\longrightarrow$ 24.

24. LESS - OF COURSE ! Now, $CaCO_3 \longrightarrow CaO + CO_2$

100 g. produces 44 g.

25 g. produces __ g ? $\longrightarrow$ 25.

25. 11 g. - VERY GOOD. $(\frac{25}{100} \times 44)$

What weight of sulphur is required to react completely with 32.5 of zinc ? $Zn + S \longrightarrow ZnS$

1 mole 1 mole 1 mole

65 g. 32 g.

32.5 g. __ g. $\longrightarrow$ 26.

26. 16 g. - CORRECT. $(\frac{32.5}{65} \times 32)$

Now look at this reaction, $Mg + Cl_2 \longrightarrow MgCl_2$

What weight of Cl_2 will react with 12 g. of magnesium ?

(a) 71 g. ☐ → 27.

(b) 35.5 g. ☐ → 28.

27. (a) 71 g. - SORRY, THIS IS NOT CORRECT.

Using the balanced equation, $Mg + Cl_2 \longrightarrow MgCl_2$

1 mole 1 mole

24 g. 71 g.

12 g. __ g. → 28.

28. 35.5 g. - CORRECT $(\frac{12}{24} \times 71)$

What weight of Calcium will react with 36.5 g. of HCl (hydrochloric acid) ? $Ca + HCl \longrightarrow CaCl_2 + H_2$

(a) 40 g. ☐ → 29.

(b) 20 g. ☐ → 30.

29. (a) 40 g. - NO ! Did you balance the equation ?

$Ca + \underline{\underline{2}}HCl \longrightarrow CaCl_2 + H_2$

1 mole 2 moles

40 g. 73 g.

__ g.? 36.5 g. → 30.

30. (b) 20 g. - CORRECT $(\frac{36.5}{73} \times 40)$.

END OF PROGRAM

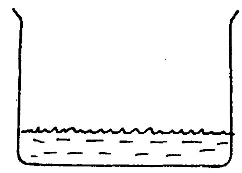
Atomic Weights

H = 1	Mg = 24	Ca = 40
C = 12	S = 32	Cu = 64
O = 16	Cl = 35.5	Zn = 65

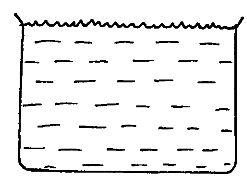
Program 3, 1972

1. Most chemical reactions occur in solution and the idea of the Mole has been adapted to deal with this.

If we dissolve 1 mole of Sodium hydroxide (NaOH), 40 g., in some water,

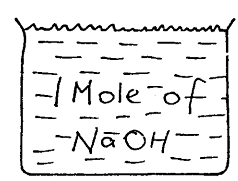


and then add more water until the volume of the solution is 1 litre.



How many moles of NaOH will this solution contain ?
________________ (write your answer here) ⟶ 2.

2. 1 MOLE - GOOD.



If one litre of a solution contains one mole of the substance dissolved in it, the concentration of the solution is ________________ per litre. ⟶ 3.

3. 1 MOLE per LITRE - YES !

If one litre of salt solution contains 1 mole of NaCl then the concentration is said to be 1 mole per litre (1 mole/litre) A solution whose concentration is 1 mole per litre can also be called a MOLAR solution.

How many moles of HCl are dissolved in 1 litre of MOLAR HCl solution ? ______________ ⟶ 4.

4. 1 MOLE - CORRECT. A molar solution of HCl contains 1 mole of HCl per litre of solution.

If a solution has a concentration of 1 mole per litre, it can also be called a ______________ solution. ⟶ 5.

5. MOLAR SOLUTION - YES !

To make a molar solution of NaOH we dissolve 1 mole of NaOH (40 g.) in water and add water until the volume of the solution is ________ → 6.

6. 1 LITRE - GOOD

What is a molar solution ? → 7.

7. A SOLUTION, 1 LITRE OF WHICH CONTAINS 1 MOLE OF DISSOLVED SUBSTANCE.

If 1 litre of NaOH solution contains 5 moles of dissolved NaOH then, the concentration is 5 moles per litre.

5 Moles per litre can also be written as 5 ________ → 9.

8. (a) ONLY - ALMOST !

1 mole per litre = 1 molar
and 1 litre contains one mole of NaCl
Return to frame 12 and try again.

9. 5 MOLAR - CORRECT !

How many moles of H_2SO_4 are contained in 1 litre of 3 molar H_2SO_4 solution ? ________ → 10.

10. 3 MOLES - YES ! Since 3 molar = 3 moles per litre.

How would you make up 1 litre of a 4 molar solution of NaOH ?

____

____

________________________________ → 12.

11. (b) ONLY - ALMOST !

1 mole per litre = 1 molar
1 litre of solution contains 1 mole
Now return to frame 12 and try again. → 12.

12. DISSOLVE 4 MOLES OF NaOH (4 x 40 g.) IN WATER AND THEN ADD MORE WATER UNTIL THE VOLUME IS 1 LITRE - GOOD !

If you are given a 1 molar solution of NaCl, does this mean that,

(a) 1 litre of this solution contains 1 mole of NaCl

or (b) the solution has a concentration of 1 mole of NaCl per litre.

If you think (a) only is correct → 8.
(b) only is correct → 11.
(a) and (b) are both correct → 13.

13. (a) and (b) ARE BOTH CORRECT - YES !

Which of the following solution contains most NaOH ?

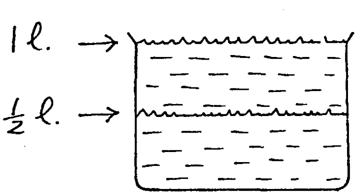
(a) 1 litre of ½ molar NaOH

(b) 1 litre of 1 molar NaOH

(c) 1 litre of 2 molar NaOH

______________ → 14.

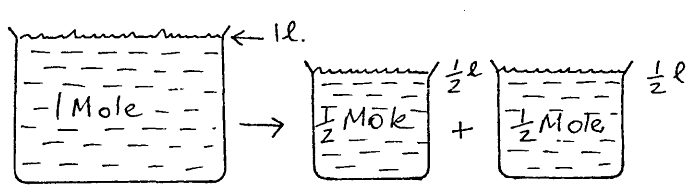
14. (c) - 2 MOLAR NaOH - CORRECT. It contains 2 moles of NaOH in 1 litre of solution.



1 litre of 1 Molar NaOH contains 1 mole of NaOH.

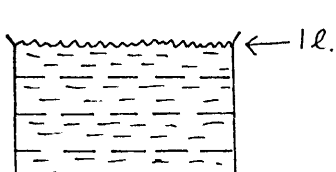
½ litre of 1 Molar NaOH contains ______ moles of NaOH. → 15.

15. ½ MOLE - GOOD !



How many moles of NaOH are contained in 100 ml (1/10 litre) of 1 Molar NaOH solution ? ______________ → 16.

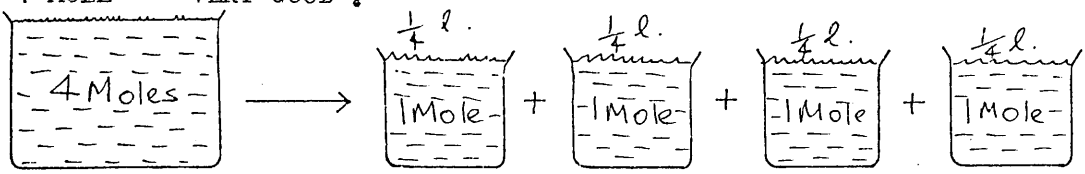
16. 1/10 MOLE - GOOD.



1 litre of 4 Molar NaOH contains 4 moles of NaOH.

250 ml. (1/4 litre) of 4 molar NaOH contains ____________ moles of NaOH. → 17.

17. 1 MOLE - VERY GOOD !



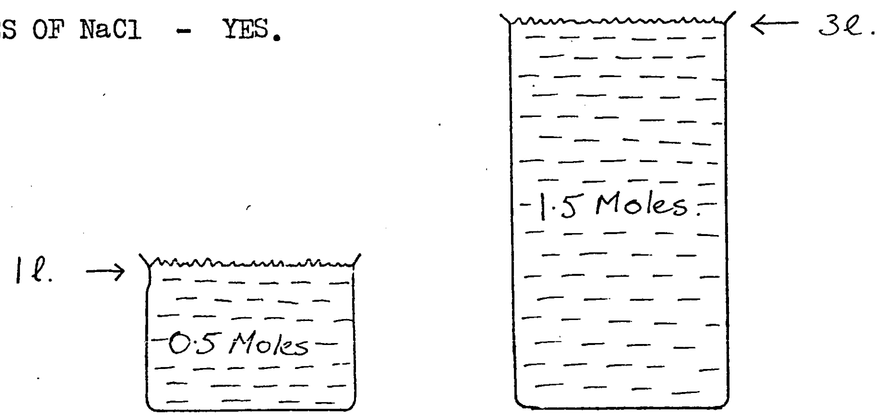
How many moles of HCl are contained in 500 ml. of 2 molar HCl solution ? ____________ → 18.

18. 1 MOLE. Since, 1 l. of 2 M. HCl solution contains 2 moles of HCl and 500 ml. of 2 M. HCl solution contains 1 mole of HCl.

(NOTE - 1 M. is short for 1 Molar
and 2 M. is short for 2 Molar etc.)

How many moles of NaCl are contained in 3 litres of 0.5 M. NaCl solution ? ____________ → 19.

19. 1.5 MOLES OF NaCl - YES.



In 1 litre of 2 M. NaOH :

(a) How many moles of NaOH are dissolved ? ____________

(b) What weight of NaCH is dissolved ? ____________

(All atomic weights are given at the end of the program.) → 20.

20. (a) 2 MOLES } CORRECT
(b) 80 g. (2 x 40 g.) }

1 litre of 2 M. NaOH contains 80 g. of NaOH.

What is the concentration of this solution, in g. per litre ? ____________ → 21.

21. 80 g. per LITRE - YES.

Given 500 ml. ($\frac{1}{2}$ l.) of 2 M. HCl solution

(a) How many moles of HCl does it contain ? ____________

(b) What weight of HCl does it contain ? ____________ ⟶ 22.

22. (a) 1 MOLE of HCl.

(b) 36.5 g. of HCl

END OF PROGRAM

Atomic Weights

H = 1		Na = 23	
O = 16		Cl = 35.5	

Program 4, 1972

1. Magnesium metal reacts with sulphuric acid forming magnesium sulphate and hydrogen gas.

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of H_2SO_4 are required to react with 1 mole of Mg ?

____________ (Write your answer in the space provided.) ⟶ 2.

2. 1 MOLE - YES.

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

1 mole   1 mole   1 mole   1 mole

What is the weight of 1 mole of H_2SO_4 ? ____________

(Atomic Weights are given at the end of this program.) ⟶ 3.

3. 98 g. - GOOD (2 + 32 + 64)

H_2SO_4 is however a liquid and it is easier to measure out a volume than a weight.

If 1 mole of H_2SO_4 is contained in 1 litre of solution, what is the molarity of this solution ? ____________ ⟶ 4.

4. 1 MOLAR (or 1 MOLE PER LITRE)

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

1 mole   1 mole

or 1 mole   1 l. of 1 molar

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ?

(a) 1 ☐ ⟶ 6.

(b) 2 ☐ ⟶ 7.

(Tick the box you think correct.)

5. 1 l. - Since 1 l. of 2 M. H_2SO_4 contains 2 moles of H_2SO_4 dissolved in it.

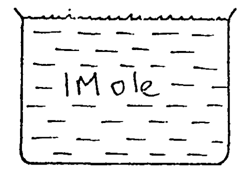
You may remember neutralising acids with alkalis in your first year e.g. adding sodium hydroxide (alkali) to hydrochloric acid (HCl).

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

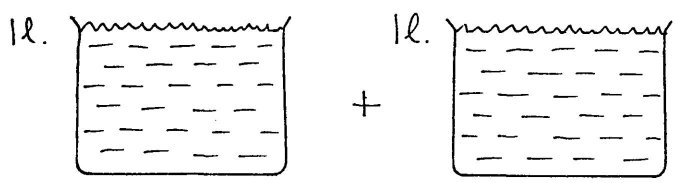
How many moles of HCl neutralise 1 mole of NaOH ? ____________ ⟶ 9.

6. (a) 1 MOLE - SORRY, this is not correct.

1 l. of 1 M. H_2SO_4 contains 1 mole of H_2SO_4

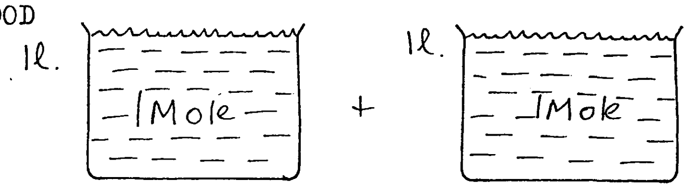


2 l. of 1 M. H_2SO_4 contains __________



→ 8.

7. 2 MOLES - GOOD



$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 moles 2 moles

or 2 moles 2 l. of 1 M.

What volume of 2 M. H_2SO_4 would react with 2 moles of Mg ? ______ →5.

8. 2 MOLES - YES

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 l. of 1 M.

? 2 moles

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ? ______ →7.

9. 1 MOLE - YES

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 mole 1 mole 1 mole 1 mole

1 l. of 1 M. HCl contains 1 mole of HCl.

What volume of 1 M. NaOH would neutralise 1 l. of 1 M. HCl ? ______ →10.

10. 1 LITRE - GOOD

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

NaOH	HCl	NaCl	H_2O
1 mole	1 mole	1 mole	1 mole
1 l. of 1M.	1 l. of 1M.		

What volume of 1 M. NaOH would react with 500 ml ($\frac{1}{2}$ l.) of 1 M. HCl ? ______________ → 11.

11. 500 ml. - YES. 500 ml. of 1 M. HCl contains $\frac{1}{2}$ mole of HCl. and 500 ml. of 1 M. NaOH contains $\frac{1}{2}$ mole of NaOH.

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

NaOH	HCl
500 ml. of 1 M.	500 ml. of 1 M.
$\frac{1}{2}$ mole	$\frac{1}{2}$ mole

What volume of 1 M. NaOH would react with 250 ml ($\frac{1}{4}$ l.) of 1 M. HCl? ______________ → 12.

12. 250 ml of 1 M. HCl - GOOD

If 100 ml. of 1 M. HCl is neutralised by 50 ml. of NaOH solution, what is the molarity of the NaOH solution ?

(a) $\frac{1}{2}$ M. ☐ → 13.

(b) 2 M. ☐ → 14.

13. (a) $\frac{1}{2}$ M. - NO !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 mole 1 mole

Therefore 1 l. of 1 M. 1 l. of 1 M.

Therefore 100 ml. of 1M. 50 ml of ______ ? → 14.

14. (b) 2 M. - YES

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 100 ml. of 1 M. 100 ml. of 1 M.

Therefore 100 ml. of 1 M. 50 ml. of x M.

$$x = \frac{100 \times 1}{50}$$ (2 on top multiplied and divided by one on bottom line)

$$= \underline{2\ M.}$$

If 200 ml. of 2 M. HCl is neutralised by 400 ml. of NaOH solution, what is the molarity of the NaOH ? ________________ → 15.

15. 1 MOLAR - YES !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 200 ml. of 2 M. 200 ml. of 2 M.

Therefore 200 ml. of 2 M. 400 ml. of x M.

$$x = \frac{200 \times 2}{400}$$

$$= \underline{1\ M.}$$

What volume of 2 M. HCl would neutralise 20 ml. of 4 M. NaOH solution ?

(a) 40 ml. ☐ ⟶ 17.

(b) 80 ml. ☐ ⟶ 18.

16. 2 MOLES - CORRECT. (Did you balance the equation ?)

$$\underline{\underline{2}}NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 moles 1 mole

Therefore 2 l. of 1 M. ____________ ? ⟶ 19.

17. (a) 40 ml. - CORRECT !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 20 ml. of 4 M. 20 ml. of 4 M.

Therefore 20 ml. of 4 M. x ml. of 2 M.

$$x = \frac{20 \times 4}{2}$$

$$= \underline{40\ ml.}$$

Now, when NaOH neutralise sulphuric acid (H_2SO_4), how many moles of NaOH are required to neutralise 1 mole of H_2SO_4 ?

$$NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$$

⟶ 16.

18. 80 ml. - NO !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

1 l. of 1 M. 1 l. of 1 M.

Therefore 20 ml. of 4 M. 20 ml. of 4 M.

Therefore 20 ml. of 4 M. x ml. of 2 M.

(Multiply two on top and divide by the one on bottom.)

$$x = \frac{20 \times 4}{2}$$

$$= \_\_\_\_\_\_ ?$$

⟶ 17.

19. 1 l. of 1 M. - VERY GOOD !

What volume of 2 M. NaOH will be required to neutralise 50 ml. of 1 M. H_2SO_4 ?

(a) 25 ml. ☐ → 20.

(b) 50 ml. ☐ → 21.

20. (a) 25 ml. of 2 M. NaOH - SORRY, THIS IS NOT CORRECT.

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

1 mole   2 moles

Therefore 1 l. of 1 M.   2 l. of 1 M.

Therefore 50 ml. of 1 M.   100 ml. of 1 M. $x = \frac{100 \times 1}{2}$

Therefore 50 ml. of 1 M.   x ml. of 2 M.   = ______ → 21.

21. (b) 50 ml. of 2 M. NaOH - CORRECT

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

1 mole   2 moles

Therefore 1 l. of 1 M.   2 l. of 1 M.

Therefore 50 ml. of 1 M.   100 ml. of 1 M. $x = \frac{100 \times 1}{2}$

Therefore 50 ml. of 1 M.   x ml. of 2 M.   = 50 ml.

END OF PROGRAM

Atomic Weights

H = 1

S = 32

O = 16

Program 5, 1972

1. Magnesium metal reacts with sulphuric acid forming magnesium sulphate and hydrogen gas.

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of H_2SO_4 are required to react with 1 mole of Mg ?

_____________ (Write your answer in the space provided.) ⟶ 2.

2. 1 MOLE - YES

$$\begin{array}{cccc} Mg & + \; H_2SO_4 \longrightarrow & MgSO_4 & + \; H_2 \\ 1\ mole & 1\ mole & 1\ mole & 1\ mole \end{array}$$

What is the weight of 1 mole of H_2SO_4 ? _____________ ⟶ 3.

(Atomic Weights are given at the end of this program.)

3. 98 g. - GOOD (2 + 32 + 64)

H_2SO_4 is however a liquid and it is easier to measure out a volume than a weight.

If 1 mole of H_2SO_4 is contained in 1 litre of a solution, what is the molarity of this solution ? ⟶ 4.

4. 1 MOLAR (or 1 MOLE PER LITRE)

$$\begin{array}{cccc} Mg & + \; H_2SO \longrightarrow & MgSO_4 & + \; H_2 \\ 1\ mole & 1\ mole & & \\ or\ 1\ mole & 1\ l.\ of\ 1\ molar & & \end{array}$$

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ?

(a) 1 ☐ ⟶ 6.

(b) 2 ☐ ⟶ 7.

(Tick the box you think correct.)

5. 1 l. - Since 1 l. of 2 M. H_2SO_4 contains 2 moles of H_2SO_4 dissolved in it.

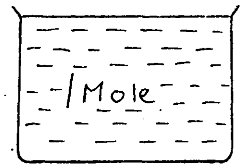
You may remember neutralising acids with alkalis in your first year e.g. adding sodium hydroxide (alkali) to hydrochloric acid (HCl).

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

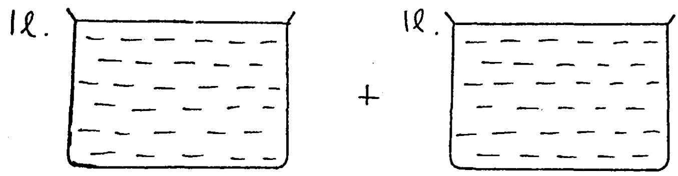
How many moles of HCl neutralise 1 mole of NaOH ? _____________ ⟶ 9.

6. (a) 1 MOLE - SORRY, this is not correct.

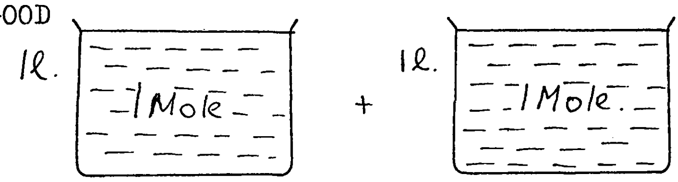
1 l. of 1 M. H_2SO_4 contains 1 mole of H_2SO_4



2 l. of 1 M. H_2SO_4 contains ________ → 8.



7. 2 MOLES - GOOD



$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 moles 2 moles

or 2 moles 2 l. of 1 M.

What volume of 2 M. H_2SO_4 would react with 2 moles of Mg ? ________ → 5.

8. 2 MOLES - YES

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

2 l. of 1 M.

? 2 moles

How many moles of Mg will react with 2 l. of 1 M. H_2SO_4 ? ________ → 7.

9. 1 MOLE - GOOD

1 litre of 1 M. HCl contains 1 mole of HCl dissolved in it.

How many moles of NaOH would react with 1 l. of 1 M. HCl ?

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

________ ? 1 l. of 1 M. → 10.

10. 1 MOLE - YES

How many moles of NaOH are contained in 1 l. of 1 M. NaOH ?

________ → 11.

11. 1 MOLE - CORRECT

What volume of 1 M. NaOH will react with 1 l. of 1 M. HCl ?

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. ______ ?

⟶ 12.

12. 1 l. of 1 M. NaOH - YES. Did you do it this way ?

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. HCl

contains 1 mole of HCl

and 1 mole of HCl reacts with 1 mole of NaOH

What volume of 1 M. NaOH contains 1 mole of NaOH ? - 1 l.

Now, what volume of 1 M. NaOH would react with 500 ml. of 1 M. HCl ? ______

⟶ 13.

13. 500 ml. of 1 M. HCl - VERY GOOD

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

1 l. of 1 M. HCl contains

1 mole of HCl

∴ $\frac{1}{2}$ l. (500 ml.) of

1 M. HCl contains

$\frac{1}{2}$ mole of HCl.

and $\frac{1}{2}$ mole of HCl reacts with $\frac{1}{2}$ mole of NaOH.

What volume of 1 M. NaOH will contain $\frac{1}{2}$ mole of NaOH ? - $\frac{1}{2}$ l.

Now, what volume of 1 M. NaOH will neutralise 250 ml. ($\frac{1}{4}$l.) of 1 M. HCl ? ______

⟶ 14.

14. 250 ml. ($\frac{1}{4}$ l.) of 1 M. NaOH - CORRECT

If 100 ml. of 1 M. HCl is neutralised by 50 ml. of NaOH solution, what is the molarity of the NaOH solution ?

(a) $\frac{1}{2}$ M. ☐ ⟶ 16.

(b) 2 M. ☐ ⟶ 17.

15. 1 M. - YES

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

200 ml. of 2 M.
contains 2/5 moles of HCl
and 2/5 moles of HCl reacts with 2/5 moles of NaOH
so 400 ml. of the NaOH solution contains 2/5 moles.
∴ 1000 ml. " " " " " 1 mole
∴ Solution is 1 M. NaOH

What volume of 2 M. HCl would neutralise 20 ml. of 4 M. NaOH ?

(a) 40 ml. ☐ ⟶ 18.
(b) 80 ml. ☐ ⟶ 19.

16. (a) ½ M. - SORRY, THIS IS NOT CORRECT !

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

100 ml. of 1 M.
contains 1/10 mole.
and 1/10 mole of HCl reacts with 1/10 mole of NaOH
∴ 50 ml. of NaOH solution must contain 1/10 mole
∴ 1000 ml. " " " " " 2 moles

So, molarity of this NaOH solution is ________ M ⟶ 17.

17. (b) 2 M. - CORRECT

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

100 ml. of 1 M.
contains 1/10 mole
and 1/10 mole of HCl neutralises 1/10 mole of NaOH
∴ 50 ml. of this NaOH solution must contain 1/10 mole.
∴ 1000 ml. " " " " " " 2 moles.

∴ Molarity = 2 M.

If 200 ml. of 2 M. HCl is neutralised by 400 ml. of NaOH solution what is the molarity of the NaOH solution ? ________ ⟶ 15.

18. (a) 40 ml. - CORRECT.

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

20 ml. of 4 M.

contains $\frac{4}{50}$ moles

and $\frac{4}{50}$ moles of NaOH neutralise $\frac{4}{50}$ moles of HCl

1000 ml. of 2 M. HCl contains 2 moles

x ml. " " " " $\frac{4}{50}$ moles

$$x = \frac{1000}{2} \times \frac{4}{50} = 40 \text{ ml.}$$

When NaOH neutralises sulphuric acid (H_2SO_4), how many moles of NaOH are required to react with 1 mole of H_2SO_4 ?

$$NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$$

______________ ⟶ 20.

19. (b) 80 ml. - WRONG !

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

20 ml. of 4 M.

contains $\frac{4}{50}$ moles.

and 4/50 moles neutralises $\frac{4}{50}$ moles of HCl

1000 ml. of 2 M. HCl contains 2 moles.

Therefore x ml. of 2 M. HCl contains $\frac{4}{50}$ moles of HCl

$$x = \frac{1000}{2} \times \frac{4}{50} = \underline{\qquad\qquad}$$

⟶ 18.

20. 2 MOLES - YES ! (did you balance the equation ?)

$$\underline{\underline{2}}NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 moles 1 mole

What volume of 1 M. H_2SO_4 will neutralise 2 l. of 1 M. NaOH ?

______________ ⟶ 21.

21. 1 l. of 1 M. H_2SO_4 - YES !

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

2 l. of 1 M.

contains 2 moles

and 2 moles of NaOH neutralises 1 mole of H_2SO_4

1000 ml. of 1 M. H_2SO_4 contains 1 mole.

What volume of 2 M. NaOH will neutralise 50 ml. of 1 M. H_2SO_4 ?

(a) 25 ml. ☐ ⟶ 22.

(b) 50 ml. ☐ ⟶ 23.

22. (a) 25 ml. - NO !

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

50 ml. of 1 M.

contains 1/20 mole

and 1/20 mole of H_2SO_4 neutralises $2 \times \frac{1}{20}$ moles of NaOH.

1000 ml. of 2 M. NaOH contains 2 moles of NaOH

Therefore x ml. of 2 M. NaOH contains $\frac{2}{20}$ moles of NaOH

$$x = \frac{1000}{2} \times \frac{2}{20} = \underline{\qquad\qquad}$$ ⟶ 23.

23. (b) 50 ml. - CORRECT

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

50 ml. of 1 M.

contains 1/20 of a mole

and 1/20 moles neutralises 2/20 moles of NaOH

1000 ml. of 2 M. NaOH contains 2 moles of NaOH

Therefore x ml. of 2 M. NaOH contains $\frac{2}{20}$ moles of NaOH

$$x = \frac{1000}{2} \times \frac{2}{20}$$

$$= \underline{50 \text{ ml.}}$$

END OF PROGRAM

Test 1, 1973

Atomic Weights

H	= 1	Na	= 23
C	= 12	Mg	= 24
N	= 14	S	= 32
O	= 16	Ca	= 40

1. The Gram Formula Weight (G.F.W.) of $NaNO_3$ is :

   A. 53 g.
   B. 85 g.
   C. 113 g.
   D. 159 g.

2. The G.F.W. of $(NH_4)_2SO_4$ is :

   A. 66 g.
   B. 84 g.
   C. 114 g.
   D. 132 g.

3. What is the weight of 1 mole of $MgCO_3$?

   A. 84 g.
   B. 108 g.
   C. 128 g.
   D. 156 g.

4. What is the weight of 1 mole of $(NH_4)_2SO_3$?

   A. 70 g.
   B. 84 g.
   C. 116 g.
   D. 180 g.

5. What is the weight of 3 moles of $CaCO_3$?

   A. 100 g.
   B. 192 g.
   C. 204 g.
   D. 300 g.

6. What is the weight of 0.25 moles of NaOH ?

A. 5 g.
B. 10 g.
C. 20 g.
D. 40 g.

7. What is the weight of 2 moles of Magnesium Nitrate ?

A. 108 g.
B. 148 g.
C. 172 g.
D. 296 g.

8. What is the weight of 0.5 moles of sodium sulphide ?

A. 27.5 g.
B. 35.5 g.
C. 39 g.
D. 51.5 g.

9. How many moles of SO_2 are contained in 48 g. of the compound ?

A. 0.25 moles
B. 0.5 moles
C. 0.75 moles
D. 1 mole

10. How many moles of H_2SO_4 are contained in 196 g. of the compound ?

A. 1 mole
B. 2 moles
C. 3 moles
D. 4 moles

Test 2, 1973

1. The correctly balanced form of the equation, $Al + O_2 \longrightarrow Al_2O_3$ is,

   A. $2Al + O_3 \longrightarrow Al_2O_3$
   B. $Al_2 + 3O \longrightarrow Al_2O_3$
   C. $4Al + 3O_2 \longrightarrow 2Al_2O_3$
   D. $Al_4 + 6O \longrightarrow 2Al_2O_3$

2. Given, $2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$,
   How many moles of NaOH are required to react with 1 mole of H_2SO_4 ?

   A. $\frac{1}{2}$ B. 1 C. 2 D. 4

3. How many moles of NO_2 could be obtained from 1 mole of $Pb(NO_3)_2$ if the equation for this reaction is,

   $2Pb(NO_3)_2 \longrightarrow 2PbO + 4NO_2 + O_2$

   A. $\frac{1}{2}$ B. 1 C. 2 D. 4

4. How many moles of H_2 are required to react completely with 1 mole of N_2, given,

   $N_2 + H_2 \longrightarrow NH_3$ (Balance the equation.)

   A. 1 B. 2 C. 3 D. 4

5. Given,

   $Mg + S \longrightarrow MgS$

   What weight of Mg would react completely with 32 g. of S ?

   A. 12 g. B. 24 g. C. 32 g. D. 56 g.

6. Given,

   $2SO_2 + O_2 \longrightarrow 2SO_3$,

   What weight of SO_2 would react with 32 g. of O_2 ?

   A. 32 g. B. 64 g. C. 96 g. D. 128 g.

7. Given,

   $C + O_2 \longrightarrow CO_2$,

   What weight of O_2 is required to react with 3 g. of C ?

   A. 8 g. B. 16 g. C. 64 g. D. 128 g.

8. Given,

$$2Al + 3CuO \longrightarrow Al_2O_3 + 3Cu$$

What weight of Al would react completely with 80 g. of CuO ?

A. 18 g. B. 27 g. C. 36 g. D. 54 g.

Test 3, 1973

1. A 1 molar solution of hydrochloric acid (HCl) contains :

   A. 1 mole of HCl dissolved in 1 mole of water.

   B. 1 mole of HCl dissolved in 1 l. of water.

   C. 1 mole of HCl dissolved in 1 l. of solution.

   D. 1 mole of water dissolved in 1 l. of HCl.

2. Which of the following HCl solutions is most concentrated.

   A. 500 ml. of 2 M. HCl

   B. 1000 ml. of 3 M. HCl

   C. 300 ml. of 4 M. HCl

   D. 800 ml. of 5 M. HCl.

3. Which solution of NaCl is most concentrated ?

A.	200 ml.	of	solution	containing	2	moles	of	dissolved	NaCl
B.	500 ml.	"	"	"	4	"	"	"	"
C.	750 ml.	"	"	"	8	"	"	"	"
D.	1000 ml.	"	"	"	6	"	"	"	"

4. If one mole of sodium hydroxide (NaOH) is dissolved in 500 ml. of solution, what is the concentration of the solution ?

   A. 0.5 moles per litre

   B. 1 mole per litre

   C. 2 moles per litre

   D. 3 moles per litre.

5. If 0.5 moles of NaOH are dissolved in 200 ml. of solution. What is the concentration of the solution ?

   A. 0.5 moles per litre

   B. 1.5 " " "

   C. 2.0 " " "

   D. 2.5 " " "

6. Which of the following solutions contains most NaCl ?

A. 500 ml. of 2 M. NaCl

B. 1000 ml. of 3 M. NaCl

C. 250 ml. of 4 M. NaCl

D. 200 ml. of 5 M. NaCl.

7. Which of the following solutions contains most NaCl ?

A. 30 ml. of 1.2 M. NaCl

B. 25 ml. of 1.4 M. NaCl

C. 20 ml. of 1.6 M. NaCl

D. 15 ml. of 1.8 M. NaCl.

8. How many moles of NaOH are dissolved in 500 ml. of 4 M. NaOH solution ?

A. $\frac{1}{2}$ mole

B. 1 mole

C. 2 moles

D. 3 moles

9. How many moles of H_2SO_4 are dissolved in 15 ml. of 2 M. H_2SO_4 ?

A. 0.3 moles

B. 0.03 moles

C. 0.2 moles

D. 0.02 moles

10. What weight of NaOH is contained in 500 ml. ($\frac{1}{2}$ l.) of 1 M. NaOH solution ?

A. 10 g.

B. 20 g.

C. 40 g.

D. 80 g.

11. What weight of NaOH is contained in 100 ml. of 5 M. NaOH solution ?

A. 10 g.

B. 20 g.

C. 40 g.

D. 80 g.

12. Given (i) 1 l. of 1 M. NaOH solution
(ii) 1 l. of 1 M. NaCl solution
(iii) 1 l. of 1 M. HCl solution

which of the following is correct ?

A. (i) contains a larger weight of dissolved substance than (ii) and (iii)

B. (ii) " " " " " dissolved substance than (iii) and (i)

C. (iii) " " " " " dissolved substance than (ii) and (i)

D. They all contain the same weight of dissolved substance.

<u>Atomic Weights</u>

H	=	1	Na	=	23
O	=	16	Cl	=	35.5

Test 4, 1973

1. Magnesium metal reacts with sulphuric acid (H_2SO_4),

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of Mg will react with 1 l. of 1 M. H_2SO_4 ?

A. ½ B. 1 C. 2 D. 4

2. How many moles of Mg will react with 100 ml. of 4 M. H_2SO_4 ?

A. 0.04 B. 0.4 C. 1 D. 4

3. What volume of 2 M. H_2SO_4 will react with 2 moles of Mg ?

A. ½ l. B. 1 l. C. 2 l. C. 4 l.

4. What volume of 4 M. H_2SO_4 will react with ½ mole of Mg ?

A. 75 ml. B. 125 ml. C. 250 ml. D. 500 ml.

5. What volume of 1 M. NaOH will neutralise 2 l. of 1 M. HCl ?

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

A. ½ l. B. 1 l. C. 2 l. D. 4 l.

6. What volume of 4 M. HCl will neutralise 80 ml. of 1 M. NaOH ?

A. 10 ml. B. 20 ml. C. 40 ml. D. 80 ml.

7. ½ l. of 1 M. NaOH is neutralised by 1 l. of a solution of HCl. What is the molarity of the HCl ?

A. ½ M. B. 1 M. C. 2 M. D. 4 M.

8. 25 ml. of 4 M. HCl is neutralised by 100 ml. of NaOH solution. What is the molarity of the NaOH solution ?

A. ½ M. B. 1 M. C. 2 M. D. 4 M.

9. NaOH solution can be used to neutralise sulphuric acid.

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

What volume of 1 M. NaOH solution will neutralise 1 l. of 1 M. H_2SO_4 ?

A. ½ l. B. 1 l. C. 2 l. D. 4 l.

10. What volume of 2 M. H_2SO_4 will neutralise 250 ml. of 4 M. NaOH ?

A. 125 ml. B. 250 ml. C. 375 ml. D. 500 ml.

11. If 1 l. of 1 M. NaOH neutralises ½ l. of H_2SO_4, what is the molarity of H_2SO_4 solution ?

A. ¼ M. B. ½ M. C. 1 M. D. 2 M.

12. If 20 ml. of 2 M. H_2SO_4 neutralises 100 ml. of NaOH solution, what is the molarity of the NaOH solution ?

A. 0.04 M. B. 0.08 M. C. 0.4 M. D. 0.8 M.

Test 1, 1972

Atomic Weights required

H	= 1	Na	= 23
C	= 12	Mg	= 24
N	= 14	S	= 32
O	= 16		

1. The Gram Formula Weight (G.F.W.) of NO is :

   A 28 g. B 30 g.
   C 32 g. D 34 g.

2. The G.F.W. of SO_2 is :

   A 48 g. B 64 g.
   C 80 g. D 96 g.

3. The G.F.W. of $NaNO_3$ is :

   A 53 g. B 85 g.
   C 113 g. D 159 g.

4. The G.F.W. of $(NH_4)_2SO_4$ is :

   A 66 g. B 84 g.
   C 114 g. D 132 g.

5. What is the weight of 1 mole of CO :

   A 26 g. B 28 g.
   C 30 g. D 32 g.

6. What is the weight of 1 mole of NO_2 :

   A 30 g. B 44 g.
   C 46 g. D 60 g.

7. What is the weight of 1 mole of $MgCO_3$:

A	84 g.	B	108 g.
C	128 g.	D	156 g.

8. What is the weight of 1 mole of $(NH_4)_2SO_3$:

A	70 g.	B	84 g.
C	116 g.	D	180 g.

Test 2, 1972

1. The correctly balanced form of the equation,

$$Al + O_2 \longrightarrow Al_2O_3 \text{ is :}$$

A. $2Al + O_3 \longrightarrow Al_2O_3$
B. $Al_2 + 3O \longrightarrow Al_2O_3$
C. $4Al + 3O_2 \longrightarrow 2Al_2O_3$
D. $Al_4 + 6O \longrightarrow 2Al_2O_3$

2. Given, $2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$

How many moles of H_2SO_4 are required to react with 1 mole of NaOH ?

A. $\frac{1}{2}$ C. 2
B. 1 D. 4

3. How many moles of NO_2 could be obtained from 1 mole of $Pb(NO_3)_2$ if the equation for this reaction is :

$$2Pb(NO_3)_2 \longrightarrow 2PbO + 4NO_2 + O_2 \text{ ?}$$

A. $\frac{1}{2}$ C. 2
B. 1 D. 4

4. Given, $Na + S \longrightarrow Na_2S$

How many moles of Na are required to react with 1 mole of S ?

A. $\frac{1}{2}$ C. 2
B. 1 D. 4

5. Given, $N_2 + H_2 \longrightarrow NH_3$

How many moles of H_2 are required to react completely with 1 mole of N_2 ?

A. 1 C. 3
B. 2 D. 4

6. Given, $Mg + S \longrightarrow MgS$

What weight of Mg would react completely with 32 g. of S ?

A. 12 g. C. 32 g.
B. 24 g. D. 56 g.

7. Given, $2SO_2 + O_2 \longrightarrow 2SO_3$

What weight of SO_2 would react with 32 g. of O_2 ?

A. 32 g. C. 96 g.
B. 64 g. D. 128 g.

8. Given, $C + O_2 \longrightarrow CO_2$

What weight of O_2 is required to react with 3 g. of C ?

A. 8 g. C. 64 g.
B. 16 g. D. 128 g.

9. Given, $2Al + 3CuO \longrightarrow Al_2O_3 + 3Cu$

What weight of Al would react completely with 120 g. of CuO ?

A. 27 g. C. 81 g.
B. 54 g. D. 108 g.

10. What weight of CO_2 would be obtained by heating 25 g. of calcium carbonate ?

A. 11 g. C. 44 g.
B. 22 g. D. 88 g.

<u>Atomic Weights</u>

C = 12		Al = 27	
O = 16		S = 32	
Mg = 24		Ca = 40	
		Cu = 64	

Test 3, 1972

1. A 1 molar solution of hydrocholric acid (HCl) contains :

   A. 1 mole of HCl dissolved in 1 mole of water.
   B. " " " " " " 1 l. of water.
   C. " " " " " " 1 l. of solution.
   D. " " " water " " 1 l. of HCl.

2. Which of the following HCl solutions is most concentrated.

   A. 500 ml. of 2 M. HCl.
   B. 1000 ml. of 3 M. HCl.
   C. 300 ml. of 4 M. HCl.
   D. 800 ml. of 5 M. HCl.

3. Which solution of NaCl is most concentrated ?

   A. 200 ml. of solution containing 2 moles of dissolved NaCl.
   B. 500 " " " " 4 " " " "
   C. 750 " " " " 8 " " " "
   D. 1000 " " " " 6 " " " "

4. If one mole of sodium hydroxide (NaOH) is dissolved in 500 ml. of solution, what is the concentration of the solution ?

   A. 0.5 moles per litre.
   B. 1 " " "
   C. 2 " " "
   D. 3 " " "

5. If 0.5 moles of NaOH are dissolved in 200 ml. of solution. What is the concentration of the solution ?

   A. 0.5 moles per litre.
   B. 1.5 " " "
   C. 2.0 " " "
   D. 2.5 " " "

6. Which of the following solutions contains most NaCl ?

A. 500 ml. of 2 M. NaCl.

B. 1000 ml. of 3 M. NaCl.

C. 250 ml. of 4 M. NaCl.

D. 200 ml. of 5 M. NaCl.

7. Which of the following solutions contains most NaCl ?

A. 30 ml. of 1.2 M. NaCl.

B. 25 ml. of 1.4 M. NaCl.

C. 20 ml. of 1.6 M. NaCl.

D. 15 ml. of 1.8 M. NaCl.

8. How many moles of NaOH are dissolved in 500 ml. of 4 M. NaOH solution ?

A. $\frac{1}{2}$ mole   C. 2 moles

B. 1 mole   D. 3 moles

9. How many moles of H_2SO_4 are dissolved in 15 ml. of 2 M. H_2SO_4 ?

A. 0.3 moles   C. 0.2 moles

B. 0.03 moles   D. 0.02 moles

10. What weight of NaOH is contained in 500 ml. ($\frac{1}{2}$ l.) of 1 M. NaOH solution ?

A. 10 g.   C. 40 g.

B. 20 g.   D. 80 g.

11. What weight of NaOH is contained in 100 ml. of 5 M. NaOH solution ?

A. 10 g.   C. 40 g.

B. 20 g.   D. 80 g.

12. Given
(i) 1 l. of 1 M. NaOH solution
(ii) 1 l. of 1 M. NaCl solution
(iii) 1 l. of 1 M. HCl solution

which of the following is correct ?

A. (i) contains a larger weight of dissolved substance than (ii) and (iii).

B. (ii) " " " " " dissolved substance than (iii) and (i).

C. (iii) " " " " " dissolved substance than (ii) and (i).

D. They all contain the same weight of dissolved substance.

Atomic Weights

H	=	1
O	=	16
Na	=	23
Cl	=	35.5

Test 4, 1972

1. Magnesium metal reacts with sulphuric acid (H_2SO_4),

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

How many moles of Mg will react with 1 l. of 1 M. H_2SO_4 ?

A. ½ B. 1 C. 2 D. 4

2. How many moles of Mg will react with 10 ml. of 4 M. H_2SO_4 ?

A. 0.04 B. 0.4 C. 1 D. 4

3. What volume of 2 M. H_2SO_4 will react with 2 moles of Mg ?

A. ½ l. B. 1 l. C. 2 l. D. 4 l.

4. What volume of 4 M. H_2SO_4 will react with ½ mole of Mg ?

A. 75 ml. B. 125 ml. C. 250 ml. D. 500 ml.

5. What volume of 1 M. NaOH will neutralise 2 l. of 1 M. HCl ?

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

A. ½ l. B. 1 l. C. 2 l. D. 4 l.

6. What volume of 4 M. HCl will neutralise 80 ml. of 1 M. NaOH ?

A. 10 ml. B. 20 ml. C. 40 ml. D. 80 ml.

7. ½ l. of 1 M. NaOH is neutralised by 1 l. of a solution of HCl. What is the molarity of the HCl ?

A. ½ M. B. 1 M. C. 2 M. D. 4 M.

8. 25 ml. of 4 M. HCl is neutralised by 100 ml. of NaOH solution. What is the molarity of the NaOH solution ?

A. ½ M. B. 1 M. C. 2 M. D. 4 M.

9. NaOH solution can be used to neutralise sulphuric acid.

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

What volume of 1 M. NaOH solution will neutralise 1 l. of 1 M. H_2SO_4 ?

A. $\frac{1}{2}$ l. B. 1 l. C. 2 l. D. 4 l.

10. What volume of 2 M. H_2SO_4 will neutralise 250 ml. of 4 M. NaOH ?

A. 125 ml. B. 250 ml. C. 375 ml. D. 500 ml.

11. If 1 l. of 1 M. NaOH neutralises $\frac{1}{2}$ l. of H_2SO_4, what is the molarity of the H_2SO_4 solution ?

A. $\frac{1}{4}$ M. B. $\frac{1}{2}$ M. C. 1 M. D. 2 M.

12. If 20 ml. of 2 M. H_2SO_4 neutralises 100 ml. of NaOH solution, what is the molarity of the NaOH solution ?

A. 0.04 M. B. 0.08 M. C. 0.4 M. D. 0.8 M.

2.9. APPENDIX II

RESULTS

1973 Tests - Facility Values

Question	1	2	3	4	5	6	7	8	9	10	11	12
Pre-test 1	0.77	0.81	0.69	0.71	0.62	0.70	0.10	0.24	0.55	0.60		
Post-test 1	0.86	0.84	0.82	0.82	0.74	0.87	0.09	0.29	0.73	0.79		
Control 1	0.90	0.85	0.88	0.88	0.87	0.91	0.08	0.39	0.76	0.81		
Pre-test 2	0.31	0.64	0.32	0.32	0.38	0.17	0.41	0.17				
Post-test 2	0.35	0.58	0.46	0.41	0.66	0.24	0.65	0.27				
Control 2	0.53	0.76	0.50	0.54	0.74	0.34	0.77	0.30				
Pre-test 3	0.17	0.25	0.44	0.31	0.46	0.33	0.27	0.49	0.22	0.46	0.42	0.38
Post-test 3	0.28	0.44	0.49	0.38	0.56	0.48	0.34	0.64	0.32	0.61	0.56	0.51
Control 3	0.58	0.50	0.57	0.56	0.77	0.51	0.35	0.81	0.58	0.76	0.72	0.74
Pre-test 4	0.82	0.36	0.32	0.27	0.57	0.58	0.37	0.41	0.35	0.26	0.25	0.23
Post-test 4	0.89	0.40	0.40	0.39	0.69	0.66	0.50	0.43	0.36	0.24	0.22	0.16
Control 4	0.90	0.78	0.64	0.62	0.81	0.79	0.61	0.74	0.58	0.23	0.27	0.19

1973 Tests - Discriminating Powers

	1	2	3	4	5	6	7	8	9	10	11	12
Pre-test 1	0.50	0.38	0.58	0.57	0.63	0.61	-0.15	0.24	0.57	0.65		
Post-test 1	0.39	0.44	0.46	0.45	0.57	0.35	0.01	0.32	0.48	0.49		
Control 1	0.32	0.32	0.34	0.31	0.37	0.31	0.09	0.45	0.50	0.41		
Pre-test 2	0.32	0.33	0.11	0.41	0.45	0.34	0.46	0.30				
Post-test 2	0.56	0.41	0.12	0.44	0.57	0.29	0.43	0.30				
Control 2	0.37	0.19	0.37	0.64	0.45	0.52	0.44	0.43				
Pre-test 3	0.17	0.15	0.33	0.23	0.32	0.19	0.10	0.38	0.21	0.40	0.29	0.37
Post-test 3	0.23	0.36	0.20	0.48	0.57	0.14	0.24	0.57	0.41	0.40	0.41	0.40
Control 3	0.37	0.44	0.32	0.25	0.31	0.37	0.30	0.33	0.30	0.42	0.43	0.33
Pre-test 4	0.17	0.34	0.29	0.12	0.34	0.31	0.25	0.35	0.31	0.19	0.30	0.25
Post-test 4	0.21	0.42	0.37	0.40	0.43	0.44	0.28	0.51	0.30	0.08	0.23	0.19
Control 4	0.31	0.35	0.35	0.46	0.34	0.31	0.41	0.33	0.38	0.38	0.27	0.37

1973 Validation of Programs

	Mean	S.D.	n		% Sig
Pre-test 1	5.80	2.52	289	5.24	< 1
Post-test 1	6.83	2.18	288		
Pre-test 2	2.74	1.59	256	5.63	< 1
Post-test 2	3.62	1.86	241		
Pre-test 3	4.19	1.84	234	6.96	< 1
Post-test 3	5.61	2.55	238		
Pre-test 4	4.77	1.97	231	2.74	< 1
Post-test 4	5.32	2.27	226		

1973 Method and the Mole

Program 1*	P_1	P_3	P_4	Control
Pre-test 1	4.5	6.1	6.7	
Post-test 1	6.4	7.1	6.7	7.3
Post-test 2	3.1	3.9	3.9	4.5
Post-test 3	5.2	5.3	6.4	7.2
Post-test 4	5.0	4.9	6.2	7.2

* Each group followed a different route through the first program - denoted P_1, P_3 or P_4.

These are mean scores in the tests.

	Program 4	Program 5	Control
Pre-test 4	4.5	5.3	
Post-test 4	4.7	6.3	7.2

1973 Maturity Experiment

		Mean	S.D.	n
Test 1	Class III	7.30	1.94	241
	Class IV	8.16	1.82	188
	Class V	8.32	2.10	87
Test 2	Class III	4.47	1.92	241
	Class IV	5.83	2.00	181
	Class V	6.82	1.58	86
Test 3	Class III	7.16	2.92	246
	Class IV	7.47	2.87	187
	Class V	8.94	2.13	78
Test 4	Class III	7.15	2.37	151
	Class IV	6.98	3.29	172
	Class V	9.57	2.02	68

1972 Tests - Facility Values

Question	1	2	3	4	5	6	7	8	9	10	11	12
Pre-test 1	0.97	0.88	0.84	0.91	0.95	0.87	0.88	0.87				
Post-test 1	1.0	0.95	0.93	0.94	0.98	0.92	0.93	0.93				
Control 1	0.96	0.90	0.86	0.85	0.92	0.86	0.89	0.86				
Pre-test 2	0.40	0.41	0.42	0.68	0.30	0.62	0.26	0.59	0.33	0.39		
Post-test 2	0.55	0.51	0.56	0.59	0.36	0.80	0.37	0.72	0.48	0.51		
Control 2	0.59	0.47	0.54	0.53	0.44	0.71	0.41	0.58	0.45	0.43		
Pre-test 3	0.24	0.33	0.57	0.37	0.51	0.34	0.27	0.55	0.30	0.52	0.44	0.44
Post-test 3	0.25	0.42	0.66	0.49	0.71	0.39	0.28	0.79	0.43	0.71	0.65	0.62
Control 3	0.55	0.49	0.68	0.50	0.64	0.36	0.31	0.70	0.41	0.68	0.58	0.72
Pre-test 4	0.84	0.36	0.33	0.39	0.61	0.60	0.44	0.49	0.30	0.18	0.21	0.10
Post-test 4	0.92	0.48	0.56	0.55	0.75	0.79	0.56	0.73	0.53	0.30	0.30	0.12
Control 4	0.84	0.54	0.46	0.47	0.65	0.72	0.59	0.57	0.48	0.41	0.29	0.36

1972 Tests - Discriminating Powers

Question	1	2	3	4	5	6	7	8	9	10	11	12
Pre-test 1	0.10	0.35	0.46	0.27	0.15	0.39	0.37	0.39				
Post-test 1	0.01	0.14	0.21	0.18	0.07	0.23	0.22	0.21				
Control 1	0.11	0.28	0.42	0.42	0.19	0.42	0.31	0.42				
Pre-test 2	0.50	0.50	0.42	0.28	0.33	0.55	0.53	0.68	0.58	0.47		
Post-test 2	0.53	0.39	0.49	0.39	0.49	0.45	0.75	0.47	0.62	0.74		
Control 2	0.67	0.75	0.47	0.33	0.33	0.64	0.61	0.67	0.47	0.56		
Pre-test 3	0.29	0.36	0.44	0.40	0.56	0.36	0.31	0.88	0.46	0.79	0.56	0.61
Post-test 3	0.32	0.18	0.48	0.60	0.67	0.15	0.21	0.49	0.53	0.58	0.56	0.59
Control 3	0.29	0.10	0.37	0.75	0.70	0.20	0.39	0.54	0.42	0.65	0.62	0.35
Pre-test 4	0.22	0.34	0.45	0.53	0.65	0.47	0.53	0.64	0.43	0.31	0.33	0.09
Post-test 4	0.19	0.44	0.54	0.77	0.38	0.43	0.72	0.52	0.66	0.42	0.50	0.13
Control 4	0.24	0.48	0.59	0.40	0.62	0.40	0.62	0.78	0.84	0.45	0.56	0.56

1972 Validation of Programs

	Mean	S.D.	n	t	% sig.
Pre-test 1	7.15	1.65	209	3.05	<1
Post-test 1	7.57	1.24	268		
Control 1	7.10	1.59	104		
Pre-test 2	4.40	2.21	233	5.32	<1
Post-test 2	5.52	2.52	275		
Control 2	5.15	2.48	108		
Pre-test 3	4.86	2.68	219	6.59	<1
Post-test 3	6.39	2.41	278		
Control 3	6.34	2.52	109		
Pre-test 4	4.86	2.50	207	6.08	<1
Post-test 4	6.38	2.66	222		
Control 4	6.38	2.89	109		

COLOUR AND PARAMAGNETISM IN TRANSITION METAL COMPLEXES

COLOUR AND PARAMAGNETISM IN TRANSITION METAL COMPLEXES

3.1. Introduction

In 1962 the scottish Education Department put forward proposals for A-levels[17] which they hoped would become a recognised course at Sixth form level in Scotland and so provide a uniform course in chemistry during the so-called "maturing year". These proposals were never brought to fruition and were replaced by what is now known as the Certificate of Sixth Year Studies in Chemistry.[18] The syllabus was finally produced in 1968 and followed by the first national examination in 1969. Johnstone, Morrison and Sharp[2] have studied the concepts which cause difficulty -

	Easy to Grasp	Difficult to Grasp	Never Grasped
Origin of Colour	59	32	9
Orbitals - degenerate and split	37	48	15
Paramagnetism	60	31	9

(Figures expressed as percentages.)

The primary aim of this work was to examine these topics more closely in order to discover more precisely where difficulties lie. The test designed to expose these difficulties was objective, but not a type in common use, and a secondary aim emerged - to study the effectiveness of such a test.

3.2. Experimental Techniques

Program

In this part of the work it was also decided to use programmed learning materials in order to control such variables as -

(a) Depth of treatment and length of time spent on the topic.

(b) Rate of progress by individual pupils.

(c) Teacher attitude.

(d) Content, e.g. units, nomenclature etc.

The material to be presented was to be used by maturer pupils, between the ages of 17 and 18. A structural program[19,20,21] was constructed (see Appendix III pg. 1) rather than a linear or branching type, as this was considered to be more suited to the maturer and perhaps more inquiring minds of senior pupils. In 1972 an attempt was made to validate the program, but because of difficulties in getting a sufficient number of pupils to use the program and associated test, no significant results were obtained. Several mistakes in the program content were brought to light however and individual pupil comments about their difficulties in following the rather complicated instructions were helpful in making some minor revisions. Only the final copy of the program (used in 1973) is included in Appendix III.

The program took the form of a normal text on Transition Metal Chemistry followed by questions which tested their knowledge and understanding of the subject. Their answers had to be chosen from an array of information, some relevant and some irrelevant. From the answers chosen, they were directed to a discussion section which included material related to their choice of answer - remedial if their answer merited it.

Test

Again an objective testing method was selected in order to make analysis of the answers as objective as possible. The test had to fulfil two objectives.

(i) To identify pupil difficulties.

(ii) To test the validity of the programmed material.

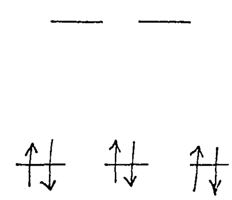
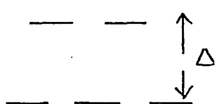
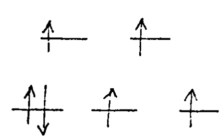
It was also hoped to judge the effectiveness of such a test in assessing the pupils' knowledge of the topic concerned. The people who sat this rather unusual test should also have sat a "normal" test in order to compare results. This was not done and the effectiveness of this type of question compared with a more traditional type remains to be gauged. The group using the program should have sat a traditional test along with a group who had been taught by normal class methods, and the results compared. Regrettably, due to pressure of time, this could not be completed and the program was merely judged on its effectiveness in a rather unusual test.

The questions answered by pupils were :-

$FeSO_4.7H_2O$ is green and is attracted into a magnetic field. $K_4Fe(CN)_6$ is yellow and is not attracted into a magnetic field.

1. Explain why $K_4Fe(CN)_6$ is yellow.
2. Explain why the colour of the two complexes is different.
3. Explain why $FeSO_4.7H_2O$ is magnetic.
4. Copper Sulphate solution turns a deeper blue colour when NH_3 is added. Explain this in terms of the theories given in the program.

As these questions stand the pupils would have to write a paragraph to answer each. Here, however, they had to construct an answer by choosing information from this grid -

CN^- ligands produce large splitting (Δ) of d-orbitals 1.	The possibility of spin pairing occurs with d^4, d^5, d^6, and d^7 configurations only 2.	Where Δ is large, electrons do not obey Hund's Rule when filling available orbitals 3.	Visible light is of the correct energy value to promote electrons from the lower to the higher energy level 4.
Fe^{2+} has a d^6 electron configuration 5.	NH_3 ligands produce a larger splitting (Δ) of d-orbitals than H_2O 6.	If blue light is absorbed, then the colour of the complex is yellow (Red + Green) 7.	In a low spin d^6 configuration, the electrons are arranged  8.
Cu^{2+} has a d^9 electron configuration 9.	Transition metals contain partly filled d-subshells 10.	d-Orbitals which contain unpaired electron spins cause complexes to be paramagnetic 11.	Low spin configurations have smaller paramagnetism than high spin configurations 12.
When is large, energy of a higher value is needed to promote electrons 13.	The energy gap between the two sets of orbitals is called Δ  14.	H_2O ligands produce small splitting of d-orbitals 15.	In an octahedral field, the 5 degenerate d-orbitals are split into two energy levels 16.
Fe^{3+} has a d^5 electron configuration 17.	High spin configurations occur when Δ is small 18.	Different light colours have different energy values 19.	In a high spin complex, the electrons are arranged  20.

The pupils had to select the relevant responses from this grid and discard the irrelevant ones - rather like a large multiple choice question. This proved to be a difficult task for them, probably because all of the responses were chemically correct, but not necessarily relevant. (In 1972 test, wrong information was included in the answer grid but these were omitted in 1973.) The pupils merely had to record the numbers of the responses they thought to be relevant and these were marked by computer.

$$\left[\frac{\text{No. of relevant responses chosen}}{\text{Total no. of relevant responses}} - \frac{\text{No. of irrelevant responses chosen}}{\text{Total no. of irrelevant responses}}\right]$$

$$= \text{Coefficient of Confusion}$$

The maximum score for this Coefficient was +1 and the minimum -1.

Having selected the relevant responses they had then to link these in an order which would most logically answer the question concerned.

Linking the responses in the most logical order was an attempt to simulate the answering of an open-ended, essay type question, i.e. where the pupil has to decide on information which he wishes to include in a written answer and then construct a coherent unit from these. Here however the pupils had to select information from that supplied on the grid and then place this in the most logical order without actually writing a paragraph or essay. The order they chose was recorded as a series of numbers and this again made marking by computer possible. This was extremely complex. It must be realised that although the marking of the sequence was completely objective, the choice of correct sequence was not. In this respect it is probable that 2 or 3 equally logical sequences could be produced. The possibility of limitless numbers of seemingly logical sequences can be eliminated by careful choice of grid responses. This was a most difficult task. In marking any sequence, e.g.

10 9 16 14 4 15 6 13 19,

the number of possible combinations is very large and to attempt to put these in rank order of logical correctness would have been an impossible task. A computer program was produced to tackle this in a mechanical fashion.

This is best explained by example.

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	10	9	16	14	4	15	6	13	19

Perfect sequence score = 18 (2 for each in correct position)

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	10	9	14	15	6	3	13	19	

Sample is rewritten with any wrong responses replaced by 0 and as many numbers as possible "lined up" by incorporating 0's in the spaces i.e.

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	10	9	0	14	0	15	6	13	19

Score = 14

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	10	16	14	15	6	9	13	4	19

Score = 9

Here, only two are lined up exactly and five are out of position by no more than three places – these score only one point. Responses 4 and 9 are more than three places out of position and do not score.

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	9	10	15	6	13	19	4		

becomes -

Correct	-	10	9	16	14	4	15	6	13	19
Sample	-	9	10	0	0	15	6	13	19	4

Score = 6

This sequence has come out badly using this method of marking simply because the 4 at the end has displaced several other responses. Had response 4 been omitted the score could have been ten. Is a drop of four points fair for having one number so far out of position ?

It is not suggested that this program is perfect because other anomalies such as this do arise, but on the whole the scores reflect fairly the logic of the answer.

The percentage of pupils choosing each response was calculated in order to discover the difficulties. A high percentage choosing a relevant response was taken to indicate that the pupils were sure that the information was relevant and understood it : the implications of a low % in a relevant response and vice versa are obvious.

3.3. Results

87 schools were issued with 1170 programs and tests. 37 returned 350 completed tests.

In each question, the percentage choosing each response was examined in order to identify areas of student difficulty. This however, was a very complex and difficult task. Several responses contained formal prompts[12], e.g. the inclusion of colours in a response would dissuade pupils from using this response if the question involved paramagnetism and vice versa. E.g. in Question 1 (Why is $K_4[Fe(CN)_6]$ yellow ?)

11.	9.	4.	7.
d-Orbitals which contain unpaired electron spins cause complexes to be paramagnetic.	Cu^{2+} has a d^9 electron configuration.	Visible light is of the correct energy value to promote electrons from the lower to the higher energy level.	If blue light is absorbed, the the colour of the complex is yellow (red + green)
0.6%	0.3%	86.5%	98.3%

The percentages choosing these indicated that the prompting had certainly been noticed.

The effect of these formal prompts could not of course be measured. The validity of the implication that a student had chosen or discarded a particular response was in doubt in such situations. These "formal prompt" responses must be kept to a minimum in designing such an answer grid.

In three of the questions, less than 40% of the pupils thought that response 10 was worthwhile including, despite the fact that this

10.
Transition metals contain partly filled d-subshells

had been the fundamental definition of a Transition Metal given to them. Q.1, Q.2 and Q.3 all included questions about Fe^{2+} complexes.

Response 5

Response box		% answering
Fe^{2+} has a d^6 electron configuration	Q.1.	23.3
	Q.2.	16.3
	Q.3.	46.0

This response was considered necessary as it placed Fe, by definition, in the transition series. Obviously the pupils only thought that this was important when paramagnetism was concerned. A similar low response occurred in response 9 in Q.4.

In the first two questions, a very high proportion of pupils correctly included.

4.	19.	7.
Visible light is of the correct energy value to promote electrons from the lower to the higher energy level.	Different light colours have different energy values.	If blue light is absorbed, then the colour of the complex is yellow (red + green).

Whether these were included because pupils fully understood the concept or whether they were merely reacting to the formal prompts so obviously present in these responses is difficult to determine.

The importance of splitting the degenerate d-orbitals to produce colour and paramagnetism in transition metal complexes seemed to be apparent to pupils. About 50% included :

16.	and	14.
In an octahedral field, the 5-degenerate d-orbitals are split into two energy levels.		The energy gap between the two sets of orbitals is called Δ 

in their answers to all four questions. The importance of ligands in affecting Δ also attracted high response, e.g. in Q.2

1.	and	15.
CN^- ligands produce large splitting (Δ) of d-orbitals		H_2O ligands produce small splitting (Δ) of d-orbitals
76%		75%

Both however contain ligands named in the question. They were not sure however if H_2O was the ligand which caused the blue colour in Cu^{2+}(aq.) in Q.4.

15.	and	6.
H_2O ligands produce small splitting (Δ) of d-orbitals		NH_3 ligands produce larger splitting (Δ) of d-orbitals than H_2O
36.5%		91.0%

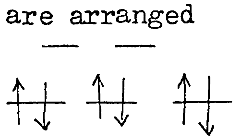
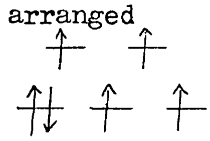
The concept of "Oxidation Numbers" seemed well understood. In Q. 1, 2 and 3 only a small % made the mistake of choosing

17.		5.
Fe^{3+} has a d^5 electron configuration	instead of	Fe^{2+} has a d^6 electron configuration

One real problem area is in the understanding of Hund's Rule for filling available orbitals. This rule is of no importance as far as colour is concerned in transition metal complexes.

3.			
Where Δ is large, electrons do not obey Hund's Rule when filling available d-orbitals	Q. 1	18.7%	included in answer
	Q. 2	10.7%	
	Q. 4	8.3%	

In this same area, the pupils had difficulty in deciding whether spin pairing and low/high spin had anything to do with colour.

	2.	8.	18.	20.
	The possibility of spin pairing occurs with d^4, d^5, d^6, d^7 configurations only	In a low spin d^6 configuration the electrons are arranged 	High spin configurations occur when Δ is small	In a high spin complex, the electrons are arranged 
Q. 1	3.9%	11.6	0.3	0
Q. 2	3.3	5.3	5.3	6.2
Q. 4	7.1	2.7	2.4	2.1

In Q.3 which concerned paramagnetism, only 13% considered Hund's Rule relevant enough to be included. They were not sure about this rule. Also on the question of spin pairing, only 32% and 15% of the pupils included responses 2 and 8 in their answers.

They seem to realise that high spin situations produced paramagnetism, although the proportion including response 11 because the term "paramagnetic" was included is indeterminable.

11. d-orbitals which contain unpaired electron spins cause complexes to be paramagnetic

89% chosen in Q. 3.

There is little doubt that the pupils found this type of question difficult and there could be several reasons for this :-

(i) Their lack of practice in such questions.

(ii) The questions were too difficult and could not have been answered well even in a more traditional form.

(iii) This type of question is by its very nature difficult to answer.

(iv) The program was not effective.

In general, the greater the number of responses included in the "correct" answer the poorer were the results in both the Coefficient of Confusion scores and the sequence scores. This is understandable since the correct choice and sequencing of a large group of numbers is necessarily more complex than for a smaller group.

The percentage correctly sequenced was very low for each question. In one case, Q. 3 response 2, no one correctly sequenced the response. If however a high percentage chose a particular response then it tended to be correctly sequenced, e.g.

Q. 1 response 4 % Chosen = 86.5

% Correctly sequenced = 59.0

Of those who correctly chose a response, more tended to sequence it correctly, e.g.

Q. 2 response 5	% Chosen	=	16.3
	% Chosen correctly and sequenced correctly	=	74.6

3.4. Conclusions

The difficulties in this topic are concentrated in two particular areas :-

(i) Failure to understand that electrons do not obey Hund's Rule when Δ is large.

(ii) Understanding the ramifications of spin pairing in low/high spin complexes.

The areas which seem to be well understood are :-

(i) The colour of a complex is the complement of the absorbed colours.

(ii) The light absorbed depends on Δ and that this depends on the ligand.

(iii) Oxidation number.

(iv) Paramagnetism is associated with d-orbitals which contain unpaired electron spins.

These conclusions however must be viewed in the light of the limitations outlined in 3.2. pg. 3

The pupils undoubtedly found this type of question difficult, especially the sequencing of the relevant responses. The mental effort involved in choosing relevant responses from such a large grid was also very demanding. It is probably inevitable in constructing such a large grid that "give away" responses will be in cluded, but a great effort must be made to eliminate them.

In the light of pupils comments and teacher reactions to this test some guidance can be given in constructing such questions: Fewer relevant responses should be included in each correct answer and only a few, if any at all, should be included in any other answers.

The marking of Coefficient of Confusion was straight-forward, assuming of course that there is agreement about the choice of relevant responses. The marking of sequence was much more difficult and although a satisfactory method of computer marking was found, it is not even suggested that this is perfect. In any case, many subjective decisions must be made before a marking system can be devised, e.g. in assigning a value to a sequence containing 2 or 3 responses only, or in assessing the penalties to be imposed for having responses out of sequence.

In any future work on this type of question, it would be useful to look at the following problems :-

(i) Giving pupils relevant pieces of information only (i.e. no selection beforehand), and testing simply there ability to sequence these in a logical manner.

(ii) The effect of increasing or reducing the size of the response grid.

(iii) The effect of different or almost equally acceptable sequences on rank order for the test.

3.5. APPENDIX III

PROGRAMS, TESTS, RESULTS

THE TRANSITION ELEMENTS

Aims

1. To look more closely at the electron arrangements in atoms, in particular, the s,p,d, and f subshells, and relate this to the Transition Metal series.
2. To study the shapes and orientation of atomic oribtals.
3. To relate these to colour in transition metal complexes.
4. To note magnetic effects (paramagnetism) in transition metal complexes and relate these to atomic orbitals.

Electrons in atoms are arranged in SHELLS, each shell being at a different energy level.

e.g. He 2) has 2 electrons in the 1st. shell

Cl 2)8)7 has 2 electrons in the 1st. shell

8 " " " 2nd. "

and 7 " " " 3rd. "

Each principal energy level, or shell, contains SUBSHELLS, each of a slightly different energy level. These are called the s, p, d and f subshells in ascending order of energy.

PRINCIPAL SHELL (or energy level)	NUMBER OF ELECTRON IN EACH SUBSHELL s	p	d	f	TOTAL
4	2	6	10	14	32
3	2	6	10		18
2	2	6			8
1	2				2

Thus, the more detailed electron arrangement for He 2) is

He $1s^2$ i.e. 2 electrons in the s-subshell of the 1st. principal shell.

and for Cl 2)8)7 is Cl $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$.

The <u>TRANSITION ELEMENTS</u> contain partly filled d-subshells, i.e. fewer than 10d electrons.

The 1st. transition series :-

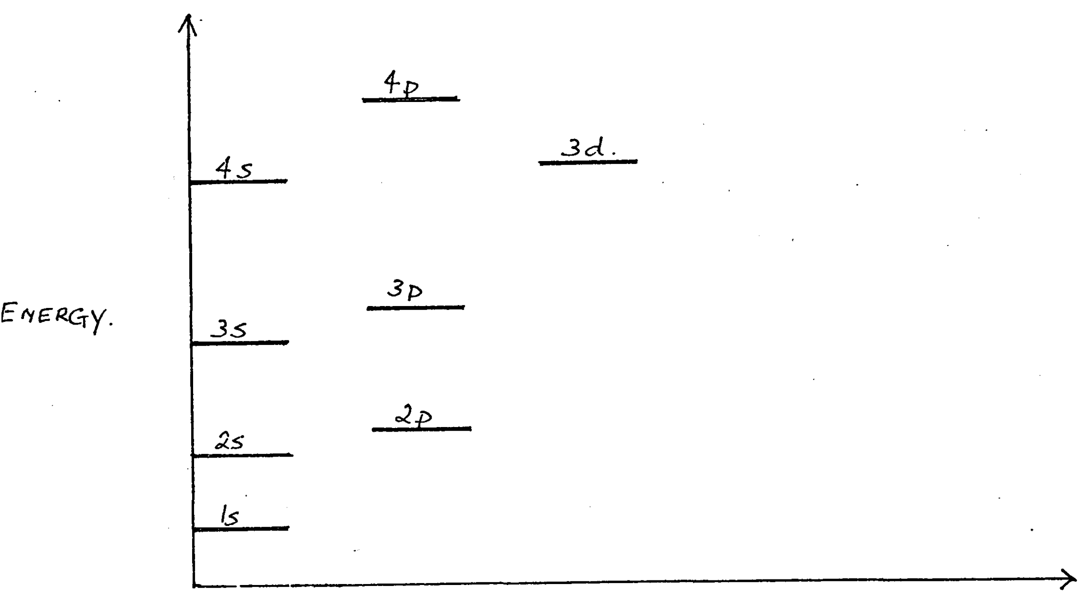
Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu contain a partly filled 3d-subshell.

Look at the electron arrangements of the elements immediately preceding the transition metals.

Ar 2)8)8 $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$.

In the next element you might expect the 3d subshell to accommodate the next electron, viz. K $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1$.

It does not ! Look at this energy diagram for a gaseous atom.



The 4s-subshell is at a lower energy level than the 3d and therefore takes the next electron

i.e. K $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ \underline{\underline{4s^1}}$ (or shorter is K[Ar]$4s^1$)

and Ca[Ar]$4s^2$ followed by Sc[Ar] $3d^1$ $4s^2$

Ti[Ar] $3d^2$ $4s^2$

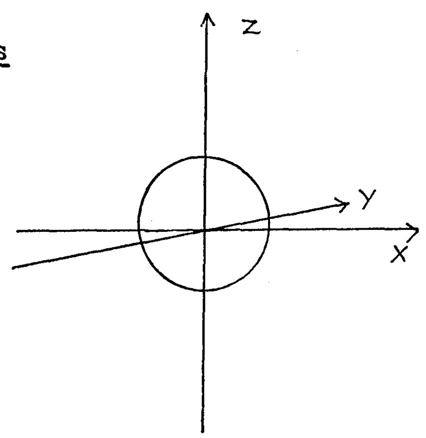
V[Ar] $3d^3$ $4s^2$ etc.

So, only when the 4s subshell is full, does the 3d commence.

The electrons within these subshells move in certain paths called

ATOMIC ORBITALS

s-orbitals

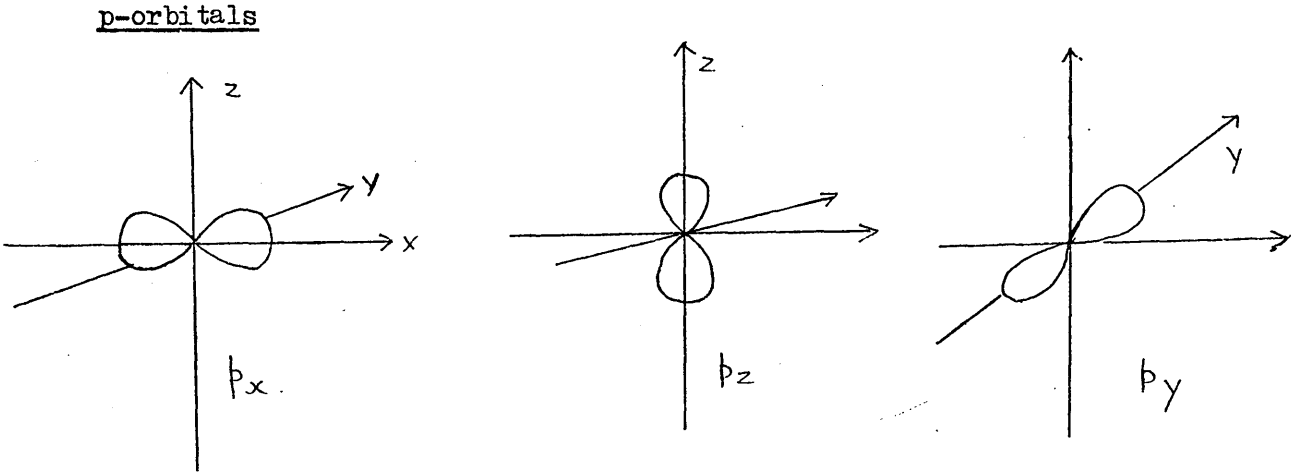


All s-orbitals have this shape regardless of the principal shell.

The nucleus of the atom is positioned at the intersection of the axes.

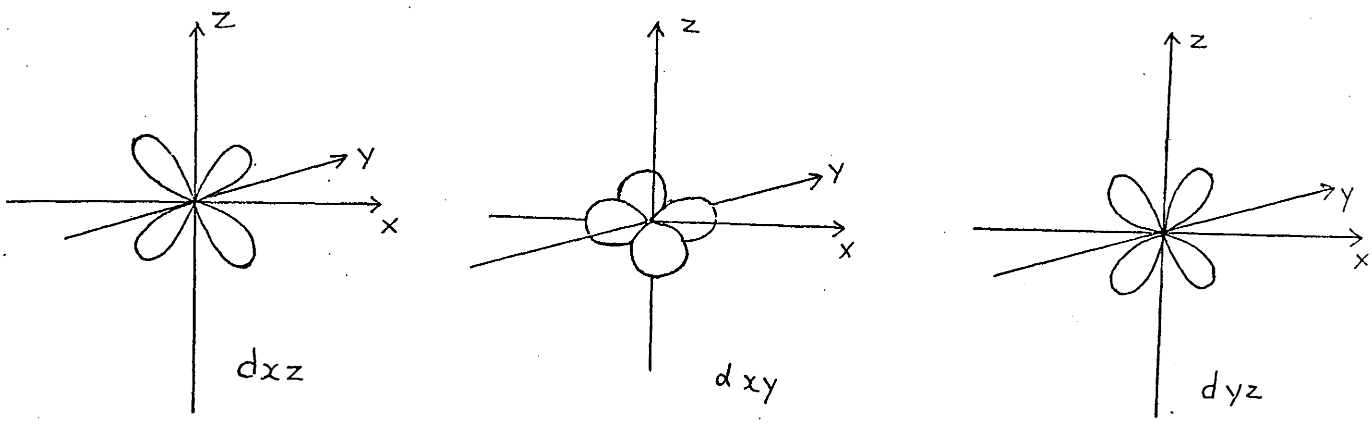
It is impossible to pinpoint the position of an electron at any instant of time and the lines showing the shape of these orbitals define a volume within which there is about a 95% probability of finding the electron.

p-orbitals



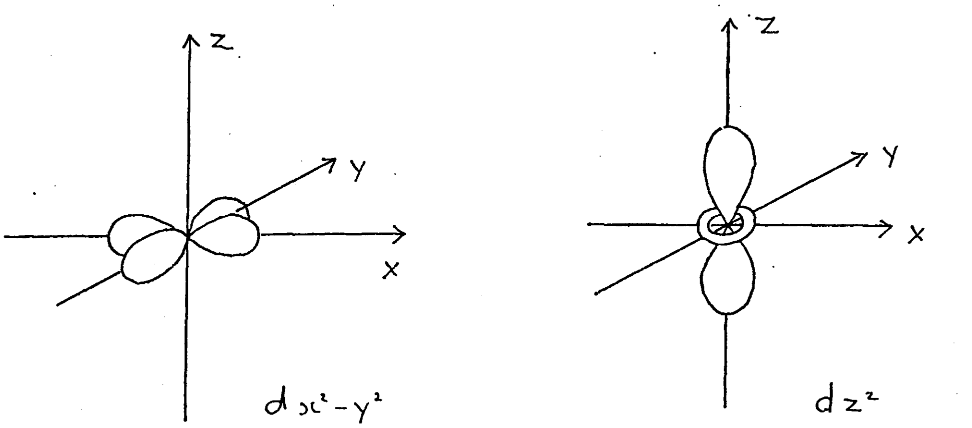
The names of the orbitals are related to axes along which they lie.

d-orbitals



The names are related to the axes between which the orbitals lie,

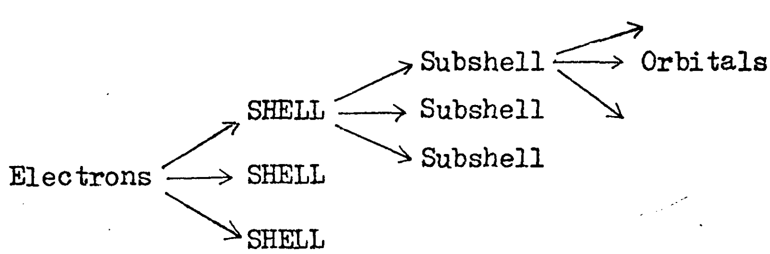
e.g. dxz - the orbitals lie between the x and z axes,



(orbitals on the x and y axes) (orbitals on the z axis)

f-orbitals There are 7 of these but they need not concern us.

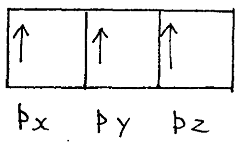
Summary

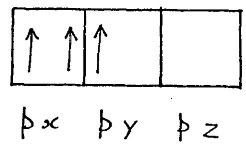


As the number of electrons is increased, each additional electron goes into an orbital according to the following conditions :-

(1) The first available orbital with the lowest energy level is occupied first.

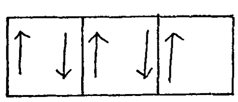
(2) Where a number of orbitals are available, each having the same energy level (called <u>DEGENERATE</u> orbitals), the orbitals are each occupied singly, before any pairing occurs (Hund's Rule).

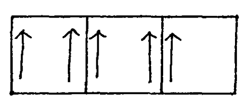
e.g. 

<u>and not</u> 

(3) No two electrons in the same orbital may have the same spin.

(<u>Note</u>. As well as moving in orbitals, electrons also spin, like the earth spinning on its axis as it rotates round the sun. Of course around any one axis they may spin in two directions. The direction spin of an electron is normally denoted by the direction of the arrowhead, e.g. ↑).

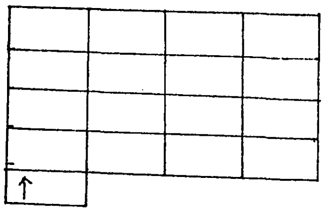
e.g. 

and <u>not</u> 

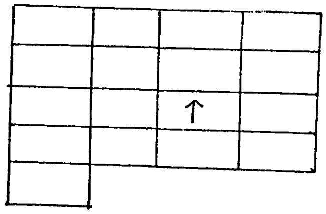
As an analogy to help you understand these rules, think of a block of flats, which is about to be occupied by people according to the following rules.

(A) People will occupy flats (orbitals) in lower floors (shells) first - to save them climbing stairs.

i.e.



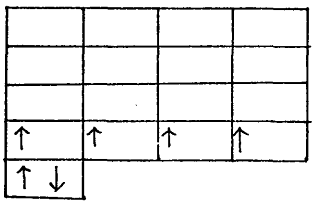
and not



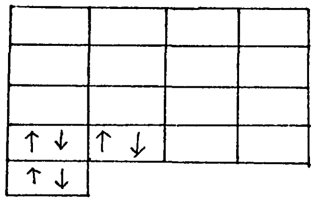
c.f. rule 1.

(B) All the flats on any one floor will be occupied singly before doubling up occurs.

i.e.

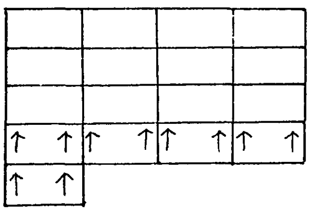


and not

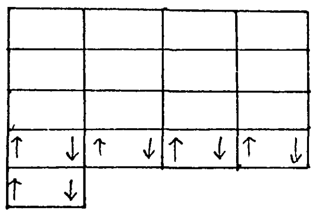


(C) No men (↑) are allowed to share rooms with other men (↑), i.e. men (↑) must share rooms with women (↓) !

not this



but



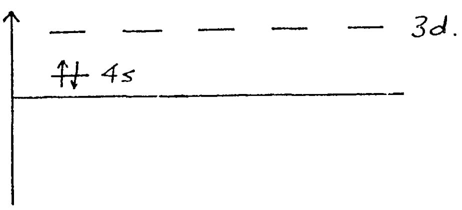
c.f. spin pairing.

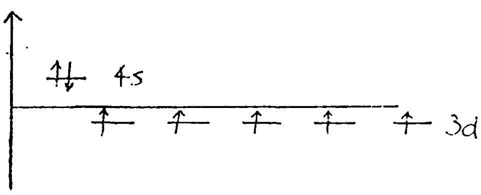
Transition metal ions

When forming metal ions it is not as you might expect, the 3d electrons that are removed first - it is the 4s electrons. The reason for this is rather complicated, but simply :- as the electrons occupy the 3d-subshell it moves down to a lower energy level.

e.g.

Energy





but

So ! - the 4s electrons are the easiest to remove and are first to come off.

$$Sc[Ar]\ 3d^1\ 4s^2 \longrightarrow Sc^{2+}[Ar]\ 3d^1$$

$$Ni[Ar]\ 3d^8\ 4s^2 \longrightarrow Ni^{2+}[Ar]\ 3d^8$$

In many cases, some of the d-electrons may also be lost.

$$Ti[Ar]\ 3d^2\ 4s^2 \longrightarrow Ti^{3+}[Ar]\ 3d^1$$

Because of this, these elements exhibit variable OXIDATION STATES (The atomic number minus the number of electrons left in orbitals.)

e.g. Mn(II), Mn(IV), Mn(V), Mn(VI), Mn(VII) all exist.

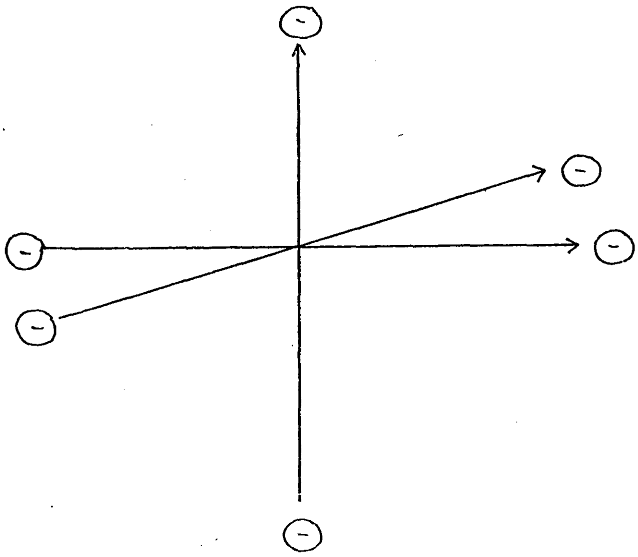
Colour in Transition Metal Complexes

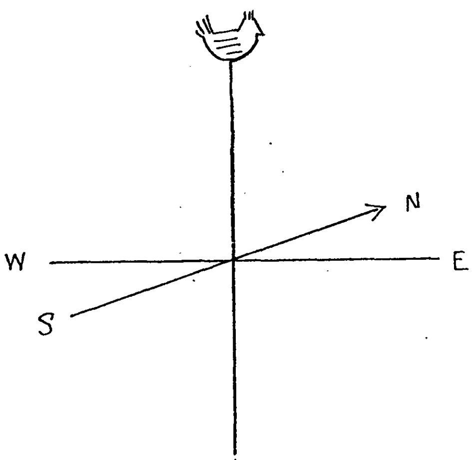
Even in your first year of a chemistry course it would have been brought to your attention that coloured salts, involved metal ions from the central part of the periodic table, i.e. involving the transition metal ions. You can now understand why this is so.

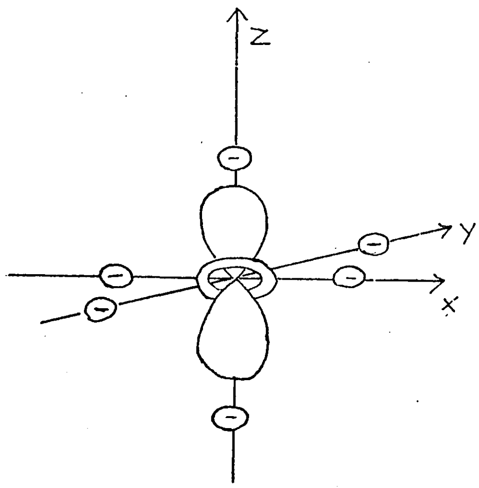
For the free $Ti^{3+}[Ar]\ 3d^1$ ion, the one d-electron may occupy any one of the five 3d atomic orbitals since all five are degenerate (i.e. have the same energy level).

Now consider what happens when the Ti^{3+} ion is surrounded by six negative ions e.g. CN^- or Cl^- in an OCTAHEDRAL arrangement.

(like a weather cock)

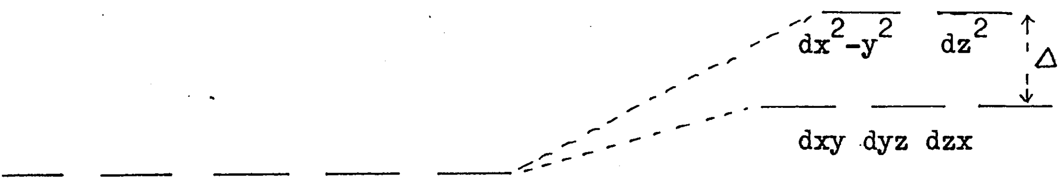






The negative ions repel the dx^2-y^2 and dz^2 atomic orbitals - an electrostatic interaction. They also interact with other orbitals but there is not quite so much repulsion because they point <u>between</u> the ions.

Thus, the dx^2-y^2 and dz^2 orbitals have higher energy than the other three, i.e. it is harder to fit electrons into these orbitals.

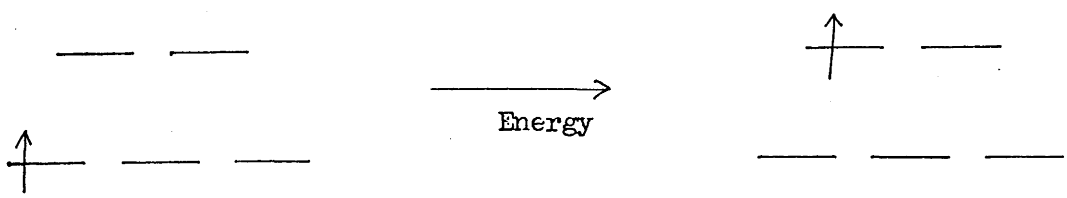


5 original degenerate
d-orbitals in
Free <u>ion</u>

<u>Ion in an octohedral field</u>
Orbitals no longer degenerate

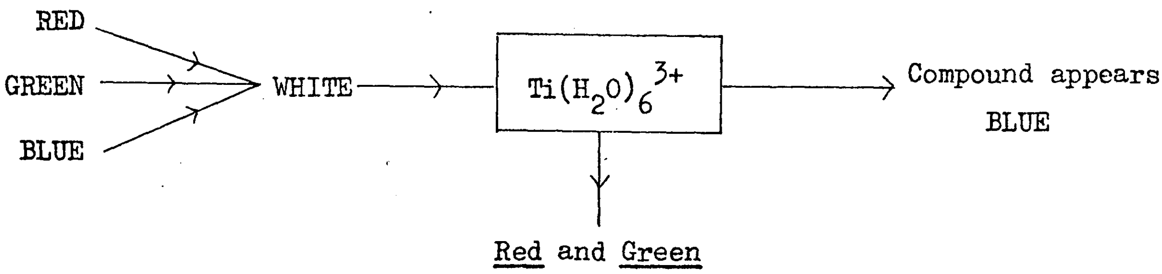
The difference in energy levels is called Δ, or the <u>Crystal Field Strength</u>

The single d-electron in the Ti^{3+}[Ar] $3d^1$ will now occupy one of the 3 lower energy orbitals.



<u>If the electron is supplied with extra energy it can jump to the other level. It so happens that visible light is of the correct energy values to cause this jump to take place.</u>

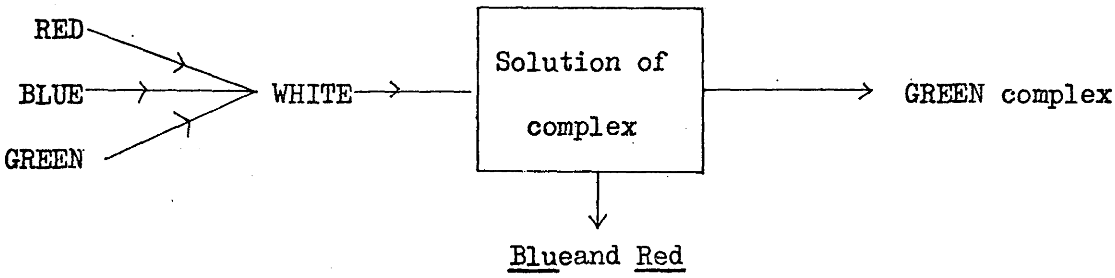
e.g.



i.e. are of the correct energy value to cause the jump.

The colour of the complex is due to the visible radiation which is not absorbed.

e.g.



Not only negative ions can cause this splitting of the energy levels but also anything which has a high electron density, e.g. H_2O or NH_3. These negative ions and electron donors are called LIGANDS and the difference in energy between the two levels (Δ) depends on the type of ligand.

$$X^- < H_2O < NH_3 < CN^- \qquad (X^- = \text{halide})$$

i.e. CN^- produces a larger Δ than NH_3 etc.

NO MATTER WHICH CENTRAL METAL ION.

You may now be wondering what happens to the electrons when they have reached the higher energy level ?

(a) Do they all stay there ? - eventually the solution becoming colourless when all the electrons have been promoted up.

NO ! - at no time are all of the electrons in the higher level. An equilibrium exists between those in the upper and lower energy levels.

(b) When the white light is switched off, do the electrons fall back down and emit the light which they have just absorbed ? -

NO ! (These substances do not appear coloured in the dark.)

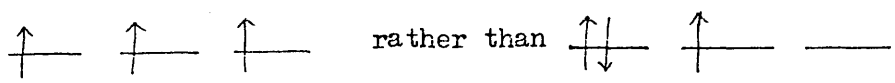
The electrons do drop down, but they do not emit light energy in doing so. They emit <u>heat energy</u>, because they do not drop down in one jump. They drop down by a series of smaller steps, a small amount of heat being given out with each step down.

<u>Magnetism in Transition Metal Complexes</u>

In addition to the very large magnetic effects shown by Fe, Co and Ni metals viz. ferromagnetism, some of the transition metal elements and their complexes exhibit a weaker magnetic effect called <u>PARAMAGNETISM</u>. Paramagnetic substances when brought near to a magnet are attracted towards it. Paramagnetism is related to the number of unpaired electrons in the complex ion (i.e. the number of orbitals which contain only <u>one</u> electron).

Two factors influence the distribution of d-electrons within the available orbitals :-

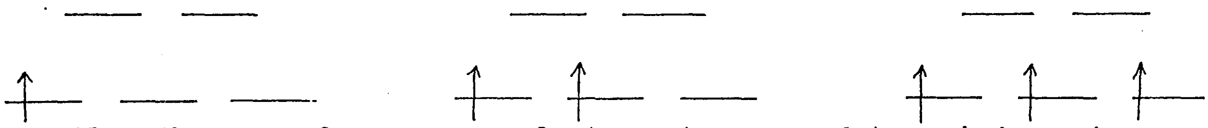
(a) <u>Hund's Rule</u> - electrons will go into another orbital, if empty, rather than pair up with another.

e.g. 

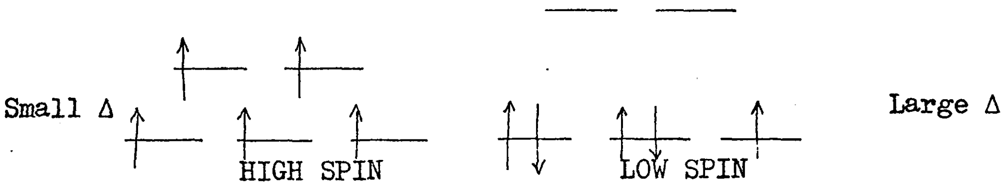
This rule applies where the orbitals are all at the same energy level i.e. degenerate orbitals.

(b) The electric field of the ligand produces splitting of the orbitals, and, depending on the size of Δ, the electrons may depart from Hund's Rule <u>by completely filling the lower energy orbitals first in preference to the higher energy ones</u>.

With 1, 2 or 3 electrons there is no problem. They will enter the three orbitals of lower energy.



When there are four or more electrons to accommodate a choice arises. If Δ is small, electrons 4 and 5 may enter the two higher energy orbitals. This will give the HIGH SPIN situation in which the maximum number of electrons are unpaired. If Δ is large, electrons 4, 5 and 6 may be forced to pair with the electrons in the orbitals of lower energy. This will give the LOW SPIN situation in which the minimum number of electrons will be unpaired.

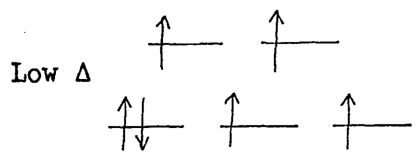


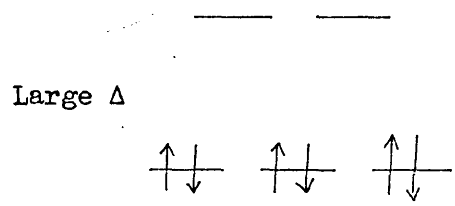
The possibility of spin pairing in an octahedral field only occurs with d^4, d^5, d^6 and d^7.

e.g. Fe^{2+}[Ar] $3d^6$

$[Fe(H_2O)_6]^{2+}$ $[Fe(CN^-)_6]^{4-}$

H_2O as ligand produces CN$^-$ as a ligand produces





4 unpaired electrons No unpaired electrons

<u>High-spin and paramagnetic</u> <u>No Spin and no paramagnetism</u>

Now, in order to discover whether or not you have fully understood the main points covered in the information section, you should study the questions which follow. Possible answers to questions are tabulated in the ANSWER GRID. Once you have selected your answers from the Grid, those you think to be correct, move on to the ANSWER GUIDE.

Use of Answer Guide

Four possible sets of answers are given :- (a)
(b)
(c)
(d)

Firstly, look at (a) - have you included or omitted any of the answers mentioned here ? If so - go to the appropriate discussion section. After looking at this section return to (b) in the ANSWER GUIDE.

On the other hand, if none of the answers which you have selected appear in (a), then move on to (b) then (c) and so on.

If none of the answers you choose appears in (a) - (d) then your answers are perfectly correct.

QUESTIONS

1. Which complexes have absorbed mainly blue and green light ?
2. Which complexes contain ions which have a d^6-electron configuration ?
3. Which complexes will have a low spin as opposed to a high spin configuration ?

ANSWER GRID

1 $[Ti(H_2O)_6]^{3+}$ BLUE	2 $[Ni(H_2O)_6]^{2+}$ GREEN	3 $[Fe(CN^-)_6]^{4-}$ YELLOW	4 $[Ni(NH_3)_6]^{2+}$ BLUE
5 $[Co(NH_3)_6]^{3+}$ YELLOW	6 $[Cr(H_2O)_6]^{3+}$ BLUE	7 $[Fe(H_2O)_6]^{2+}$ GREEN	8 $[Co(H_2O)_6]^{2+}$ RED
9 $[CoF_6]^{3-}$ YELLOW	10 $[Fe(H_2O)_6]^{3+}$ RED	11 $[V(H_2O)_6]^{2+}$ BLUE	12 $[Co(CN^-)_6]^{3-}$ RED
13 $[Fe(CN^-)_6]^{3-}$ RED	14 $[Cr(H_2O)_6]^{2+}$ BLUE	15 $[Mn(H_2O)_6]^{2+}$ RED	16 $[Co(H_2O)_6]^{3+}$ BLUE

ANSWER GUIDE

	Discussion Section
1.(a) If you have included 1,4,6,11,14 or 16 in your answer ⟶	A
(b) " " " " 2 or 7 " " " ⟶	A
(c) " " " omitted 8,10,12,13 or 15 " " " ⟶	A
(d) " " " included 3,5 or 9 " " " ⟶	A and B
2.(a) " " " " 10 or 13 " " " ⟶	C and E
(b) " " " " 2 or 4 " " " ⟶	D
(c) " " " omitted 3 or 7 " " " ⟶	C and E
(d) " " " " 5,9,12 or 16 " " " ⟶	F

3.(a) If you have included 1,6 or 11 in your answer ⟶ G

(b) " " " " 2 or 4 " " " ⟶ H

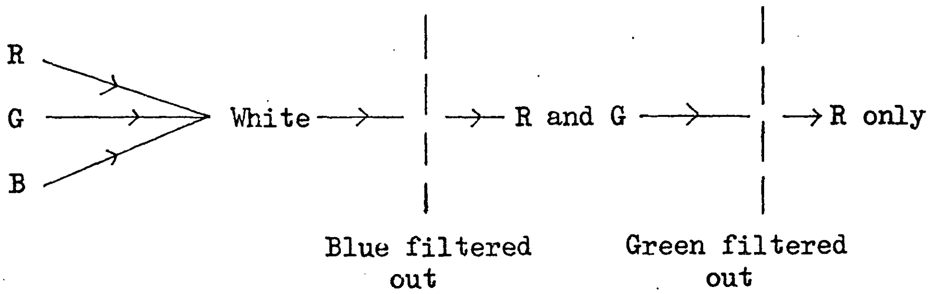
(c) " " " " 7,8,9,10,14,15 or 16 " " " ⟶ I

(d) " " " omitted 3,5,12 or 13 " " " ⟶ I

DISCUSSION SECTION

A. White light consists of 3 primary colours : Red, Green and Blue. If Blue and Green absorbing filters are placed in the path of a beam of white light they absorb, in turn, blue and green light - leaving red light to pass straight through.

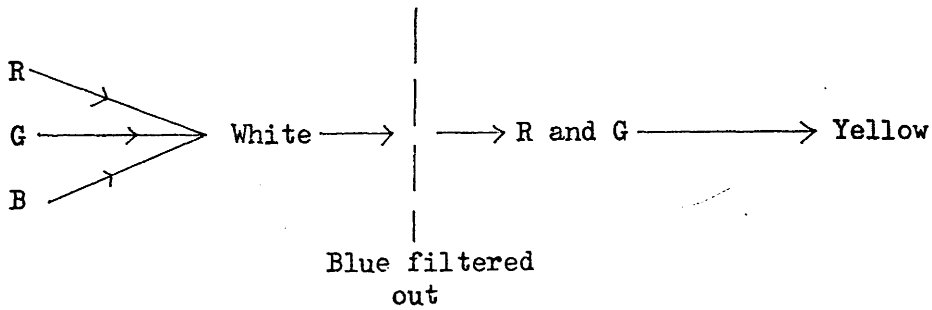
i.e.



Similarly, if a complex ion absorbs blue and green light (i.e. it acts as a filter), then it appears Red.

B. Yellow is not a primary colour - it is called a Complementary colour. Yellow is produced when Blue light only is filtered out from white light.

i.e.



C. Iron atoms have an electron configuration $Fe[Ar]3d^6 4s^2$ and do have a d^6 configuration. However, the Fe^{3+} ion is 3 electrons short of this - 2 electrons are taken from the 4s subshell, since it is at a higher energy level than the 3d subshell, and the third electron is taken from the 3d subshell. Fe^{3+} has therefore a d^5 configuration.

D. $Ni[Ar]d^8 4s^2$

To form the Ni^{2+} ion, electrons are removed from the 4s subshell leaving the 3d electrons untouched, (see paragraph - "Transition Metal Ions" - in the information section).

Thus, the Ni^{2+} ion has a d^8 and not a d^6 configuration.

E. $Fe[Ar]3d^6 4s^2$

To form Fe^{2+}, it is the 2 electrons in the 4s subshell which are removed - not those in the 3d subshell. Fe^{2+} therefore has a d^6 configuration.

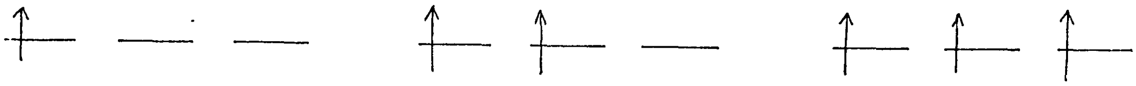
Note - $[Fe(CN^-)_6]^{4-}$ contains the Fe^{2+} ion. Since the overall charge is 4^- and the complex contains 6 x CN^-, the Fe ion must be 2+.

F. $Co[Ar]3d^7 4s^2$

To form Co^{3+}, 2 electrons must be removed from the 4s subshell and from the 3d subshell. This leaves the Co^{3+} ion with a d^6 configuration.

Note - $[CoF_6]^{3-}$ and $[Co(CN^-)_6]^{3-}$ both contain Co^{3+} ions (see E)

G. When there are three d-electrons or less, Hund's Rule applies, for the filling of atomic orbitals, i.e. no spin pairing unless all other available orbitals already contain one electron.

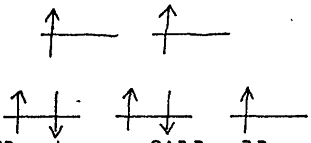


The problem of deciding whether a complex will have a high spin or a low spin configuration does not occur with d^1, d^2, or d^3 configurations.

H. Each of these has a d^8 electron configuration.

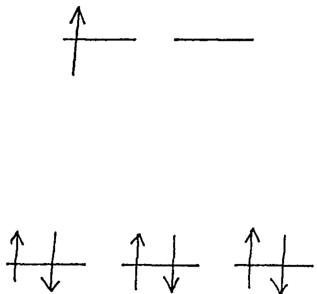
Look first of all at a d^7 electron configuration.

Weak field (small Δ)



Electrons fill all available orbitals first before pairing up (Hund's Rule obeyed).

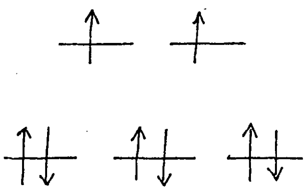
Strong field (large Δ)



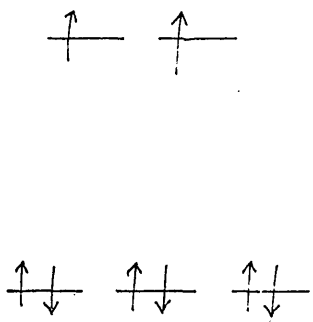
Electrons fill lower energy levels first (disobeying Hund's Rule). Energetically it is more favourable to pair up spins than for electrons to jump up to the higher orbitals.

Now with d^8 configuration

Weak field (small Δ)



Strong field (large Δ)



i.e. There is only one electron arrangement possible.

The problem of high spin or low spin does not occur with d^8, d^9 or d^{10} configurations.

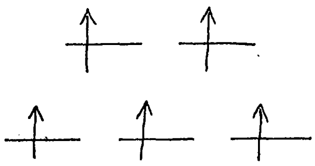
I. All of the answers chosen by you have either a d^4, d^5, d^6 or d^7 electron configuration and in each of these, the problem of high or low spin configuration occurs.

H_2O and the halides (Cl^-, Br^-, I^- etc.) produce a weak crystal field (small Δ) and Hund's Rule is obeyed.

With these ligands - high spin complexes are the result.

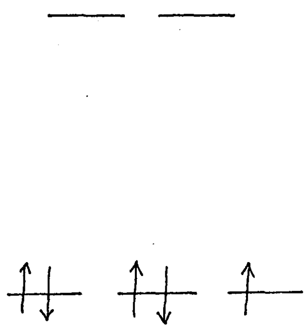
e.g.
with 5 electrons

Weak field (small Δ)



High spin complex - no pairing up of opposite spins.

Strong field (large Δ)



Hund's Rule is not obeyed with large Δ. Spin pairing occurs with NH_3 and CN^- ligands (see spectro chemical series), resulting in low spin complexes.

STRUCTURED TEST ON TRANSITION METALS (1972)

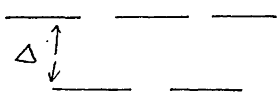
$FeSO_4.7H_2O$ is green and is attracted into a magnetic field. $K_4Fe(CN)_6$ is yellow and is not attracted into a magnetic field.

1. Explain why $K_4Fe(CN)_6$ is yellow.
2. Explain why the colour of the two complexes is different.
3. Explain why $FeSO_4.7H_2O$ is magnetic.

For each question, construct your answer from the following answer grid. Disregard any irrelevant information. Write down only the number sequence you have chosen to answer the question.

The numbers and the sequence are important.

ANSWER GRID (1972)

CN^- ligands produce large splitting (Δ) of d orbitals 1.	The possibility of spin pairing only occurs with d^4, d^5, d^6 and d^7 configurations 2.	Where Δ is large electrons do not obey Hund's Rule when filling available orbitals 3.	Visible light is of the correct energy value to promote electrons from the lower to the higher energy level. 4.
Fe^{2+} has a d^6 electron configuration 5.	The energy gap between the two sets of d-orbitals is called Δ  6.	If blue light is absorbed, then the colour of the complex is yellow (Red + Green) 7.	Low spin configurations occur when Δ is small 8.
Blue light is of a higher energy value than Red or Green light 9.	High spin complexes occur only with d^8, d^9 and d^{10} configurations 10.	d-orbitals which contain unpaired electron spins cause complexes to be para-magnetic 11.	Low spin configurations have smaller paramagnetism than high spin configurations 12.
When Δ is large, energy of a higher value is needed to promote electrons 13.	The energy gap between the two sets of d-orbit-als if called Δ  14.	H_2O ligands produce a small splitting (Δ) of d-orbitals 15.	In an octahedral ligand field, the 5 degenerate d-orbitals are split into two energy levels. 16.
If yellow light is absorbed then the complex appears yellow 17.	High spin configurations occur when Δ small 18.	If Red and Blue light are absorbed, the complex appears Green 19.	Fe^{2+} has a d^8 configuration 20.

STRUCTURED TEST ON TRANSITION METALS (1973)

A.

$FeSO_4.7H_2O$ is green and is attracted into a magnetic field. $K_4Fe(CN)_6$ is yellow and is not attracted into a magnetic field.

In terms of the theories given in this program, explain :-

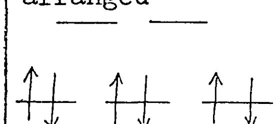
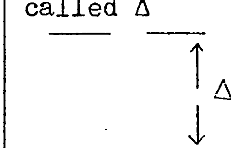
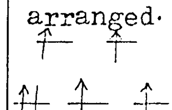
1. Why $K_4Fe(CN)_6$ is yellow.
2. Why the colour of the two complexes is different.
3. Why $FeSO_4.7H_2O$ is paramagnetic.

B.

Explain, in terms of the theories given in this program, why $CuSO_4$ solution turns a deeper blue when NH_3 is added.

For each question, construct your answer from the following answer grid. Write down ONLY the number sequence you have chosen to answer the question. The grid contains more than enough material for you to answer each question. Pick out the relevant pieces and arrange these in the most ligical order. Answer each question in full, independently of all the others. The numbers and sequence are important.

ANSWER GRID (1973)

CN^- ligands produce large splitting (Δ) of d-orbitals 1.	The possibility of spin pairing occurs with d^4, d^5, d^6 and d^7 configurations only 2.	Where Δ is large, electrons do not obey Hund's Rule when filling available orbitals 3.	Visible light is of the correct energy value to promote electrons from the lower to the higher energy level 4.
Fe^{2+} has a d^6 electron configuration 5.	NH_3 ligands produce a larger splitting (Δ) of d orbitals than H_2O 6.	If blue light is absorbed, then the colour of the complex is yellow (Red + Green) 7.	In a low spin d^6 configuration, the electrons are arranged  8.
Cu^{2+} has a d^9 electron configuration 9.	Transition metals contain partly filled d-subshells 10.	d-Orbitals which contain unpaired electron spins cause complexes to be paramagnetic 11.	Low spin configurations have smaller paramagnetism than high spin configurations. 12.
When Δ is large, energy of a higher value is needed to promote electrons 13.	The energy gap between the two sets of orbitals is called Δ  14.	H_2O ligands produce small splitting of d-orbitals 15.	In an octahedral field, the 5 degenerate d-orbitals are split into two energy levels 16.
Fe^{3+} has a d^5 electron configuration 17.	High spin configurations occur when Δ is small 18.	Different light colours have different energy values 19.	In a high spin complex, the electrons are arranged.  20.

Results

Question 1.

Correct Sequence	10	5	16	14	1	13	4	19	7
% Chosen	38.3	23.3	53.5	47.8	59.4	36.9	86.5	70.9	98.3
% Sequenced correctly	35.3	16.6	42.4	34.4	33.4	16.3	59.0	50.4	88.0
% Chosen correctly & correctly sequenced	91.6	68.4	81.7	71.7	56.2	44.0	68.2	71.1	89.1

Irrelevant responses	2	3	6	8	9	11	12	15	17	18	20
% Chosen	3.9	18.7	0	11.6	0.3	0.6	0.6	0.9	1.2	0.3	0

Coefficient of Confusion - Mean = 0.540 S.D. = 0.239

Sequence Score - Mean = 8.534 S.D. = 4.420

(47.4%)

Question 2.

Correct Sequence	10	5	16	14	1	15	4	13	19	7
% Chosen	31.2	16.3	44.8	53.4	76.0	74.7	59.0	69.7	90.2	9.5
% Sequenced correctly	28.8	12.2	38.8	38.8	42.1	39.4	21.7	33.8	67.9	7.7
% Chosen correctly & correctly sequenced	92.4	74.6	86.7	72.8	55.5	52.8	36.7	48.5	75.4	81.3

Irrelevant responses	2	3	6	8	9	11	12	17	18	20
% Chosen	3.3	10.7	2.7	5.3	1.8	0.6	0.9	5.9	5.3	6.2

Coefficient of Confusion - Mean = 0.482 S.D. = 0.226

Sequence Score - Mean = 7.905 S.D. = 4.164

(39.5%)

Question 3.

Correct Sequence	10	5	16	14	11	3	2	8	12	18	20	15
% Chosen	47.7	46.0	48.6	49.8	88.7	13.4	32.3	15.1	33.8	79.2	73.5	74.5
% Sequenced correctly	43.3	21.4	25.5	25.5	13.6	3.0	0	3.0	5.6	45.1	45.7	0.6
% Chosen correctly & sequenced correctly	90.7	46.4	52.4	51.2	15.4	21.2	0	19.6	16.7	57.0	62.0	1.2

Irrelevant responses	1	4	6	7	9	13	17	19
% Chosen	3.6	1.5	1.8	0.6	0.6	6.2	5.9	2.1

Coefficient of Confusion - Mean = 0.472 S.D. = 0.213

Sequence Score - Mean = 6.531 S.D. = 3.419

Question 4.

Correct Sequence	10	9	16	14	4	15	6	13	19
% Chosen	38.8	41.5	50.7	52.8	55.5	36.5	91.0	74.1	75.9
% Sequenced correctly	35.6	29.9	41.5	40.3	8.9	15.1	38.5	37.6	62.0
% Chosen correctly & sequenced correctly	91.6	71.2	82.0	76.5	16.1	41.5	42.4	50.8	81.7

Irrelevant responses	1	2	3	5	7	8	11	12	17	18	20
% Chosen	0.6	7.1	8.3	0.9	2.7	2.7	2.1	0.6	0.9	2.4	2.1

Coefficient of Confusion - Mean = 0.546 S.D. = 0.249

Sequence Score - Mean = 7.421 S.D. = 3.850
(41.3%)

Combined Results

Coefficient of Confusion - Mean = 0.510 S.D. = 0.234

Sequence Score - Mean = 7.598 S.D. = 4.048

ACKNOWLEDGEMENTS

The very nature of this research required the co-operation of a vast number of people, and to them I am eternally grateful.

I am indebted to my supervisors, Professor D.W.A. Sharp, and Dr. A.H. Johnstone for the encouragement and advice so willingly given by them throughout my period of research; the staff and pupils (voluntary and coerced) of the schools who participated; Lanarkshire Education Authority for their financial assistance; Miss Kate Urquart, a research assistant, for her help with statistics; Mrs. Natalie Kellet, also a research assistant, for her expertise in computer programming; Dr. J. Syme and Mr. I. Bryson of the University Computing Department for their advice and devotion toduty in processing mounds of computer cards; and finally to the secretarial staff of the University for their help producing programs and tests.

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