"Studies in the Chemistry / Mathematics boundary at Secondary level"

by

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GLOSSARY

'O' grade Examination

This is the ordinary grade examination in Chemistry set by the Scottish Certificate of Education Examination Board (S.C.E.E.B.), and taken normally by pupils in the fourth year of their secondary course at school.

S1, S2, S3 etc.

This indicates the year of study in secondary school. In Scottish schools the majority of pupils commence the S1 stage at 12 years of age. The 'O' grade examination is normally taken towards the end of S4.

A, B_1, B_2, ... C_1, ...

A denotes Section A of the Chemistry Syllabus

B_1 " " B " " " " , Subsection 1

etc.

A1,1; A1,2; .... G1,1; .... Ar1,1; .... T5,1; .... C8,1; ....

A denotes Algebra; G - Geometry; Ar - Arithmetic; T - Trigonometry; and C - Calculus as sections in the Mathematics Syllabus

1,1 denotes Book 1, Chapter 1 of Modern Mathematics Series of text-books

1,2 denotes Book 1, Chapter 2

2,1 denotes Book 2, Chapter 1

ABSTRACT

It is at least twelve years since the Alternative Syllabuses in Chemistry and Mathematics were first introduced into Scottish schools. The "new" syllabus in Chemistry stressed the importance of having pupils involved in learning by discovery and exploration while the "new" syllabus in Mathematics had as its main aim the encouragement of an interest in Mathematics and a greater understanding of fundamental principles. As the two subjects have developed in their own way over the past years, a considerable gulf has formed between them and now separates them.

This research is concerned with a close examination of the present Chemistry and Mathematics syllabuses side by side and an attempt is made to identify real problem areas in Chemistry which are linked to Mathematics.

The Chemistry and Mathematics syllabuses up to 'O' grade were set out in chronological order and this revealed some related topics which were obviously out of phase. Chemical topics were also examined for mathematical content and a list of these topics was drawn up. It showed just how much Mathematics there is in the Chemistry syllabus. Pupils in schools were then used as subjects in an examination of their ability to cope with some of these topics, e.g. chemical concept of 'containment', graphs and proportionality. It was borne in mind that the necessary mathematical skills had been taught in the Mathematics department and that Chemistry teachers assumed that for their needs the teaching was adequate and done at the right time. Findings showed:-

(i) that the pupils' ability to grasp a concept was inadequate mainly because the concept chosen was not dealt with in context or not dealt with at all;

(ii) /

(ii) that for graphs, the pupils' ability to picture data clearly and interpret it in real terms was not what it was assumed to be;

(iii) that for proportionality, the mathematical operations were beyond pupils who had not reached 'formal' thinking level and chemists' teaching in chemical examples was a significant factor.

The methods used included written tests and face to face investigation when pupils defined their methods of tackling problems. From results, it was possible to define for teachers and curriculum planners specific recommendations which can only better the present situation.

In general, chemists are not aware of 'new' language, notation and methods used by Mathematicians, and so there is unavoidable confusion for the pupils, and hence they do not achieve the 'mastery' of topics they might aspire to. Choice of topics for a rewritten syllabus will be of prime importance for curriculum planners but they must also remember long-term objectives for making Chemistry a significant part of a child's education.

CHAPTER 1

ORDER IN THE TEACHING OF MATHEMATICS AND CHEMISTRY

1.1. INTRODUCTION

Traditionally Mathematics and Chemistry have been linked for 'calculations in equivalents' but now that developments in Mathematics and Science courses at all levels have taken place independently, Mathematicians and Scientists often find themselves at cross purposes when topics they are teaching overlap.

From previous work, recorded in the first report[1] to the Scottish Education Department in 1969, several distinct areas of difficulty in the 'O' and 'H' grade Chemistry syllabuses of the Scottish Certificate of Education Examination Board[2] were revealed.

This work was followed by an investigation into the aspect of maturity entering into the learning process[3]. Results still indicated that areas which were a real source of trouble could be grouped under three headings, namely -

1) concepts of writing formulae and the mole
2) salt interconversions
3) condensation reactions

It has also been established that the 'O' grade course may be taught in the recommended order or in an alternative way, with essentially 4th year and 3rd year work interchanged, without detriment to the pupils.[4]

A follow-up report[5] to the Scottish Education Department in October, 1972 confirmed that the same areas of difficulty as above reappeared and so it was decided that some research into these areas would be advantageous. The topics in the 'O' grade Chemistry syllabus which were identified as difficult were:-

H_3 - use of ion detector and measure of conductivity

H_5 - writing chemical equations

H_7 - calculations from equations

I_3 - electron transfer in redox reactions

J_1 - acidic and basic oxides

J_3 - methods of preparing soluble salts

J_4 - methods of preparing insoluble salts

J_6 - calculation of molarity

K - ion electron half equations

L_3 - the making of addition polymers

N_2 - ester formation

N_3 - the conversion of fats to soaps

O - condensation polymers

Work has already been carried out to investigate the understanding of concepts related to writing formulae,[4] and the mole[6] and work is at present being done to investigate the perception of patterns in organic structures.[7]

1.2. Topic Difficulties in Chemistry 'O' grade and the link with Mathematics 'O' grade.

Many of the topics in Chemistry 'O' grade would appear to assume a knowledge of related mathematical topics and this may affect the pupils' understanding of the Chemistry. In fact, fifty-six out of the eighty-one topics in Chemistry 'O' grade have a link with Mathematics, in concept, if not in mechanical mathematical usage - these will be identified later in this chapter.

The initial part of this investigation, therefore, involved an examination side by side of the Chemistry[2] and Mathematics 'O' grade[8] syllabuses for any obvious anomalies and to check the order in which each was generally taught.

Of course, the key to the interdisciplinary problem may well be found in a study of the development of logical thinking in the adolescent, but verification of order and timing had to come first. On the face of it, each syllabus has a logical development with a certain amount of hierarchical structure, so that some topics appear several times with increasing degrees of sophistication, therefore teachers were well advised to follow the order in which the syllabuses were written as being the order of teaching.

1.3 Experimental Design

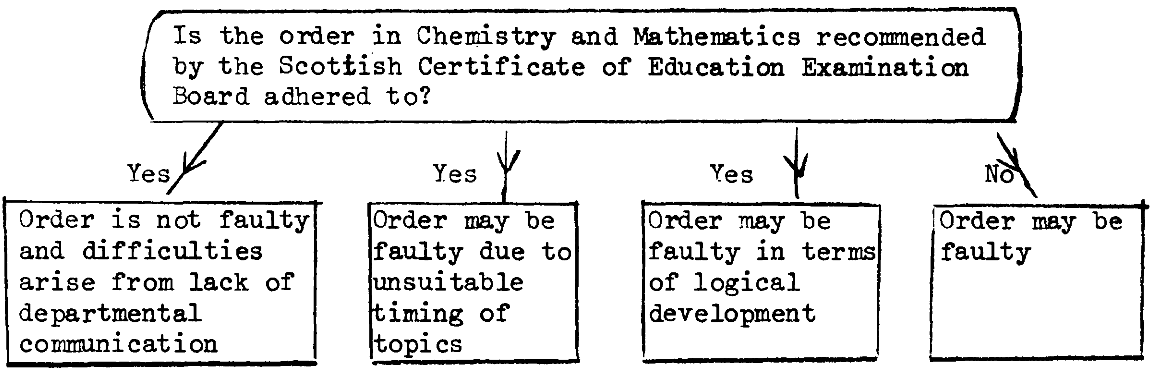
The initial hypothesis adopted and tested was that schools tend to adhere to the order of topics recommended in the Chemistry 'O' and Mathematics 'O' grades. Sheets, copies of which are in the Appendix page 19 requesting the necessary information - namely week, month and year when each topic was taught - were sent out to Heads of Chemistry and Mathematics Departments in schools which were randomly selected. Schools which had undertaken a recommended order change in Chemistry instigated by T.V. Howe's work[4] and schools which were involved in the Mathematics alternative syllabus B,[9] or Mathematics with Statistics, were not asked to provide information - this explains why twenty schools supplied information for Chemistry and only twelve supplied information for Mathematics. The completed sheets were summed with respect to month and year when each topic was taught and this summariesed form can be seen in the Appendix pages 19-27 Information provided was in general not explicit enough to state for all schools the week when topics were taught. So, the frequency distribution of results showed for each topic in the Chemistry and Mathematics syllabuses the number of schools teaching each topic in any month between September and June for S 1-4.

Topics in Mathematics were listed in the order of appearance in the original Modern Mathematics series of books[10], since the syllabus does not detail topics nor order adequately for teaching purposes - it was assumed that most schools used this series of books, at least as a guide.

1.4. Explaining the Results

Individual topics were not taught by all schools in one month of the same year, and so it was decided to assume that the 'most popular' or modal month was that month when the largest number of schools taught each topic. A table showing which month each topic was taught in, in both Mathematics and Chemistry, was made for each year up to 'O' grade - See Appendix page 28. This provided an order of teaching topics based on the results from the randomly selected schools used for the investigation.

The results were explained in diagram form:-



There was clearly only little deviation from the recommended order and only slight variation in agreement for monthly timing of individual topics, so we could accept the hypothesis stated and assume there was unlikely to be any change as long as the present syllabuses stood.

So, there were three possibilities for further investigation:-

(a) There was lack of departmental communication, or little or no co-operation between Chemists and Mathematicians.

(b) There was unsuitable timing of topics.

(c) There were problems in terms of logical development.

It would also appear that the problem could be seen as belonging to one of two other areas:-

(1) Techniques and processes of the 'new' Mathematics exist which might benefit Chemistry

(2) Weaknesses in Mathematics exist which might hinder the attainment of objectives of Chemistry.

To help identify the proper level of mathematical ability for Chemistry pupils, it was felt at this stage that a close examination of the content of both Mathematics and Chemistry syllabuses had to be made and possible interdisciplinary links checked for timing. Obviously a uniformly high level in all branches of Mathematics would be desirable for all pupils of Chemistry but in practice it could only be important for pupils -

(a) to acquire facility in mathematical manipulations

(b) to cultivate sufficient mathematical ability for comprehension of topics in Chemistry which involve Mathematics.

In the preface to their book "Mathematical Methods for Chemists", Mackie, Shepherd and Vincent say:- "At the simplest level, the use of Mathematics enables Chemists to make precise descriptions of relationships between physical quantities. More fundamentally, however, the methods of Mathematics permit relationships to be established that could not be arrived at intuitively." This emphasised the point that high level thinking in Mathematics might very well be a necessary prerequisite for studying Chemistry. High level thinking in Mathematics involves the processes of generalisation, evaluation, proof induction and inference.

1.5. Mathematical Content of Topics in Chemistry

In broad terms, the Mathematics required for S1 and S2 Chemistry involves:-

(1) the four operations, i.e. addition, subtraction, multiplication and division

(2) fractions

(3) percentages

(4) area and volume

(5) ordering

(6) "best-line" graphs and charts

(7) sets

(8) relations

and for S3 and S4 the Mathematics required involves:-

(1) ratio and proportion

(2) indices including standard notation

(3) formulae

(4) flow diagrams

(5) interpolation and extrapolationof line graphs

(6) deductive reasoning

but a more specific account was necessary.

The result of MAST the Maths Skills Test for Chemistry[11] stated the necessary skills in maths for chemical calculation success:

(1) computation

(2) parentheses

(3) signed number usage;

(4) fractions

(5) decimals

(6) exponents

(7) percent

(8) equations

(9) ratio and proportion

(10) graphs

Each Chemistry topic from S1 - S4 was scrutinised for Mathematics content in terms of skills and abilities implied or stated as explicitly required and the information was detailed in a table - see Appendix p. 29. The Mathematics content was then directly linked to an appropriate part of the Mathematics syllabus and possible interdisciplinary links were made. This timing of linked topics was investigated by superimposing the appropriate Chemistry and Mathematics graphs for the same year. A sample of these can be found on p. 37 in the Appendix.

Some topics in Chemistry and Mathematics which were linked showed an obvious time lag in Mathematics required and these were summarised as the following:-

	Chemistry Topic	Related Mathematics Topic
B_3	kinetic model in particular cooling to give ordered crystals	close packing of spheres
C_2	solubility and its uses	graphs and rate of change
D_1	oxygen, nitrogen and carbon dioxide in particular temperatures for fractional distillation of liquid air	reading scales with positive and negative signs
E_3 E_4 F_2 F_3	action of metals on cold water action of metals on dilute acid naturally occurring elements naturally occurring sulphides, oxides and carbonates	seriation: the idea of an "ordered" rate series using logic of the form:- if $A < B$ and $B < C$ then $A < C$
H_6 J_1	salt interconversions acidic and basic oxides	Flow diagrams[12]

In the light of this information the following considerations had to be made:-

(a) Should the Chemistry teachers reject the topics above because the Mathematics is out of step?

(b) Should the Mathematics teachers who provide a service to so many other subjects alter their order to suit the Chemists' requirements?

(c) Should the Chemistry teachers accept the lack of necessary Mathematics and alter the content of the Chemistry to accommodate only Mathematics of a lower level which has been taught?

(d) Should the Chemistry teachers teach the Mathematics themselves?

1.6. Difficulties in Mathematics topics which were linked to Chemistry topics

Specific difficulties of topics linked in the Mathematics/Chemistry interface included:-

(1) objectives of the courses were not the same

(2) interpretation of words was not the same

(3) notation used was not the same

(4) approach used was not the same

(5) emphasis made was not the same

(6) depth of treatment - Mathematics treatment was too shallow

(7) age at which taught

In particular, weaknesses in Mathematics which seriously affected understanding of related chemical concepts were identified as -

(1) Language and Symbolism

So many areas exist in which a continuing dialogue is needed between Chemistry and Mathematics teachers; it is vitally important that the two departments speak the same language. At present, it appears that Chemists are not familiar with language used in the 'new' Mathematics, for example, they don't employ, and therefore don't understand, concepts such as 'sets' and 'mappings'. They make no clear distinction between:-

(a) minus as an operation on a number and negative as a state of a number

(b) the equals sign '=' in a Mathematics equation and the equals sign in a Chemical equation

Given $NaOH + HCl = NaCl + H_2O$

Equality can be assumed for mass alone and therefore ' apparent' equality of reactants and products should be shown by using $\rightarrow$ to mean 'gives' and not 'equals'

(c) the similarity sign '≡' in Mathematics in connection with similar shapes and the same sign in Chemistry used in connection with neutralisation problems to mean 'is equivalent to'.

For example: What volume of 0·5M HCl is required to neutralise 50ml of 0·5M NaOH solution?

50ml of 0·5M NaOH ≡ x ml of 0·5M HCl

This is a symbolic representation of the situation which presents problems for the pupils. A symbol must have one interpretation only, and it must be used in context.

(d) the meaning of the word 'contains' in Mathematics with respect to sets and 'contains' in Chemistry with respect to mixtures and compound.

(e) symbolism in chemical formulae, for example, Mg_3N_2 meaning 3 Mg's and 2 N's while the analogous algebraic expression would be:- 3Mg + 2N

Gauss is reputed to have said:- "Mathematics is the Queen and Servant of Science"[13]. It is imperative that Chemists as a pre-requisite familiarise themselves with the language that is used by Mathematicians.

There is also a lack of conformity in standard abbreviations for units used in calculations - SI units should be used exclusively or another system adopted. There should be no confusion as to whether it is lb/yd^2 or lb/yd^{-2}, or regarding the equality of ml and cm^3.

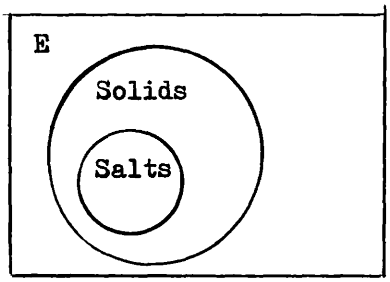
(2) Sets

Classification of concepts, data and arbitary lists of facts can be approached by using Venn Diagrams[14] - this ensures the classification process is done in a rational and systematic way. In this respect

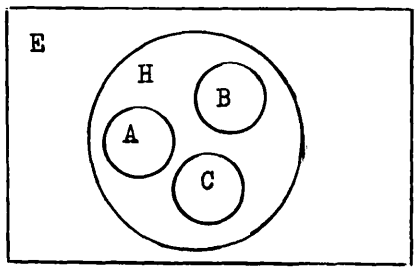
Mathematicians could introduce chemical examples, showing relations between, for example, acids, bases and salts or isomers, stereoisomers and optical isomers.

Suggestions could include

(i)



(ii)



E– Entire Set

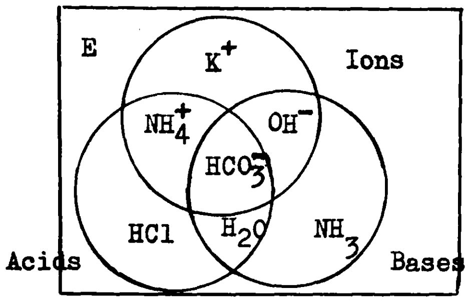
H– Set of all hydrocarbons

A– Set of all alkanes

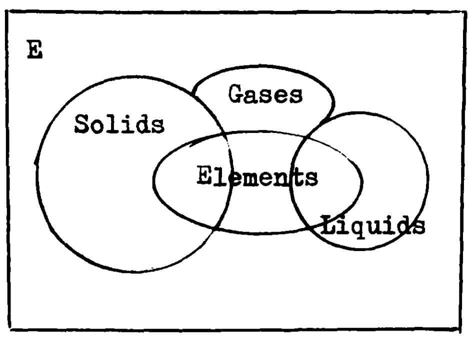
B– Set of all alkenes

C– Set of all alkynes

(iii)



(iv)

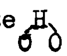


(3) Shapes, Crystals and Symmetry

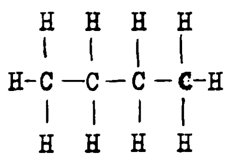
Spatial properties of crystals can involve ideas of symmetry and the idea of regularity in the crystal shape can be related to close packing of spheres. Symmetry is also a useful concept in recognition of structural formulae in organic compounds. Mirrors could be used as lines of symmetry when building up shapes and structures.

(4) Equations and Formulae

These are used as Mathematical models for chemical situations and the problem in manipulation is largely notational. Pb_3O_4 in Chemistry would be translated as 3Pb + 4O in Mathematics _ hence the initial problem in interpretation and secondary problem in evaluating a formula weight. Does H_2O mean 2H + O or H + 2O?

In a test given to 1st year medical students at the University of Glasgow in 1971 [15] one question asked the students to draw the structure of the water molecule showing all bonds as lines. 70% gave an incorrect response and a high proportion (around 20% of those who answered incorrectly wrote  as the structure.

In year 3, perhaps there is a case for using structural formulae only for most carbon compounds, or at least until powers and indices have been dealt with in Mathematics - hence the use of molecular formulae could be developed gradually. This would avoid writing, say, C_4H_{10} and replace by $CH_3CH_2CH_2CH_3$ or even



which are more meaningful in terms of structure.

This would also reduce the tendency for pupils to memorise molecular formulae.

(5) Rate of Change And Proportionality

Atomic weights of elements (as listed in data tables) are calculated as'proportional'means - hence the idea that atomic weight is an approximation or relative weight related to the relative abundance of isotopes of an element.

Many other chemical calculations, in particular stoichiometric ones, require applicationof the schema of proportionality. Research has shown that difficulty with this topic is due to the high level of abstraction necessary. In terms of Piaget levels, the 'formal' thinking level is necessary to develop the ability to understand and handle proportion[16]. Many pupils can cope with proportion in a Mathematical context and find difficulty in transfer of the technique into a Chemical situation. Some research by W. Gapp suggests that chemical knowledge is faulty or deficient when stoichiometric problems are presented[17]. Part of the problem is notational and part conceptual - an investigation of this particular topic is described in detail in Chapter 4 p 97.

In connection with rate of change, graphs are used a lot to represent experimental data. Interpolation and extrapolation of data can be made easier by carefully studying the relationship between the number pairs involved. An investigation of this particular topic is described in Chapter 3 p 56.

(6) Statistics

Measures of length, mass, temperature etc. can be made and a 'most likely' or <u>mean</u> measure can be calculated or a 'most frequent' or <u>modal</u> measure - hence atomic weights for elements and isotopes of elements can have more meaning and more accurate interpretation of data from quantitative experiments can be made.

(7) Logarithms and the Slide Rule

These are useful aids in computation, if estimate answers can be made first. Many pupils are not encouraged to use such mechanical aids outwith the Mathematics Department, and so practice in using them is not apparent in the science department. Slide rule is taught at the end of year 2 and logarithms at the beginning of year 3 - perhaps more extensive treatments earlier might be advantageous to both departments.

(8) Deductive Reasoning and Seriation

The derivation of one 'big' reactivity series of metals is made in S3 from five interrelated series. The metals can be ordered by trial and error but it is more feasible to use algebra to express the relationships and to work from these.

"Jane is fairer than Lilly, Jane is darker than Susan - which of the three is the fairest?" is an analogous situation to the series derivation problem A solution involves the relationships : $J < L$ and $S < J \Rightarrow S < J < L$ where $<$ means "is fairer than".

When a set of metals showing ease of oxidation is found, it can be combined with a set showing ease of reaction with dilute acid and ordered more easily if a 1 to 1 correspondence is set up with the elements and the set of natural numbers and the numbers are consequently ordered.

For example : Zn is more easily oxidised than Fe and less so than Al

Fe is less reactive with dilute acid than Al and more so than Sn

Let $Sn \leftrightarrow 1$
$Fe \leftrightarrow 2$
$Zn \leftrightarrow 3$
$Al \leftrightarrow 4$

$\leftrightarrow$ means ' corresponds to '

Now express the relationships algebraically -

$3 > 2$ and $3 < 4 \Rightarrow 2 < 3 < 4$
$2 < 4$ and $2 > 1 \Rightarrow 1 < 2 < 4$
So, $1 < 2 < 3 < 4$, which translated means $Sn < Fe < Zn < Al$ when "$<$" stands for " is less reactive than"

Careful choice of numbers for elements can mean the resulting order is strict numerical order and thus the reactivity order is more convincing. Seriation is a useful experimental tool not only for reactivity butalso for arranging in order of magnitude, e,g. heats of combustion.

1.7. Results of the Investigation

(1) The order of teaching topics in Mathematics and Chemistry recommended by the Scottish Certificate of Education Examination Board is in general adhered to.

(2) There is a lack of departmental communication and Chemistry teachers are not, in general, aware of the language and methods, used by the Mathematics teacher.

(3) There are topics in Mathematics which are either out of phase with topics in Chemistry or inadequately dealt with.

(4) There are topics in Mathematics involving techniques which could be usefully applied to Chemistry.

(5) There are problems in some Mathematics and Chemistry topics in terms of conceptual development and demands.

(6) There are topics in Chemistry where understanding is affected by an obvious weakness in related Mathematics.

(7) There is a lack of efficiency in mathematical manipulation and in doing elementary operations, hence a corresponding lack in efficiency when computing in chemical calculations, (even a high% performance in elementary operations can mean a low score in computing in a problem[18]).

1.8. Recommendations

(1) Chemistry teachers within schools should make a list of mathematical requirements of their course in time-order of being required.

(2) Mathematics teachers and Chemistry teachers must get together and discuss interdisciplinary problems - if chemists use Mathematics as a tool they must surely learn the mathematicians' language and look into the mathematical basis of other techniques required. As well as this, the Mathematics teachers can look for scientific applications of their theory.

(3) Standards of numeracy could be improved by providing more opportunity to practise manipulative skills in Mathematics departments and hence the transfer of repetitive practice to Chemistry would be easier. A chemist works with numerical quantities not pure numbers, hence what would appear a 'mundane' mathematical operation is perhaps not[19].

(4) Planners of Chemistry and Mathematics syllabuses should check intellectual demands of the respective disciplines before rewriting the next version of the syllabuses to prevent obvious clashes in conceptual demand and also timing.

(5) Authors of school Chemistry text books should give guidance on mathematical techniques required for "mastery" in Chemistry.

To Head of Chemistry Department

Could you please indicate, as close as you can, the time at which you teach the following topics in the 'O' grade and 'H' grade syllabuses. Please indicate any omission of topics clearly.

Chemistry Topics	OMITS	~~WEEK~~ ~~(if possible)~~ ~~MONTH~~ MONTH Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	YEAR (1st, 2nd etc.) 1st	2nd	3rd
A. INTRODUCING SCIENCE	12	8										8		
B. MATTER AS PARTICLES														
1. Evidence for fine division of matter		8	5	6		1						20		
2. Structure of matter		3	8	7	1	1						20		
3. Kinetic model		3	1	10	5	1						20		
C. SOLVENTS AND SOLUTIONS														
1. Water cycle	3		1	2	3	8	2	1				17		
2 Solubility and its uses	1			1	4	8	4	2				19		
3 Emulsions and colloids	1	2	1		1	3	7	2	1		2	16	3	
D. SOME COMMON GASES														
1 Oxygen, nitrogen, carbon dioxide		6				1	1	2	3	3	4	14	6	
2 Inhaled air and exhaled air	3	3	2			1	1	1	2	2	5	12	5	
3 Composition of air		4	1	1		1	2	2	2	3	4	14	6	
4 Solubility of air in water	1	6	1	2		1			1	3	5	10	9	
E. HYDROGEN, ACIDS AND ALKALIS														
1 Hydrogen		8	3	4	1	1				1	2	3	17	
2 Burning of hydrogen		7	3	4	1	1				2	2	4	16	
3 Action of metals on cold water		6	3	4	2	1				2	2	4	16	
4 Action of metals on dilute acids		3	6	4	1	2				1	3	4	16	
5 Acids and alkalis		2	4	4	2	3	1		3		1	4	16	
F. THE EARTH														
1 Origin and structure of the earth	2			1	3	6	4	4					18	
2 Naturally occurring elements	1			1	2	2	7	6			1		19	
3 Naturally occurring sulphides/ Oxides and carbonates				1	2	3	7	6			1		20	
4 Silica and silicates					2	3	3	6	4	2			20	

	OMITS	~~WEEK (if possible)~~ MONTH ~~MONTH~~										YEAR (1st. 2nd etc.)			
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1st	2nd	3rd	4th
F 5 Coal					1	2	3	3	7	3	1		20		
6 Oil			1	1		3	2	3	4	3	2		19	1	
7 Salts from the sea	1	1		1		2	3	3	2	4	2		18	1	
G. ATOMIC STRUCTURE															
1 Evidence for atomic nature of matter		16				1				2	1	1	3	16	
2 Symbols for elements		16	3				1					3	2	15	
3 Constituents of atoms and their arrangement in the atom		17				1	1				1		3	17	
4 Atomic no.		18				1	1						2	18	
5 Mass numbers		17	1			1	1						2	18	
6 Isotopes		17	1			1	1						2	18	
7 Atomic weights		17	1			1	1						2	18	
H. CHEMICAL COMBINATION															
1 Conduction of electricity by substances		9	10		1							1		19	
2 "Model" of chemical combination which fits in with the facts discovered in H.I.		8	12											20	
3 Experiments to support the ionic theory		6	12		1				1					20	
4 Conductivity related to number and mobility of ions		3	11	1	1	2	1		1					17	3
5 Chemical formulae		5	10	5										20	
6 Ions containing more than one element		3	7	6	1				2	1				20	
7 Deduction of chemical formulae from analysis		3	7	8			2							20	
8 Formula weights		2	7	6	1		2			1	1			20	
9 Equations and their use in chemical calculations		2	6	6	1	1	2		2					19	1
I. ACTIVITY AND THE ELECTROCHEMICAL SERIES															
1 Action of metals on oxygen, water and acids			2	4	6		1	1	1	4	1			20	
2 Displacement of one metal by another			1	4	6	1	1	1	1	4	1			20	
3 Reduction of oxides			1	3	6	2	1	1	1	4	1			20	
4 Do all metals form ions equally readily in solution?			1	2	6	2	2	1	1	4	1			20	

	~~WEEK~~ (~~if possible~~) MONTH										YEAR (1st 2nd etc.)			
OMITS	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1ST	2ND	3RD	4TH
5 The ionisation of water		1	3	2	3	5		1	4	1			20	
6 Oxidation and reduction as transfer of electrons			2	5	4	2	2	1	3	1			20	
7 Corrosion of metals and protection			2	1	7	2	1	2	1	4			20	
J. ACIDS, BASES AND SALTS														
1 Acidic and basic oxides	1			2	5	7	2	2	1				19	1
2 The hydrogen ion H^+ aq.	1			2	4	8	2	2	1				19	1
3 Characteristics of acids	1			2	4	7	2	3	1				19	1
4 pH and its uses	1			1	5	6	3	3	1				19	1
5 The OH^- aq. ion and the characteristics of bases	1				5	7	3	3	1				19	1
6 The process of neutralisation and precipitation. Heat of neutralisation		1			2	4	6	3	3	1			19	1
7 Preparation of salts		1				7	6	2	3	1			19	1
8 Simple volumetric work involving acids and bases		1				4	5	6	2	2			19	1
9 Preferential discharge of ions (a) Electrolysis of dilute H_2SO_4 (b) Electrolysis of sodium halide solutions		1	2		5	2	3	3	2	2			19	1
K. SULPHURIC ACID														
1 Burning of iron pyrites and sulphur in air as industrial sources of sulphur dioxide				1		1	4	4	6	4			19	1
2 Properties of sulphur dioxide				1		1	4	2	8	4			19	1
3 SO_3^{2-} as an electron donor				1				6	7	6			19	1
4 Conversion of sulphur dioxide into sulphur trioxide	1			1				6	5	7			18	2
5 Conversion of sulphur trioxide into sulphuric acid	1				1		1	4	6	7			18	2
6 Properties of concentrated and dilute sulphuric acid	1				1		1	2	7	8			18	2
7 Industrial uses of sulphuric acid	1				1		2	2	5	9			18	2
L. FUELS AND RELATED SUBSTANCES														
1 Element carbon : different forms	7	8	5											20
2 Combustion of carbon	6	9	5											20
3 Saturated hydrocarbons	5	9	6											20
4 Oil and natural gas	5	10	5											20
5 Hydrocarbons as fuels	5	9	6											20
6 Unsaturated hydrocarbons	3	7	10											20
7 Nitrogen	2	7	8	3										20

	~~WEEK (if possible)~~ MONTH										YEAR (1st 2nd etc.)		
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	3RD	4TH	5TH
M. AMMONIA AND NITRIC ACID													
1 Ammonia	3	6	3		3	5			1	1	3	17	
2 Manufacture of ammonia by Haber synthesis	2	6	3		2	4	1		1	1	3	17	
3 Oxidation of ammonia	2	4	4		1	6		1	1	1	3	17	
4 Properties of nitric acid	2	3	3	3	1	5	2	1			3	17	
5 Nitrogenous fertilisers	1	3	3	3	2	5	2	1			3	17	
6 Nitrogen cycle	2	2	4	5	1	3	3				2	18	
N. FOODSTUFFS AND RELATED SUBSTANCES.													
1 Carbohydrates			3	6	7	4					1	19	
2 Alcohols, acids and esters			1	3	8	4	2	1	1		1	19	
3 Fats and detergents				1	7	4	5	2	1		1	19	
4 Proteins				1	5	5	7	1	1		1	19	
O. MACROMOLECULES													
1 Synthetic polymers					6	7	7					20	
2 Silicones					5	7	8					20	
'H' GRADE - ADDED TOPICS TO 'O' GRADE													
P. ATOMS, MOLECULES AND THE MOLE													
1 Mass numbers of atoms	8	5	2	1	1		1		1	1		3	17
2 Use of mass spectrometer to determine molecular masses	8	5	2	1	1		1		1	1		3	17
3 Isotopic constitution of elements	8	4	2	1	1		2		1	1		4	16
4 Nuclear chemistry (i) α, β and γ rays	6	6	2	1	1		1		2	1		3	17
(ii) Half-life of radioactive substances	6	6	2	1	1		1		2	1		3	17
(iii) Effect of radiation loss on parent nucleus	6	5	2	1	1		2		1	2		3	17
(iv) Formation of radioisotopes by neutron capture	6	5	3	1	1		1		1	2		3	17
(v) Uses of radioisotopes	6	5	3	1	1		1			3		3	17
5 Avogadro's Number and the Mole	3	8	3	1	1		1			3		3	17
6 Avogadro's Law	4	8	4	1						3		3	17
7 Calculations involving the mole Concept and including gas volumes	2	8	5	1	1			1		1		3	17

	~~WEEK~~ (~~if possible~~) MONTH ~~MONTH~~										YEAR (1st 2nd etc.)	
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	4TH	5TH
Q. BONDING AND THE PERIODIC TABLE												
1 Heats of reaction and bond energies		5	10	3	1	1						20
2 Redox reactions		2	9	2	4	3						20
3 Study of the elements in the short periods		2	5	6	4	3						20
4 Bonding, polarity, interatomic and intermolecular forces of compounds of elements in the short periods		2	3	7	6	2						20
5 The Alkali metals		2	2	4	5	2	5					20
6 The halogens		2	1	4	1	3	6	1	1	1	1	19
R. CHEMICAL REACTIONS												
1 Factors affecting speed of reaction	1	1	1	3	1	4	3	1	2	3	5	15
2 Reaction mechanism and effect of concentration	1	1	1	3	2	4	3			5	5	15
3 Effect of temperature	1	1		2	2	5	3	1		5	5	15
4 Effect of catalysts	1	1		2	2	5	3	1		5	5	15
5 Effect of light	1	1		3	2	3	5			5	5	15
6 Idea of equilibrium	3	1		1	2	3	6	2		2	2	18
7 Factors influencing the position of equilibrium	4		1	1	3	2	8			1	1	19
8 Equilibrium in practice	3	1	1	1	3	2	8			1	1	19
S. CARBON COMPOUNDS												
1 The paraffins	4	1	1		5	4				5	5	15
2 Unsaturated hydrocarbons	3	1	2		5	4				5	5	15
3 Benzene	5	2	1		2	7	1			2	2	18
4 The OH group in alcohols, phenols and acids	5	3		1	1	7	2			1	1	19
5 The NH_2 group	2	4	2	1		4	6			1	1	19
6 The CO group	1	5	2	1		4	5	1		1	1	19

Results for 12 schools

To Head of Mathematics Department.

Could you please indicate, as close as you can, the time at which you teach the following topics in the 'O' grade and 'H' grade syllabi. Please indicate any omission of topics clearly.

MATHS TOPICS Note: Topics are listed in Algebra, Geometry etc. sections.

'O' GRADE		~~WEEK~~ ~~(if possible)~~					~~MONTH~~					YEAR (1st, 2nd etc.)			
ALGEBRA	OMITS	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1ST	2ND	3RD	4TH
BOOK 1.															
A1,1 Introduction to sets		11	1									12			
A1,2 Math. Sentences : Equations		3	7	2								12			
A1,3 Multiplication using commutative Associative and Distributive laws.			3	8	1							12			
A1,4 Replacements and Formulae			1	3	5	3						12			
A1,5 Math. Sentences : Inequations					4	6	2					12			
BOOK 2.															
A2,1 Distributive law					1	4	4	2	1			12			
A2,2 Powers and Indices						1	1	5	2	1	2	12			
A2,3 Negative numbers		2					2	1	1	5	1	10	2		
A2,4 Methods of solving equations and inequations		3	1			1		2		1	4	8	4		
BOOK 3.															
A3,1 Relations and mappings		6	4	1	1								12		
A3,2 Operations on the Integers		1	4	4	2	1							12		
A3,3 Number systems	2	1		3	2	1	2	1					12		
A3,4 Equations and Inequations in 1 variable		1	2	2	2	3	1	1					12		
BOOK 4.															
A4,1 Further Sets		1			1	3	3	1	2	2			11	1	
A4,2 Linear Equations and inequations in two variables			1			1	1	3	2	2	2		11	1	
A4,3 Systems of Linear Equations and Inequations in two variables		3	1					2	3	2			8	4	
A4,4 Formulae		1	1	2	1					4	3		7	5	
BOOK 5.															
A5,1 Reasoning and Deduction	6	3		1	1	1								5	1
A5,2 Language of Variation		5	3	3	1									11	1
A5,3 Further Addition and Multiplication			3	3	3	1	1	1						12	
A5,4 Functions : the Quadratic Function and its graph				2	3	3	3		1					12	

	~~WEEK~~ ~~(if possible)~~ MONTH					~~MONTH~~ MONTH					YEAR (1st. 2nd etc.			
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1st	2nd	3rd	4th
BOOK 6.														
A 6,1 Factors and fractions	3			1	2	3	3	3	1				9	3
A 6,2 Surds	1	2	1			2	2	2	2				8	4
A 6,3 Quadratic Equations and Inequations	2	1	1	1	2		1	1	2	2			6	6
BOOK 7.														
A 7,1 Indices	4	4		1	3									12
A 7,2 Introduction to Linear Programming		3	4	1		3	1							12
GEOMETRY														
BOOK 1.														
G 1,1 Cube and Cuboid	11	1									12			
G 1,2 Rectangle and Square	4	7	1								12			
G 1,3 Coordinates	2	2	8								12			
G 1,4 Right-angled triangle			4	6			1		1		12			
G 1,5 Isosceles and Equilateral Triangles			1	3	6	2					12			
BOOK 2.														
G 2,1 Rhombus and Kite	1				4	5	2				11	1		
G 2,2 Parallelograms, Triangles and Parallel lines	1					2	4	5			11	1		
G 2,3 Angles - rotation	1	1					1	1	4	4	10	2		
BOOK 3.														
G 3,1 Locus	7	3		1						1		11	1	
G 3,2 Calculation of Distance		5	4		2	1						12		
G 3,3 Translation			5	1	3	3						12		
G 3,4 Reflection	1			5	2		3	1				12		
BOOK 4.														
G 4,1 Specification of Triangles	2	1			4	1		1	1	2		9	3	
G 4,2 Similar figures	1	3				3	2	1	1	1		8	4	
G 4,3 Rotational and bilateral symmetry of the circle	2	2	1				2	3	1	1		7	5	
BOOK 5.														
G 5,1 Vectors				1	4	5	2						12	
G 5,2 Theorems and Converses				1	2	2	2	5					12	

	~~WEEK~~ ~~(if possible)~~ MONTH						~~MONTH~~				YEAR (1st, 2nd etc.)			
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1ST	2ND	3RD	4TH
BOOK 6.														
G6,1 Dilatation	6	1	1				2	2					4	8
G6,2 Tangent and angle properties of the circle	1	1	2	3					5	1			6	6
BOOK 7.														
G7,1 Composition of Transformations	4	6	2											12
G7,2 Coordinates, Vectors and Transformations		1	2	2	2	5								12
TRIGONOMETRY														
T5 Cosine, Sine and Tangent Functions	1		3	3	1	1	1			1			10	2
T6,1 Triangle formulae	2	2	1	1			1	2	3				6	6
T6,2 Three dimensional trigonometry	4	3	4	1										12
ARITHMETIC														
BOOK 1.														
Ar1,1 Length, Area and Volume	6	4	2								12			
Ar1,2 System of Whole Numbers	2	3	7								12			
Ar1,3 Fractions, ratios and percentages			1	2	5	4					12			
BOOK 2.														
Ar2,1 Decimals and the metric system	1	1	1	1	1	2	4	1			12			
Ar2,2 Binary Numbers							2	8	2		12			
Ar2,3 Introduction to Statistics	1							1	8	2	11	1		
Ar2,4 Introduction to Probability	1		1	1					2	7	9	3		
BOOK 3.														
Ar3,1 Square Roots	4	5	1	1								12		
Ar3,2 Proportion	1	3	5	3								12		
Ar3,3 Social Arithmetic	2		3	5	1	1						12		
Ar3,4 Number Patterns and Sequences	1		1	1	5	2	1	1				12		
BOOK 4.														
Ar4,1 Use of Slide Rule				1	1	3	2	2	2	1	1	8	3	
Ar4,2 Length, Area and Volume associated with the circle	2				1	3	3	2		1		9	3	
Ar4,3 Applications of percentages, discount, profit and loss, interest	3	2	1				1	3	2			6	6	
Ar4,4 Statistics	1	1	2	1			1	1	2	3		4	5	

		OMITS	(~~if possible~~) MONTH Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	(1st. 2nd etc.) 2ND	3RD	4TH	5TH
	BOOK 5.															
Ar5,1	Logarithms and Calculating Machines		4	4	2	1	1			1			1	10	1	
Ar5,2	Areas and Volumes		1		4	3	1	2	1					10	2	
Ar5,3	Estimation of Error					2	5	1	1	1	1	1		10	2	
	BOOK 6.															
Ar6,1	Social Arithmetic		2	1				3	2	2	1	1		9	3	
Ar6,2	Counting Systems		2	2	1	1		1	1	3	1			6	6	
Ar6,3	Statistics			1	2	1	2				2	4		6	6	
	BOOK 7.															
Ar7	Flow Diagrams and Computers	4	1	1		1	2	2					1		7	
	ALGEBRA — **HIGHER GRADE**															
	BOOK 8.															
A8,1	Sequences and Series		2	1						1	4	4			9	3
A8,2	Matrices		3	1	2	1					1	4			5	7
A8,3	Functions, Composition of functions and inverse functions		4	3	2		2				1				1	11
A8,4	Polynomials, The Remainder Theorem and Applications		2	3	4	4										12
	BOOK 9.															
A9,1	Quadratic equations and functions			1	3	3	5									12
A9,2	Systems of equations				4	1	2	3			1	1			1	11
A9,3	Exponential and logarithm functions				1	1	2	5	2		1					12
A9,4	Deductive reasoning	6						2	4							6
	GEOMETRY															
	BOOK 8.															
G8,1	Gradient and Equations of a straight line		4	2							2	4			6	6
G8,2	Composition of Transformations		2	1	5	4			1							12
	BOOK 9.															
G9,1	Equations of a Circle		1	2	1	1	5	2								12
G9,2	Vectors					2	3	5	2							12
	TRIGONOMETRY															
T8,1	Addition Formulae		4	2	1						1	4			5	7
T8,2	Products and Sums of Cosines and Sines		3	2	1	2	4									12
T9	Functions: a cos x° + b sin x° + applications				2	1	1	5	3							12
	CALCULUS															
C8,1	Differential Calculus		6	4	1							1			1	11
C8,2	Integral Calculus			1	4	4	3									12
C9	Trig functions					5	5	2								12

	YEAR 1 CHEMISTRY TOPICS	MATHS TOPICS			YEAR 3. CHEMISTRY TOPICS	MATHS TOPICS.			
SEP	A, B_1	A1,1	G1,1	Ar1,1	$G_{1,2,3,4,5,6,7}$	A5,1 A5,2		Ar5,1	
OCT	B_2	A1,2	G1,2		$H_{1,2,\overset{*}{3},4,5,6,8}$				
NOV	B_3	A1,3	G1,3	Ar1,2	$H_{\overset{*}{7},9}$	A5,3		Ar5,2	T_5
DEC		A1,4	G1,4		$I_{1,2,\overset{*}{3},4,6}$				
JAN	C_1, C_2	A1,5	G1,5	Ar1,3	I_7 J_9	A5,4		Ar5,3	
FEB	C_3	A2,1	G2,1		I_5 $J_{1,2,3,\overset{*}{4},5,7}$		G5,1	Ar6,1	
MAR		A2,2		Ar2,1	$J_{\overset{*}{6}}$	A6,1			
APR			G2,2	Ar2,2	J_8	A6,2	G5,2	Ar6,2	
MAY		A2,3	G2,3	Ar2,3	$K_{\overset{*}{1},2,3}$		G6,2		T6,1
JUN	D_2, D_3	A2,4		Ar2,4	$K_{4,5,6,7}$.	A6,3		Ar6,3	
	YEAR 2.				YEAR 4				
SEP	D_1, D_4, $E_{1,2,3}$	A3,1	G3,1	Ar3,1		A7,1	G6,1		T6,2
OCT	E_4	A3,2	G3,2		$L_{\overset{*}{1},2,\overset{*}{3},4,5}$ $M_{1,2}$		G7,1		
NOV	E_5	A3,3	G3,3	Ar3,2	$L_{6,7}$	A7,2			
DEC			G3,4	Ar3,3	M_6				
JAN	F_1	A3,4	G4,1	Ar3,4	$N_{1,\overset{*}{2},\overset{*}{3}}$			Ar7	
FEB	F_2, F_3	A4,1	G4,2	Ar4,1 Ar4,2	$M_{3,4,5}$ O^{*}_{1}		G7,2		
MAR	F_4	A4,2			N_4, O_2				
APR	F_5, F_6	A4,3	G4,3	Ar4,3					
MAY	F_7	A4,4							
JUN				Ar4,4					

* TOPIC DIFFICULTIES[8]

MATHEMATICS IN S.C.E. 'O' GRADE CHEMISTRY

Topic and Section	Title	Maths skills and abilities required	Topic and section in Maths
YEAR 1			
B 1	Evidence for fine division of matter	Ideas of relative size, volume and Brownian motion. (Use of models as analogies)	Year 1 G1, 1 Ar 1, 1
B 2	Structure of matter	Relation between elements, compounds, atoms and molecules, solids, liquids and gases -classification using sets Idea of chemical compounds "containing" elements	Year 1 A 1, 1
B 3	Kinetic model	Close packing of spheres. Idea of 'energy' with solid liquid and gaseous particles - size of space between molecules	Year 2 Ar 4, 2
C 1	Water cycle	Flow Chart Reading temperature and other scales	Year 1 Ar 1, 1
C 2	Solubility and its uses (Crystals) Chromatography	"Rate" in connection with solubility in a multivariate situation. Interpretation of graphs. Shapes, cleavage and packing to form a pattern. Relations between variables in a multivariate situation.	Year 2 A 3, 1 Year 1 G 1, 3

C 3	Emulsions and colloids	Binary relation of "holding" when emulsification. Idea of particle size and energy.	Year 2 A 3, 1
D 1	Oxygen, nitrogen and carbon dioxide	pH scale 0 – 14	Year 1 A 2, 3
D 3	Composition of air	Idea of air "containing" O_2 and N_2 " " water " H_2 and O_2 Use of negative temp. scale for manufacture of O_2 and N_2	Year 1 A2,3
YEAR 2 E3	Action of metals on cold water	Idea of "ordered" rate series in terms of reactivity (Logic: If A>B and B>C then A>C)	Year 2 A 3,1 Year 3 A5,1
E4	Action of metals on dilute acids.	" "	" "
E5	Acids and Alkalis (neutralisation)	pH scale 0–14 of acidity and alkalinity – no proportionality. (PH=7 only neutral for strong acid / base)	Year 1 A 2,3
F 1	Origin and structure of the earth	% composition of elements	Year 1 Ar 2,3
F 2	Naturally occurring elements	"Ordered" rate series in terms of reactivity with oxygen. Combine with series in E3 and E4	Year 3 A 5,1

F 3	Naturally occurring sulphides, oxides and carbonates.	Deductive reasoning in identifying elements Inverse relation between metal and oxide series involving energy	Year 3 A 5,1
F 5	Coal	Set of forms and products	Year 1 A 1,1
F 6	Oil	Charts	Year 1 Ar 2,3
<u>YEAR 3</u>			
G 1	Evidence for atomic nature of matter	Set of relative atomic masses. Handling numbers in standard form e.g. $6 \cdot 02 \times 10^{23}\ mol^{-1}$	Year 1 A 1,1
G 2	Symbols for elements	Sets of elements. Use of the formula $Density = \frac{Mass}{Vol.}$ (formula)	Year 1 A 1, 1 A 1,4
G 4	Atomic Number	Sequence of numbers related to Periodic Table	Year 2 Ar 3,4
G 6	Isotopes	Tabular information with atomic weights and idea of proportional average	Year 2 Ar 3,3

G 7	Atomic Weights	Proportional average idea	Year 2 Ar 3,3
H 1	Conduction of electricity by substances	Connection of electrical circuits using + and – Sets of good and bad conductors	Year 2 A 3,2 Year 1 Ar 1,1
H 2	"Model" of chemical combination which fits in with the facts discovered in H 1	Tetrahedral disposition in models	Year 1 G 1,5
* H 3	Experiments to support ionic theory	+ and – charges	Year 2 A 3,2
H 4	Conductivity related to number and mobility of ions	Ordered relation from binary relations Seriation A > B > C	Year 2 A 3,1 Year 3 A 5,1
* H 5	Chemical formulae	Evaluation of molecular weight using algebraic evaluation when given an expression with powers	Year 1 A 2,2 for terminology
H 6	Ions containing more than 1 element	Flow diagrams for salt inter-conversions	Year 4 Ar 7,1
H 8	Formula Weights	Calculation as process of evaluation in parts – similar to algebraic evaluation with the expression involving powers and/or coefficients	Year 1 A 2,2

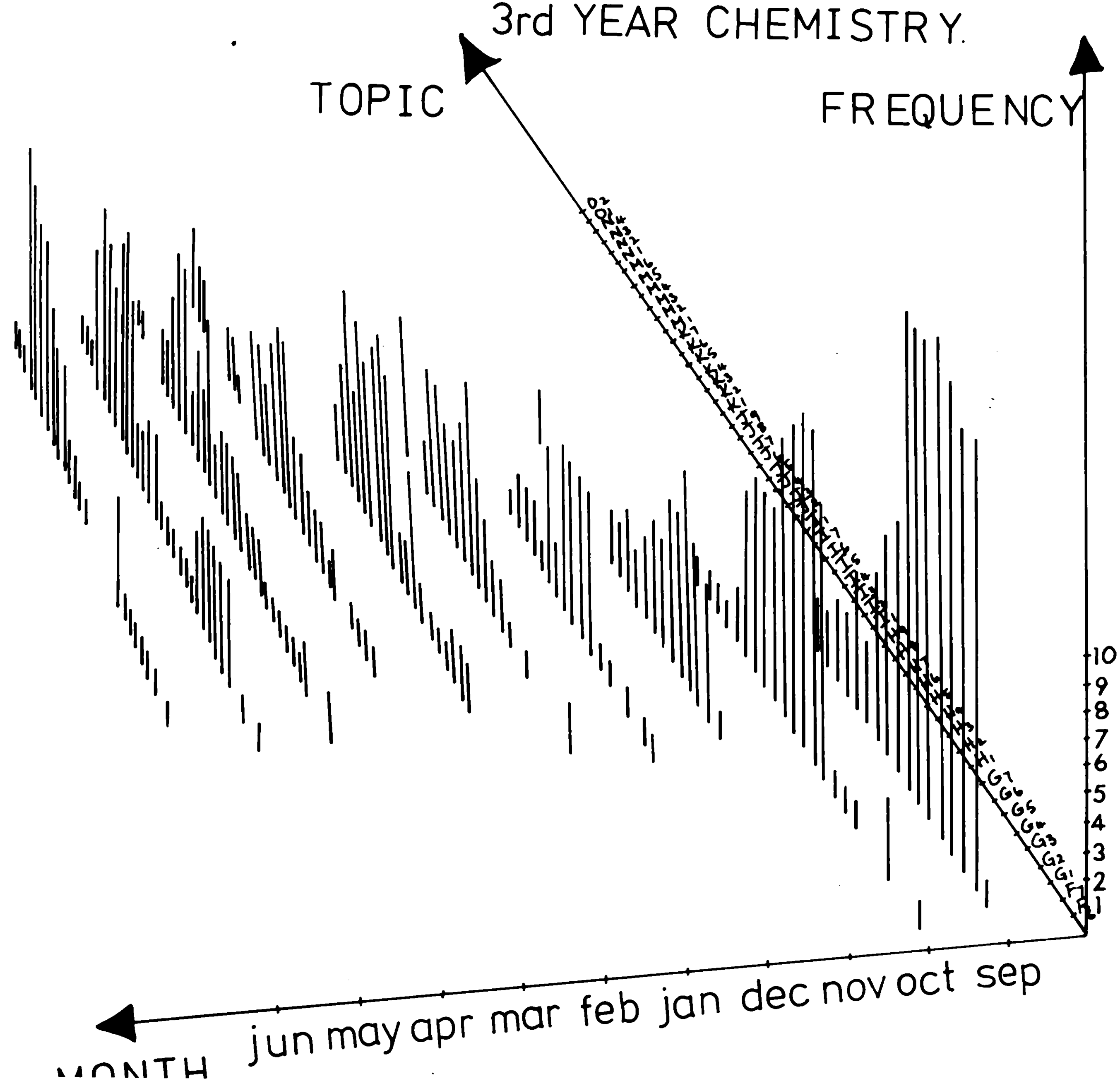
H 9	Equations and their use in chemical calculations	Equality in terms of mass and solution of an equation for an unknown variable.	Year 2 A 3,2 for evaluations and Year 2 A 3,4 for solving
* H 7	Deduction of chemical formulae from analysis	Proportional parts, notation - $H_2O \neq H20$ It would equal 2H + O in algebra	Year 1 A 2,2
I 1 I 2 * I 3	Action of metals on oxygen, water and acids Displacement of one metal by another Reduction of oxides	Five series become one 'Big' series - ordering into a series	Year 2 A 4,1 for union Year 3 A 5,1 for ordering
I 6	Oxidation and reduction as transfer of electrons	Transfer of electrons i.e. of + and - terms in equation	Year 2 A 3,4
* J 4	pH and its uses	pH scale as inverse log scale	Year 3 Ar 5,1
J 9	Preferential discharge of ions	Order of elements using inequalities	Year 3 A 5,1
* J 1 J 7	Acidic and basic oxides Preparation of salts	Flow diagrams. Classification of acids, bases and ions using a Venn diagram	Year 2 A 4,1 Year 4 Ar 7,1

* J 6	Process of neutralisation and precipitation. Heat of neutralisation.	'Trend' graphs in terms of concentration and molarity of ions. Use of direct proportion to calculate volume of a given molar solution when a balanced equation is used.	Year 2 Ar 3,2
J 8	Simple volumetric work involving acids and bases	Calculation of molarities using direct p roportion	Year 2 Ar 3,2
K 1	Burning of iron pyrites and sulphur in air as industrial sources of SO_2	3D crystal models of sulphur. % composition	Year 1 G 1,5 Year 1 Ar 2,3
* K 3	SO_3^{2-} as an electron donor	Ion electron half equations. +ve and -ve charges.	Year 2 A 3,2
K 4	Conversion of SO_2 into SO_3	Concept of equilibrium, which is similar to equivalence, with factors of temperature and catalysis taken into account	Year 3 A 5,1
<u>YEAR 4</u> L 1	Element Carbon : different forms	3D models	Year 1 G 1,5
* L 3	Saturated hydrocarbons	Geometrical structures	Year 1 G 1,5

L 5	Hydrocarbons as fuels	Geometrical structures	Year 1 G 1,5
M 2	Ammonia	Structure (tetrahedral). Work with volumes and Avogadro's law to get formula	Year 1 G 1,5
M 3	Manufacture of ammonia by Haber Synthesis	Equilibrium. Ratio of numbers of reacting particles	Year 3 Ar 3,2
M 5	Properties of nitric acid	Ion-electron half equations. +ve and -ve charges	Year 2 A 3,2
M 6	Nitrogenous fertilisers	% content of nitrogen in ammonium chloride, ammonium nitrate and urea.	Year 4 Ar 6,2
M 7	Nitrogen cycle	Flow diagram	Year 4 Ar 7,1
* N 2	Alcohols, acids and esters	Geometrical structure in 3D and mention of symmetry where that exists	Year 2 G 3,4 (symmetry)

* N 3	Fats and detergents	Geometrical structure in 3D and mention of symmetry where that exists	Year 1 G 1,5 (tetrahedron)	Year 2 G 3,4 (symmetry)
N 4	Proteins	Structures	"	"
* O 1	Synthetic polymers	Structures	"	"

* Topics found difficult in Chemistry by A.H. Johnstone [5]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TOPIC
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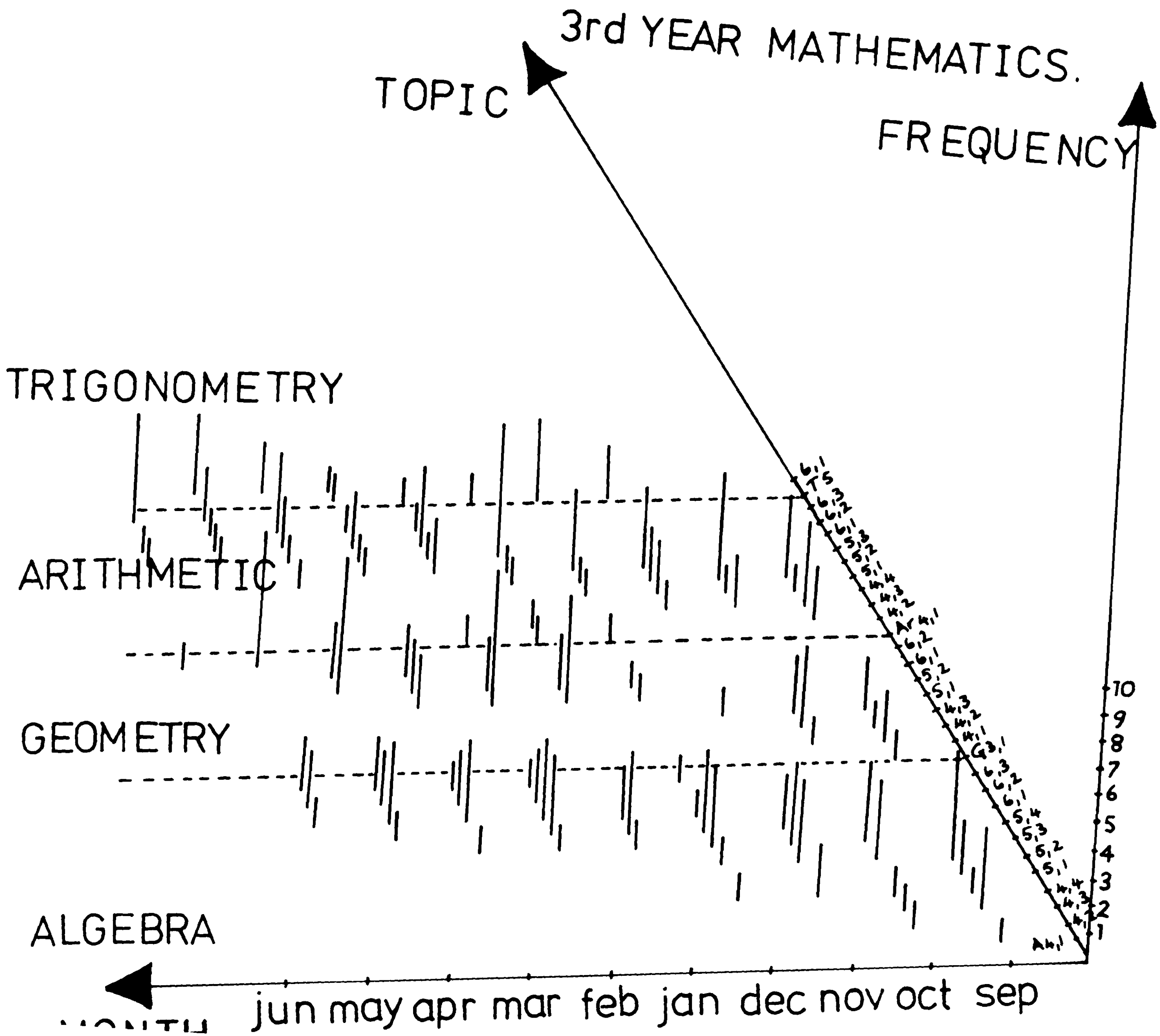
3rd YEAR MATHEMATICS.
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CHAPTER 2

THE CONCEPT OF "CONTAINMENT" IN CHEMISTRY.

2·1 Introduction

In Chemistry, concept learning is fundamental and in many cases, a model is a representative example of a simple concept. This means that the process of comparing concepts can be carried out through the mediation of memory as well as language.

A concept is defined to be an "inferred mental process" and learning a concept requires discrimination which can be demonstrated by the ability to classify. It must however be remembered that early concepts are much more constructively than analytically directed and that the environment presents or does not present a pupil with experiences and teaching suitable to his way of conceptualisation. There are three stages in the process of concept formation:-

1) "Play" stage where activity is purposeless and undirected;
2) "Direction" stage where objects are grouped into classes, compared and perhaps counted;
3) "Insight" stage where constituents of a concept click into place explicitly, constructively or analytically.

The dynamic equilibrium of concept formation is delicate and is easily upset by interference, emotional or intellectual and so a teacher must be aware of the stage through which a pupil is passing and must provide appropriate experiences or hints at times when these are beneficial. Stones (1968) said, "Concepts are formed when we abstract the essential attributes of things from many specific examples".

2·2 Concept Acquisition in Chemistry

Pupils are first introduced to the idea of a chemical substance, then to a chemical reaction and then to elements, compounds, mixtures, atoms and molecules in that order.[20] All these ideas can be related using ideas of sets which exhibit an ability to classify.

Two factors in the classroom situation affect the development of these and any concepts:-

1) the understanding of the teacher;
2) the climate of opinion, i.e. methods of discussion and demonstrations.

There is also a hierarchical structure in acquiring concepts, for example rational thought on chemical reaction or transformation cannot begin until the Piagetian concepts of conservation of chemical identity, composition and mass have been acquired.[21] Simple 'concrete' concept formation should involve classifying, relating and quantifying where more complex 'formal' concept formation should involve constructing systems and theories.

This chapter describes some research into pupils' attainment and understanding of the concept of 'containment' in Chemistry.

2·3 Understanding of the Concept of 'Containment' in Chemistry

First year pupils in secondary schools, referred to as S1, first meet the idea of containment in connection with set theory in Mathematics where it is emphasised that a set "contains" elements or members and these form a collection of objects of any kind, e.g. the individuals in a class of pupils. A set is taken from a universal set, e.g. pupils in the school, which contains all the elements in the particular context. A little later, pupils meet again the idea of 'containment' in Chemistry in connection with chemical reaction and change in composition which is a much more complex idea. The pupils will undoubtedly try to relate ideas of sets to what they are doing in Chemistry but can they surmount the difference between "contains" in Mathematics, which is a 'concrete' concept, and "contains" in Chemistry which is a 'formal' concept relying on the ion concept and bonding theory?

This investigation was set up to find out what understanding pupils in S1 had of the word "contains" in Chemistry. A sequence was developed in the experimental design as follows:-

(i) Pupils were given a situation where formation and separation of a mixture were investigated. Components were solids, recognisably present in the mixture and easily separated by mechanical means. See Questions 1 and 3.

(ii) Pupils were given a situation where progressively more intimate mixtures were presented and more subtle methods of separation were necessary. See Questions 2, 4, 7 and 8.

(iii) Pupils were given a situation where chemical reaction was described. Two solids combined to form what was clearly a new substance /

substance which could not be changed back to the original substances. See Questions 7 and 8(ii).

(iv) Pupils were given the product of a chemical reaction and asked to describe the reaction in terms of what had combined to form the new substance and how they could find out what was "contained" in the new substance. See Questions 9, 12, 14, 15 and 16.

Solids were used in all examples or situations and by presenting situations some of which were familiar and some not, it was hoped that thought processes used in connection with the word "contains" could be clearly defined; it was also hoped that thought processes which were clearly understood could be defined.

2·4 Experimental Procedure

Three groups of pupils with 4, 5 and 6 pupils respectively from a "good" first year class, and two groups of pupils with 6 and 7 pupils respectively from a "poor" first year class were used as subjects in an 'interview' experiment where the main aim was, "to test understanding by providing unfamiliar problems which could be solved only if the necessary principle was understood". The average age of the first three groups was 12·5 years, and their average class examination mark, based on one formal examination, was 74·0%. The average for the two groups was 12·7 years of age, and their average class examination mark was 40·8%. Both sets of groups had the same class examination. The outline of the discussion was based on the following questions:-

1. Here is a box and some red and blue balls. If I put the red balls into the box with the blue ones on top, can you see the red and blue ones? YES / NO

   Would it matter if I put them in in any order - can you still see the red ones? YES / NO

   and the blue ones? YES / NO

2. Here is a piece of paper with some red and blue paint. If I put a layer of red paint with a layer of blue paint on top, can you see the red and blue paint? YES / NO

   If I start again and this time put a layer of blue paint with a layer of red paint on top, can you see the blue and red paint? YES / NO

   Do you /

Do you have any difficulty

(i) recognising a colour of paint? YES / NO

(ii) seeing which primary colour combination might have been used to give a mixed colour? YES / NO

(iii) telling if there is more of one primary colour than another in a mixed colour? YES / NO

How do we know if a coloured paint "contains" one primary colour of paint or a mixture of colours?

How do we know what a dark green paint contains compared with what a light green paint contains?

(Can you explain a little more fully? Are there any other reasons? What do you mean?)

3. Let us now think of a parking meter which "swallows" 2p and 5p coins, can you see the 2p and 5p coins? YES / NO

How could I find out how many 2p and 5p coins are inside?

4. If I take some salt grains and some sugar grains and put them in a dish, can you see the salt and sugar? YES / NO

How could I find out how much salt and sugar I have?

5. What do you think are the differences in these two problems?

6. How often do you think you can see the separate contents of a mixture?

7. When you or your mother bakes a cake, you know what it contains /

contains if you see the ingredients before mixing and baking. Let us suppose you see the baked cake. Do you have difficulty

(i) seeing that it contains flour? YES / NO

(ii) seeing that it contains eggs? YES / NO

(iii) seeing that it contains raising agent? YES / NO

(iv) seeing that it contains butter or margarine? YES / NO

(v) seeing that it contains currants? YES / NO

(vi) seeing that it contains cherries? YES / NO

8. (i) Now let us take some iron filings and some sulphur and mix them. Can you see the iron filings and the sulphur? YES / NO

Could you separate them? YES / NO

(ii) If I now heat the mixture, the iron and sulphur will join together. Can you now see the iron? YES / NO

the sulphur? YES / NO

Could you separate them? YES / NO

9. Now, I would like you to tell me, if you had been given the iron and sulphur 'joined' as iron sulphide could you have said it contained iron and sulphur? (A stick of FeS is presented.) YES / NO

10. How often do you think you can see the contents of a chemical substance?

11. How often do you think you can identify contents of a chemical compound?

12. /

12. If I take a blue crystal, can you say what it might contain? YES / NO

Would it be possible to do something to find out what the crystals are composed of? ($CuSO_4$ crystals are presented.) YES / NO

13. How can you find out what is contained in a substance?

14. For example, let us look at this piece of quartz. How do you think the people who found it decided what it contained?

15. Sometimes, it is difficult to give a <u>complete</u> composition picture. For example, how do we know what air contains?

16. Can you find out what water contains?

17. One final question. Looking back on examples where we sometimes have seen easily and sometimes not seen easily one thing contain another. What is the meaning of the word "contains"?

2·5 Analysis of the Results

The following types of response were recorded. (Figures in parenthesis show:- [a] number of responses from groups; [b] number of respondents for "good" and "poor" groups of pupils respectively.) Responses for "good" groups are enclosed in rounded brackets and for "poor" pupils in squared brackets. One person from a group responded, in turn, to each question.

Question 1 presented no problem at all - pupils could easily discriminate between objects by use of colour. (3,3) [2,2]

Question 2 Pupils emphasised that any colour other than red, yellow or blue on its own must be a mixture of two or more primary colours. (3,3) [2,2] The primary colours used in making a 'secondary' colour could be found by trial and error or just by 'knowing' from past experience or from memory. [2,2] When given a 'secondary' colour, e.g. brown, the separate components could be found by using 'chromatography' to separate layers (3,1) or by using turpentine which would take off one layer at a time. (3,1) Differentiation in shades of green was easy - if light then more yellow, if dark then more blue. [2,2]

Question 3 Coins in a parking meter were separated and counted to see how many of each were present. (3,3) [2,2]

Question 4 The presence of salt and sugar in a mixture was apparent after tasting. (3,2) [2,2] Separation, however, was difficult; suggestions for separation included dissolving mixture (3,2) - only the sugar dissolved. Some thought there was a way of doing it but could not remember what it was - testing or something! - they decided that the mixture could not be separated. (3,1) [2,2]

Question 5 The difference between situations in Questions 3 and 4 /

and 4 was that solids in Question 3 were different shapes and colours and could be easily separated but solids in Question 4 were the same shapes and colours, were much smaller and could not be easily separated, if at all. (3,3) [2,2]

Question 6 One would 'occasionally' be able to separate a mixture into its components. (3,3) One would 'not very often' be able to separate a mixture into its components. [2,1] It would always be difficult to separate a mixture into its components. [2,1]

Question 7 In testing for recognition of ingredients in a baked cake responses were:-

(i)	Recognition of flour	No -	Yes (3,1) [2,1]	Doubt (3,2) [2,1]
(ii)	Recognition of eggs	No (3,1)	Yes (3,1) [2,2]	Doubt (3,1)
(iii)	Recognition of raising agent	No (3,3) [2,1]	Yes -	Doubt [2,1]
(iv)	Recognition of butter/marg.	No (3,1) [2,2]	Yes (3,1)	Doubt (3,1)
(v)	Recognition of currants	No (3,3) [2,2]	Yes -	Doubt -
(vi)	Recognition of cherries	No (3,3) [2,2]	Yes -	Doubt -

'No' indicates no difficulty in recognition; 'yes' indicates the reverse.

Responses /

Responses included comments about the obvious effect of raising agent, colouring from eggs and from butter. One response expressing doubt about the presence of butter said, "You can see 'wee particles' of butter once the cake is baked."

Question 8 In presenting a 'similar' situation using chemical substances, there was obvious recognition of iron filings and sulphur in a mixture made at the time. (3,3) [2,2]

Question 9 However, when the product of heating a similar mixture was shown, i.e. a stick of iron sulphide, FeS, the iron filings were still obviously present (3,3)[2,2] because they had not changed much, but the sulphur could not be seen easily (3,2)[2,2]; one of the "good" groups claimed they could still see the sulphur. (3,1)

A magnet could be used to separate the mixture before heating (3,2)[2,1] or separation may be done by dissolving in water (3,1), but few thought the iron sulphide could be returned to its constituents. (3,2) [2,2] One group suggested separation by melting and allowing separation as in a water and alcohol mixture. (3,1)

Question 10 Most groups agreed you could seldom see the components of a chemical mixture. (3,3) One group thought you would 'often have difficulty' [2,1] and the remaining one said 'not at all' - if there was a label on a substance then you could get the names of the components but you could not separate out the components after heating. [2,1]

Question 11 was omitted with later groups as unfair.

Question 12 Crystals of copper sulphate were presented and pupils were asked what was "contained" in the crystals. Verbal responses included:-

(i) /

(i) Copper and sulphate - the name tells you (3,2); one continued, Cu is brown so it is not easy to see .... but you could smell, look to see what you could, put in water, and if some dissolved and some did not, then you could imply two substances were present. (3,1)

(ii) There should be Cu and sulphate [2,2]; one continues, there is no copper in it [2,1], and the other continues, copper is red so heat must have turned it blue. [2,1]

(iii) The remaining group said you would first of all smell, taste and dissolve in water - could there be copper? - no, it is just a name. Copper is not blue, it is brownish red, but perhaps there could be copper.

Question 13 was incorporated with Question 12 where suggestions included smell, taste, dissolve in water.

Question 14 Verbal responses were:-

(i) Analyse it (3,1)

(ii) Break it down, then crush it, then take a magnet to see if there is any iron present (3,1)

(iii) The colour helps (3,1)

(iv) We cannot rely on a name [2,1]

Question 15 It was suggested that oxygen and carbon dioxide are constituents of air but are not visible - the reason we know they are there is because we breathe them in and out respectively. (3,1)[2,1] 70% oxygen, no 20% oxygen. (3,1) Oxygen, hydrogen and CO_2 - air is a mixture of gases, but it is not easy to see that air contains oxygen, etc. (3,1)[2,1]

Question 16 In this question it was suggested that water which is H_2O must contain hydrogen and oxygen, but that it is not obvious water contains gases. (3,2)[2,1] One group suggested breaking water down /

down into molecules to find out what it contains - if there is hydrogen then that burns - but you certainly cannot see the components of water. (3,1) The remaining group did not know what water contained - after prompting, hydrogen and oxygen were defined as components, but these were gases and were components of air and water is a liquid - they were completely mystified.

It was suggested that the difference between the air and water problems was that components are not always in their natural form. (3,1)

Question 17 To sum up, pupils were asked to say what the word "contains" meant to them with reference to Chemistry. Replies were:-

(i) contains means 'consists of' (3,1)

(ii) " " 'something it has got in it' (3,1)

(iii) " " 'what is in it - in Chemistry we cannot always see what is in it' (3,1)

(iv) " " 'substances in it' [2,1]

(v) " " 'it has in it, has the stuff in it, has the things in it' [2,1]

2·6 Conclusions

During the interviewing, language played an essential part :-

(a) when pupils were asked to label and classify what they were experiencing,

(b) when pupils' attention was directed to relevant aspects of each situation.

D.H. Russell (1956) found that "in some experiments children show clear understanding of a concept but inability to verbalise it".[22] This may well be a part of the explanation for lack of concept formation apparent in this experiment, but the lack of understanding of the word "contains" in Chemistry and the wide gap between the meaning of the word "contains" in Mathematics and Chemistry can be explained by other more serious factors.

1) Pupils tended to rely on the unsatisfactory criterion of change of state or appearance when defining elements "contained" in a mixture or compound.

2) Pupils, at this elementary level, regarded chemical change as a change in appearance which was directly perceived and not as change in composition.

3) Pupils appeared to have a lack of basic conservation concepts, hence their lack in acquiring the concept of containment in Chemistry. (The acquisition of conservation concepts by 11-12 year old children has been investigated by J.R. Hall.[23])

4) Pupils had a lack of understanding of the nature of a chemical reaction and basic chemical concepts like element, molecule and substance.

5) Pupils had an alarming lack of understanding of techniques, e.g. chromatography and separation processes for solids and miscible liquids; it would appear that these techniques had been met blindly in the /

in the laboratory and that they would work every time they were applied in a 'similar' situation.

6) Pupils were unable to define the concept of containment because they had not been aware of the concept in context when observation would have been appropriate. 'Concept by definition' is easy if 'concept by observation' has gone before.

To sum up, there is an obvious lack in understanding of the concept of containment in Chemistry as a result of a lack of basic chemical concepts and as a result of converse teaching in Mathematics, but we must really ask if the pupils are at fault. If the required background knowledge is not there, and if the concept depends on the theory of bonding, which is far too complex for S1, should we not re-think the content of S1 Chemistry?

2·7 Recommendations

1. Teachers must be more aware of their intentions to develop specific concepts and use the idea of a developing model - starting with a sufficiently simple model from which the pupil can organise his thoughts and use these as a working basis for developing specific concepts. So many concepts in science must be related to models of reality.
2. Teachers must ensure that pupils do not apply newly learned techniques and also newly learned words to new situations spontaneously by making more explicit the domain and limits of the techniques.
3. Teachers and pupils, as well as using labels for concepts, must discuss relevant aspects of the concepts so that there is no doubt in the pupil's mind; the role of language is very important in developing concepts and also in inter-relating facts and ideas of related concepts.
4. Teachers should try to relate concepts where possible so that a complete picture or explanation is given to pupils. e.g. Chemical reaction change in composition and change of properties should be related, for example:-

Chemical reaction	:	acid with water gives
Change of composition	:	hydroxonium ions accounting for
Change of properties	:	existence of acidic properties ↓

The ion concept is extremely important within this framework and must also be explained. Ausubel sums this up by saying that material learnt 'meaningfully' (i.e. in such a way that the new concepts it contains are related to the cognitive structure of the learner) is retained better over much longer periods than that which is learned by rote (i.e. 'non-meaningfully').[24]

CHAPTER 3

THE INTERPRETATION OF GRAPHS.

3·1 Introduction

In Science, numerical results of measurements are displayed using graphs and from these general theories can be validated or otherwise. Difficulties can be arithmetical or experimental since all measurements are inexact to some degree but an early appreciation of experimental error can be gained from graph drawing and also an appreciation of the underlying unit of principles involved.

It is, therefore, of great practical and theoretical importance that pupils can estimate and allow for uncertainties as early as possible. They should also be encouraged to speculate about the significance of the distribution of points; often they themselves can realise that the majority of points plotted are scattered about a straight line, the scattering being a result of experimental uncertainty. They can draw in a 'best' straight line and then go through the processes of interpolation and extrapolation getting real or actual values of the quantity being measured.

It is practically wise to say that experience in the technique of graph drawing and interpretation is of paramount importance to any science pupil. Evidence shows that there is a correlation between the experience of a class and scatter of its points [25] in using graphs to discover combining ratios.

3·2 Development of Graph Representation

Since a graph is only one of many forms of visual representation, development of graphs must follow mental growth of pupils. Piaget's research shows that distance conservation which is a prerequisite attainment for achievement of coordination concept is achieved at approximately seven years of age and the coordinate system concept is achieved at nine years of age.[26]

There are three stages in developing graph representation -

(i) Random approach - active approach using everyday objects

(ii) Helical approach - various types of charts introduced as representations on paper; axes and scaling

(iii) Topic development through graphs or graphs through topics introducing ideas of continuity and intervals of time; hence reading or interpolating of a graph.

Dodwell (1963) and Rivoire (1961)[26] have noted there is variability in age of emergence of coordinate system due to the way the task is presented.

The functions of graphs are as follows -

1) The main purpose of a graph is to give a visual display of experimental results, and it should be drawn as clearly as possible with suitably chosen scales.

2) Graphs are also often used to test an assumed relationship between two quantities or to discover a relationship between them.

3·3 Graph Drawing Process

The logical development of graph drawing interpretation is -

1) Choose a simple scale so that the experimental points are not all cramped together;
2) Give the graph a title;
3) Label axes clearly with name or symbol of the varying quantity;
4) State clearly the limit used on each scale;
5) From tabulated data draw the graph;
6) Interpret what is drawn;
7) Extrapolate by using 'common sense' to give - (a) straight line,
   (b) curve,
   (c) change in overall shape;
8) State significance of 'joined' points.

3·4 Preliminary Investigation

Since graph drawing is fundamental to Chemisrty and central to the organisation and interpretation of scientific data, it was decided to make a preliminary investigation to find out -

(i) what the concept of rate of change meant to junior pupils;

(ii) how pupils drew and interpreted 'simple' graphs.

The test designed was administered to two S1 classes (one good and one poor) and to two S2 classes (both good) all in one school. The test itself is in the Appendix, p67.

3·5 Results of the test for S1 and S2 pupils

Figures state the percentage who had the correct answer.

Question	Year 1st (N=26)	Year 2nd (N=35)
1	61·5%	88·6%
2	11·5%	80·0%
3(a)	57·7%	80·0%
(b)	61·5%	65·7%
(c)	65·4%	71·4%
(d)	42·3%	91·4%
(e)	46·2%	65·7%
(f)	38·5%	42·8%
(g)	57·7%	48·6%
4	42·3%	54·3%
5(i)	69·2%	97·1%
(ii)	7·7%	14·3%
6	34·6%	54·3%
7(i)	46·2%	77·1%
(ii)	57·7%	77·1%
(iii)	61·5%	80·0%
8(i)	42·3%	74·3%
(ii)	57·7%	94·3%
9(i)	50·0%	65·7%
(ii)	57·7%	28·6%
10(i)	73·1%	85·7%
(ii)	30·8%	45·7%
(iii)	15·4%	40·0%
(iv)	19·2%	40·0%
(v)	0	2·8%
11(i)	38·5%	31·4%
(ii)	42·3%	51·4%
12(i)	61·5%	71·4%
(ii)	19·2%	54·3%
(iii)	15·4%	34·3%
(iv)	15·4%	31·4%
(v)	11·5%	34·3%

3·6 Observations made from Results for S1 and S2 pupils

1. Concept of 'rate' presented confusion for a large proportion of junior pupils and so did rate of change particularly in a multivariate situation. See Question 1 results.

2. When making comparison between two 'simple' graphs different scales inhibited appreciation of the graphs. Steepness of the slope of the straight line joining two points was taken as a rate of change for a given time. See Question 7 results.

3. Calculation of a rate from a linear time graph was poor in junior school pupils. See Question 8 results.

4. Interpretation of graphs into real terms was poor. See Question 9 results. For 9(ii) S2 performance was not as good as S1. The better pupils tended to write answers involving a range - the obvious answer to them was probably wrong.

5. Interpolation for solubility graphs which were given was poor - even allowing for absolute error, values tended to be very inaccurate. See Questions 10, 11 and 12 results.

6. Extrapolation was very poor, but squared paper supplied in the question did not allow scales to be extended far enough. See Question 10(v) results.

The S2 classes were asked to rate the questions in the test and the following table gives results:-

Question /

Question	Easy	Difficult	Very Difficult
1	100%	-	-
2	100%	-	-
3	-	71·4%	28·6%
4	38·2%	52·9%	8·8%
5	68·6%	25·7%	5·7%
6	80·0%	11·4%	8·6%
7	88·2%	11·8%	-
8	97·1%	2·8%	-
9	74·3%	25·7%	-
10	42·8%	54·3%	2·8%
11	6·2%	75·0%	18·8%
12	31·2%	56·2%	12·5%

All questions involving interpolation were found difficult or very difficult by the majority, i.e. Questions 10, 11 and 12.

On the strength of these results, it was decided to make a more formal investigation into pupils' understanding and interpretation of graphs to see if the lack of ability was due to the graph as a method of representation or to an understanding of chemistry involved, or to both.

3·7 Experimental Design

A test was designed which had thirteen open-ended questions; see Appendix p.74 for questions, and p.79 for some of the response sheets.

The test was designed so that there were some questions using everyday terms and parallel ones using chemical terms. It was hoped that a measure of the pupils' performance in achieving the following objectives could be obtained, for Mathematics or for Chemistry.

Pupils should be able to:-

(i) obtain and tabulate data from a description of an experiment or given situation;

(ii) construct a graph from data;

(iii) interpolate from a graph;

(iv) extrapolate from a graph;

(v) state the significance of the lines on a graph.

The test was administered to 456 S4 pupils in eleven schools which were randomly selected. All pupils were taking 'O' grade Chemistry and 'O' grade Mathematics or Arithmetic courses and had just had their preliminary to 'O' grade examinations, or were due to have them. This meant they had covered most of the work in the 'O' grade syllabuses.

The results for each question were summarised in tables with frequencies for each school and then a summary of all results was made. The tables are in the Appendix p.84.

3·8 General Observations from Results

1. Axes were, in general, drawn but were not adequately labelled, nor were appropriate scales marked on before plotting points. See Questions 2 and 7 results.

2. There was inefficiency in constructing a data table from given information before use of data as coordinates of points to be plotted on a graph. See Question 3 results.

3. There was a great tendency to join points plotted without considering if the join was meaningful. See Question 3 results.

4. Points tended to be joined in dot-to-dot or wavy line fashion when a straight line of best fit would have been sensible. See Question 13 results.

5. In comparing two graphs, different scales inhibited appreciation of the graphs, hence rates of change given for a given time were incorrect. See Question 4 results.

6. For graphs relating to solubility, there was inaccuracy in plotting points, assuming that suitably scaled axes had previously been made. See Questions 7 and 8 results.

7. Interpolated values, even allowing for absolute error, tended to be very inaccurate. Also many pupils interpolated in reverse order. See Questions 6, 7, 10 and 12 results.

8. /

8. When Chemistry interacted with the process of interpolation there was a noticeable drop in performance. See Questions 7, 10 and 12 results.

9. Extrapolation was not good, even allowing for a large error. See Questions 7 and 9 results.

10. Few could extrapolate by using 'common sense' either given information or a related graph. There was a tendency to think of all graphs as being straight line ones. See Question 10 results.

3·9 Conclusions

1. There are problems with interpretation because the real physical existence of many graphs is not adequately explained - they tend to be thought of as visual representations in the abstract.

2. Variables must be defined clearly before interpolation can be done correctly. Lines of interpolation from one axis to another axis must be directed ones. This will ensure that interpolation from one variable to the other is not the reverse of what it should be.

3. Relationships between variables must be made as tangible as possible so that actual amounts are clearly visible and the concept of continuity arises naturally and spontaneously.

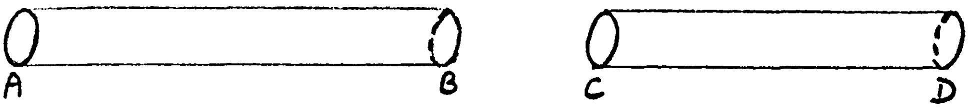
4. Development of graphs must follow closely the mental growth of the child.

5. Formal lessons on graph representation must include detailed instructions and explanation in both Mathematics and Chemistry so that topics in Chemistry can be more easily developed by using graphs where appropriate.

RATE AND INTERPRETATION OF GRAPHS (measuring rates)

Male / Female

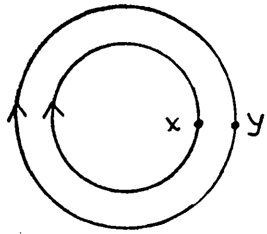
1. If AB and CD represent two separate tunnels,



Tom starts at A and moves towards B, and
Jerry " " C " " " D.

Tom and Jerry start at A and C respectively at the same time and finish at B and D respectively at the same time.

Was Tom slower or faster than Jerry ? ____________________

2. 

Laurel and Hardy start walking round the circular tracks shown in the direction indicated.

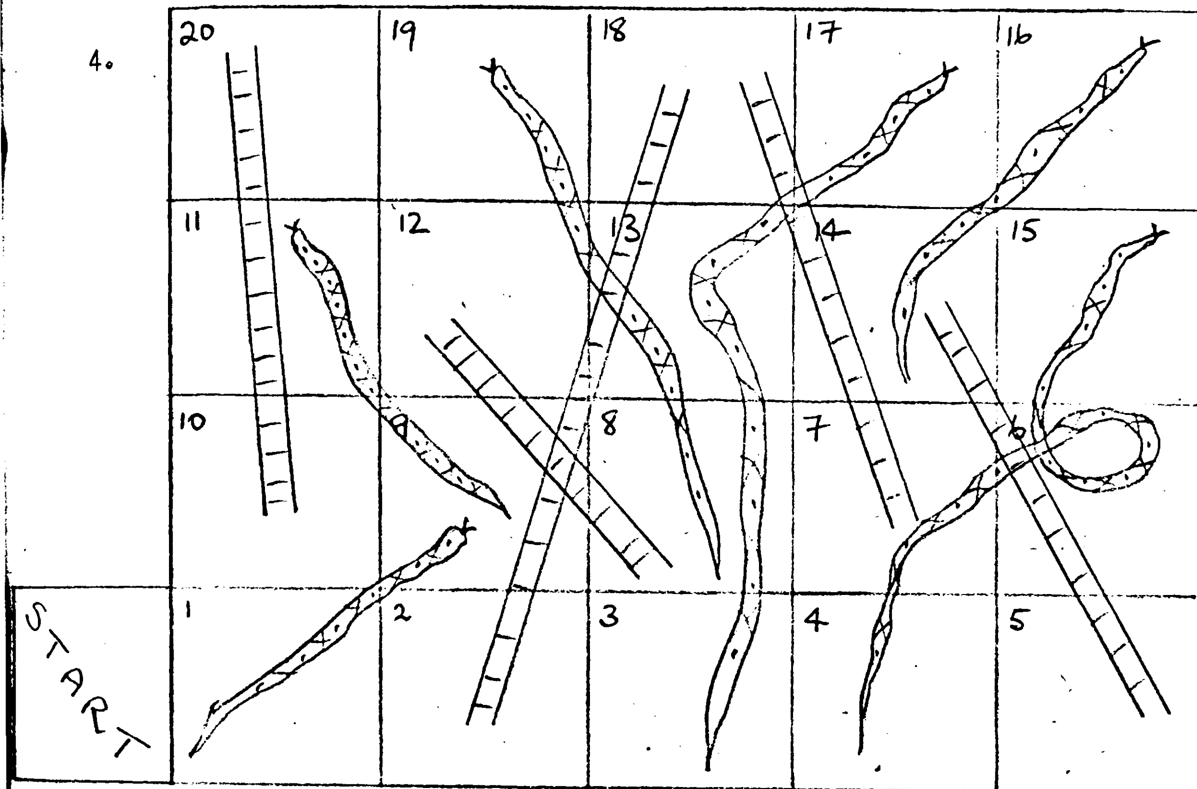
Laurel starts at X and Hardy at Y and they both finish together at X and Y respectively after walking once round the track.

Will Laurel or Hardy have moved more quickly? (they both took the same time) ____________

3. With which of the following do you associate rate with respect to time?

		YES	NO
(a)	a bicycle travelling from Edinburgh to Glasgow		
(b)	the number of newspapers you read once a week		
(c)	the growth of a plant		
(d)	the maximum number of cars that can be parked in a car park		
(e)	climbing a hill		
(f)	turning a wheel		
(g)	sales figures for ice-cream from year to year		

4. /

4. 

Two people play "snakes and ladders" from START i.e. into square 1 is the first move and try to reach square 20.

A starts and tosses, when it is his turn, the numbers

1, 2, 1, 4, 3, 5, 4, 4, 3, 2

B tosses

3, 1, 2, 5, 4, 3, 5, 6, 2.

Who is quicker in reaching square 20 ? _____

NOTE ;- in one move you can move down a snake and then "down" another snake
The last move into square 20 can be made only by tossing the number required. i.e. from square 19 a "1" is needed.

5. Does the tip of the hour hand of a clock move faster/slower than the tip of the minute hand ? Assume the hands ~~are of equal~~ length.

____

By how much? ________

6. If the minute hand of a clock which has stopped is 12" long and an insect starts at the tip of the hand and crawls towards the centre - the insect travels uniformly, i.e. it travels the same distance over regular periods of time - what is its rate of travelling if it takes one hour to complete the journey ?

________ per minute

7. /

7.

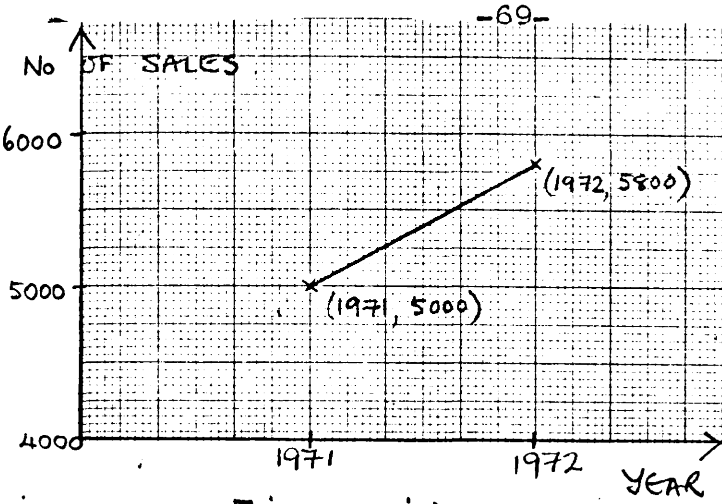


Figure (i)

This picture represents, sales figures for 1971 and 1972 for Wheat Honey Cereal.

What is the change in number of sales ?

________________ in one year.

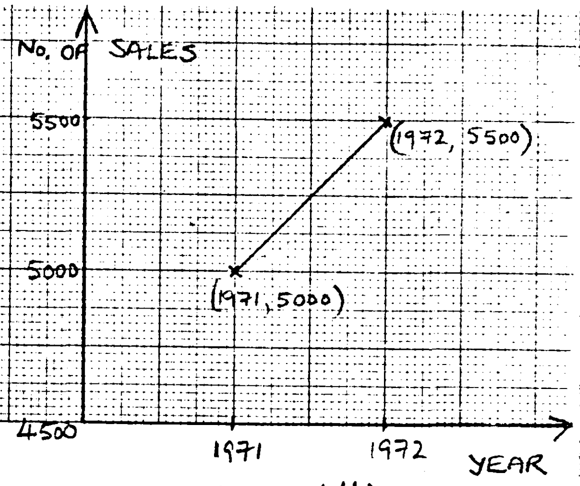


Figure (ii)

This picture represents sales figures for 1971 and 1972 for Wheat Honey Cereal.

What is the change in number of sales?

____________ in one year.

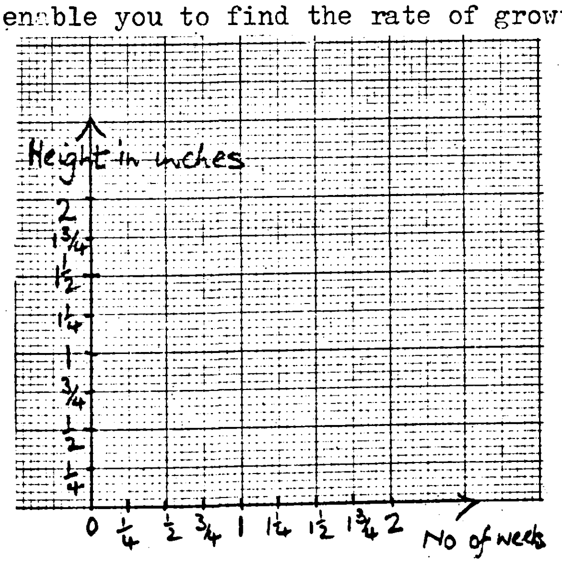
Which picture represents a bigger change in sales over the one year period ?

____

8. Figures have been obtained for calculating the rate of growth of a plant.

Number of weeks	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
Height in inches	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2

A graph or picture would show the connection between the two sets of numbers and enable you to find the rate of growth.



Draw what you think is a picture of the growth of the plant.

Then calculate (i) the rate of growth ____________

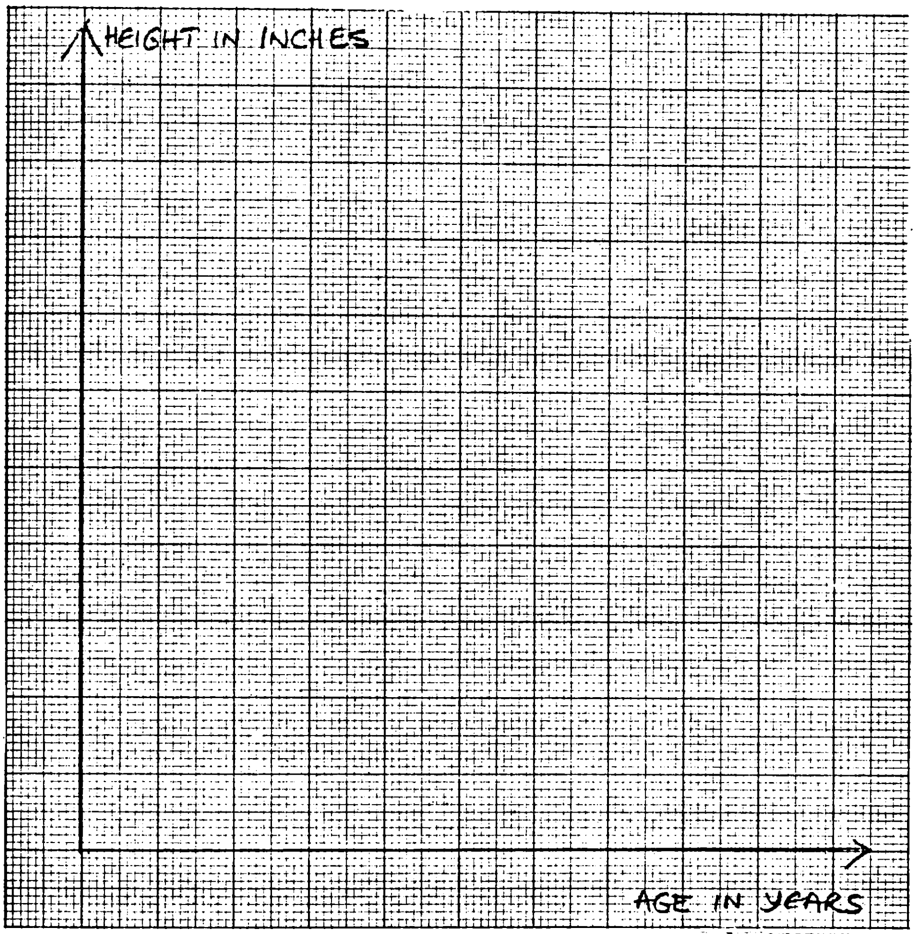
(ii) what height the plant would be after 3 weeks

9. You would expect a boy's height to increase as he gets older - would you expect him to grow at a steady rate as he gets older?

____

The following figures were collected and show a boy's height for each year from 9 - 19 years.

Age in years	9	10	11	12	13	14	15	16	17	18	19
Height in inches	50	52	52	54	57	60	62	$64\frac{1}{2}$	68	70	70



Draw a graph to represent these figures and thus his rate of growth from year to year.

(i) During which year was he growing fastest? __________

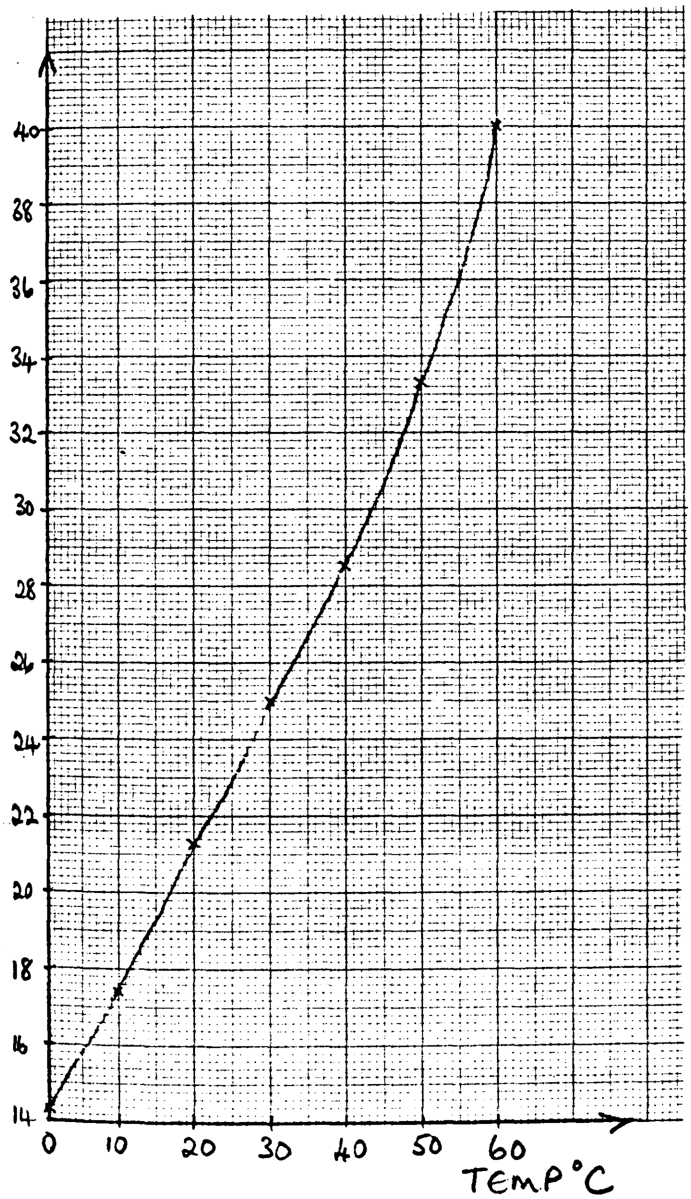
(ii) Estimate when he would stop growing __________

10. /

10. When a substance is dissolved in water, the amount which dissolves depends on the temperature, the size of the crystals used and the rate of stirring.

The following data was obtained for a certain substance (grain size and amount of stirring per minute were kept constant) and put in graph form.

Temperature	0°C	10°C	20°C	30°C	40°C	50°C	60°C
Amount dissolved in 100 ml water	14•3g	17•4g	20•7g	25g	28•5g	33•3g	40g



(i) How many grams of substance dissolved in 100 ml of water at 30°C ?

____

(ii) How many grams of substance would dissolve in 100 ml of water at 55°C ?

____

(iii) If I tried to dissolve 19g of substance in 100 ml of water, what temperature would be required?

____

(iv) To what temperature would you need to raise the water to enable you to dissolve 26•6g of substance ?

____

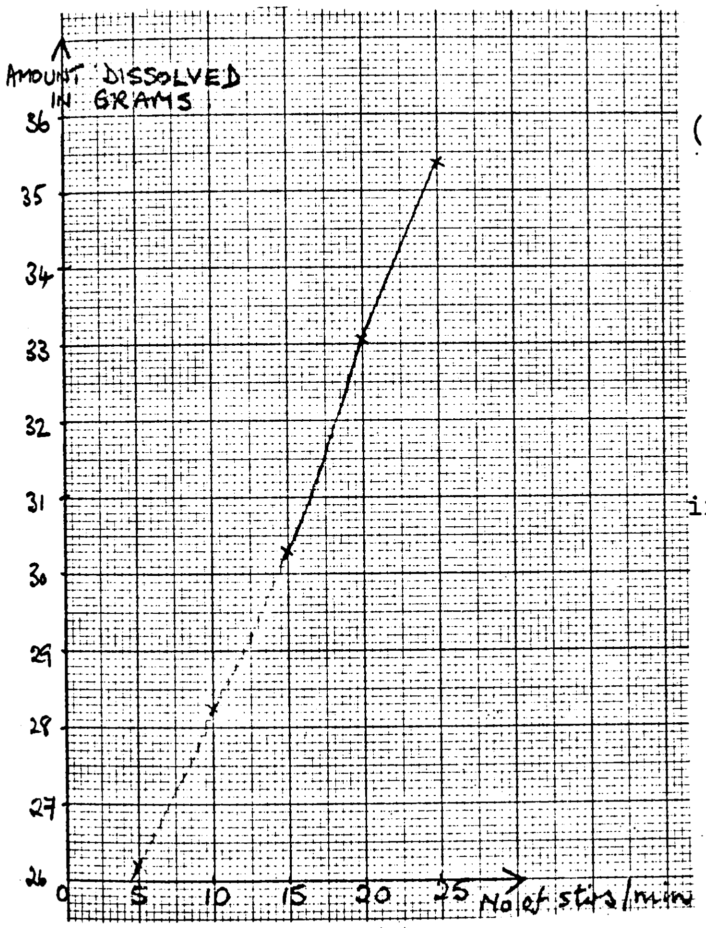
(v) Can you estimate from the graph how much substance would dissolve in 100 ml of water raised to 70°C ?

____

More /

11. More data was obtained for rate of dissolving of a substance at room temperature when grains were roughly the same size and a graph is drawn.

Amount of stirring/minute	5 times	10 times	15 times	20 times	25 times
Amount dissolved	26·2g	28·25g	30·3g	33·05g	35·4g



(i) How many grams of substance would you expect to dissolve if you stirred 12 times per minute?

____

(ii) If you wanted 31·4g to dissolve, how many times would you have to stir in one minute ?

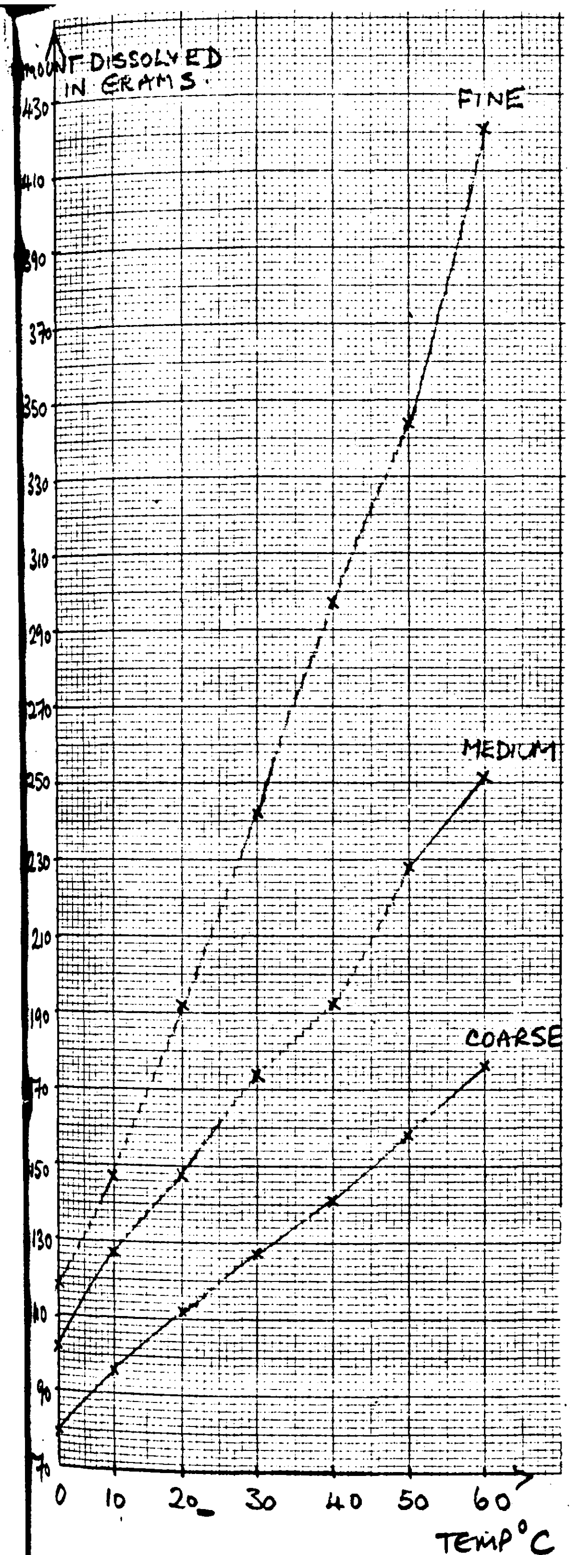
____

Examine table below. What conclusion can you come to about the rate of dissolving the crystals in relation to size of crystals when temperature and rate of stirring are kept constant ?

____

The following data was obtained and is graphed :-

Type of Crystal	"FINE"	"MEDIUM"	"COARSE"
(Temp.)			
0°C	118	102	79
10°C	147	127	96
20°C	192	148	112
30°C	242	174	127
40°C	297	192	141
50°C	344	228	158
60°C	421	251	176



12.

(i) Which is the fastest in dissolving:- fine/medium/coarse ?

____

(ii) Estimate the minimum temperature required to dissolve 200 g of "fine" crystals of the substance.

____

(iii) If this temperature was the temperature of a saturated solution with coarse crystals instead of fine, what weight of coarse crystals would dissolve ?

____

(iv) What is the minimum temperature required to make a saturated solution with 150 g medium crystals dissolved in 100 ml water?

____

(v) How much higher than in (iv) would the temperature have to be if 150g of coarse crystals were dissolved in 100 ml of water ?

____

INTERPRETATION OF GRAPHS

All answers are to be given on the attached sheets of squared paper.

(1) From the given graph you will see that intelligence seems "to reach the top of the mountain" around 25 years of age and to go steadily downhill after that.
If intelligence was replaced by enthusiasm for pop music, draw what you think the graph would look like.

(2) Locate, and join as instructed, the following points on a rectangular coordinate system.
Join (1,1) to (1,5) to (3,5) to (3,4) to (2,3) to (1,3).
Also join (2,3) to (4,1).
What shape have you formed?

(3) Suppose you have a total of 5p, made up of pence and half pence. How might this sum be made up? Complete the table started for you. Locate points of a coordinate system to find the relation between the numbers of each type of coin. What shape of graph have you formed this time?
A point P, has been marked - does it lie on the graph? Do its coordinates have any meaning? Should you join the points you located?

(4) The first graph represents sales figures for 1971 and 1972 for packets of 'Persuader' Biscuits while the second graph represents the figures for packets of 'Suggestive' Biscuits. What is the change in number of sales for each graph from 1971-1972? Which product is in fact more popular?

(5) Figures have been obtained for calculating the rate of growth of a plant.

No. of weeks	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
Height in ins.	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2

Draw what you think is a graph of the growth of the plant.

Then calculate:- (i) the rate of growth of the plant

(ii) what height the plant would be after three weeks if it continues to grow at the same rate ?

(iii) what is missing in the graph ?

(6) Here is a graph called a cooling curve. It shows the temperature of a body (say a mince pie which has been in a very hot oven) allowed to cool in a room at a temperature of 15°C.

(i) After 10 minutes of cooling what temperature is the pie?

(ii) How long does it take to cool right down?

(7) When a substance is dissolved in water, the amount which dissolves in a given time depends on the temperature, the size of the crystals used and the rate of stirring. The following data was obtained for a substance (grain size and amount of stirring/min. were kept constant).

Temperature	0°C	10°C	20°C	30°C	40°C	50°C	60°C
A mount of substance dissolved in 100 ml of water after 5 mins.	15g	22g	32g	45g	60g	80g	102g

Draw a graph to represent the solubility of the substance.

(i) How many grams of substance dissolved in 100 ml of water at 30°C ?

(ii) How many grams of substance would dissolve in 100 ml of water at 55°C ?

(iii) If I tried to dissolve 65g of substance in 100 ml of water under the same conditions, what temperature would be required? If this solution was cooled to 10°C how much substance would be thrown out of solution?

(iv) Can you estimate, from the graph, how much substance would dissolve in 100 ml of water raised to 70°C ?

(8) In general, solubility of a substance increases with temperature; for some solids, increase is greater than for others. Comparison in solubility for two or more solids can be made by use of a graph and indeed a mixture of two substances may be separated by making use of their different solubilities. The given graph represents the solubility of NaCl. Data for the solubility of KCl at different temperatures was obtained:-

Amount of substance dissolved in 100 ml of water	28·1	31·3	34·7	37·6	40·5	43·2	45·8
Temperature	0°C	10°C	20°C	30°C	40°C	50°C	60°C

Draw a graph of this data on the same set of axes used for the graph representing the solubility of NaCl.

(i) 10 ml of water is used in making saturated solutions of each substance at 60°C. One ml. of each solution was put on separate watchglasses and crystals were obtained by evaporation. In which case was there more solid?

(ii) 40 g of each of NaCl and KCl was added to separate samples of 100 g of water. Each mixture was heated to 50°C and kept at that temperature for some time. Which substance would have completely dissolved?

(9) All known radioactive isotopes follow the same pattern of decay; there is for each a period of time required for its radioactivity to drop to half of its initial value - this length of time is the half-life. It always has the same value for a given isotope whatever the conditions of temperature, pressure or nature of compound including it.

Here are a few points on the graph showing how rate of disintegration of radon $^{220}_{86}Rn$ decreases with time - can you complete the graph?

What shape is the graph?

Suppose you started with 50g of $^{220}_{86}Rn$ - what would the graph of its decay look like?

(10) To indicate how 'fast' a reaction can occur, let us suppose a marble chip is put into some dilute acid and weighings are made at regular intervals of time. If we graph total loss in weight against time, we would expect to get the graph given.

If the experiment was repeated with a marble chip of the same mass, now ground into small fragments before starting, how would you expect the graph to alter? Draw in as a dotted line what you would expect, and can you explain?

(i) How long would you expect to wait for the reaction to go to completion if the same mass of marble in any form was used?

(ii) If double volume of acid had been used with original chip, what would you expect to find ?

(iii) If more concentrated acid was used instead, what would you expect?

(11) The graph represents the distance a golf ball is from four successive holes of equal length in a round of golf.

(i) On which stroke and at which hole did the ball travel farthest?

(ii) At which hole did he play best?

(iii) At which hole did he have the longest drive?

(iv) At which hole did he have the shortest putt?

(v) When did he play his worst shot?

(vi) At which hole did he have his maximum score?

(12) Some white solid substance in a boiling tube was melted by immersing the tube in a beaker of hot water. When the substance had been liquid for some time the tube was removed from the hot water and allowed to cool in the atmosphere. The substance remained liquid. The tube was then placed in a beaker of cold water and a crystal of solid was added. The graph shows readings of temperature of contents of the tube and time.

(i) At what time did the solid begin to melt?

(ii) At what time was the solid completely molten?

(iii) When was the tube removed from the hot water bath?

(iv) When was the tube immersed in cold water?

(v) How long was it between taking out of hot water and putting into cold?

(vi) When was the crystal of solid added?

(13) The results of an experiment where the reaction of pieces of Ca with water was investigated are as follows:-

Weight of Ca (g)	Volume of hydrogen (cm^3) evolved
0•032	20
0•050	30
0•054	31
0•061	37
0•070	42
0•082	40
0•108	65
0•108	58
0•120	66
0•149	70
0•176	90
0•190	115

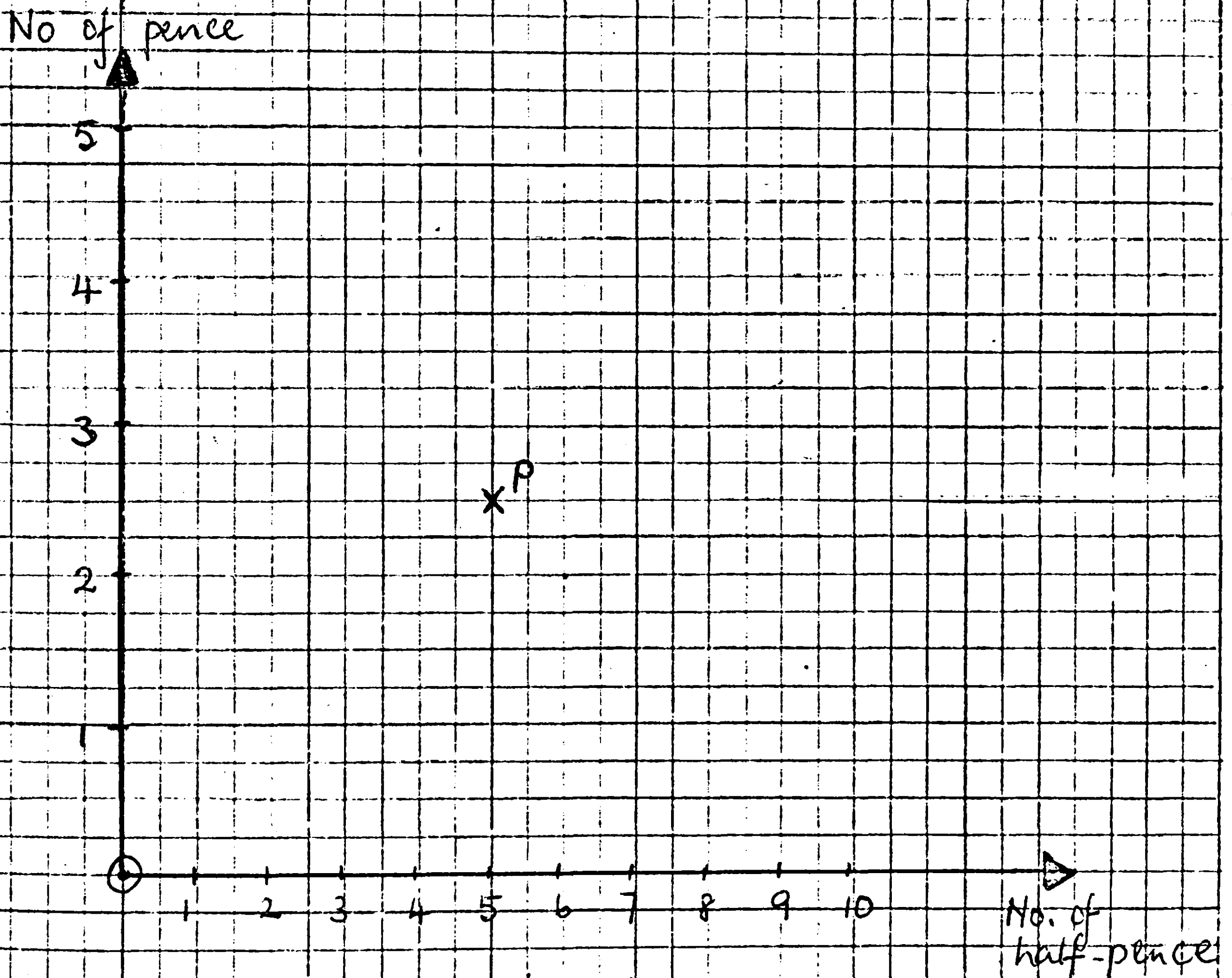
Draw a graph to represent the data.

(i) Can you explain the positions of the points located?

(ii) How much calcium would have to be used to produce 1 mole of hydrogen gas (24 l at room temperature and pressure) ?

(3)

No of pence	No of half-pence.
5	0



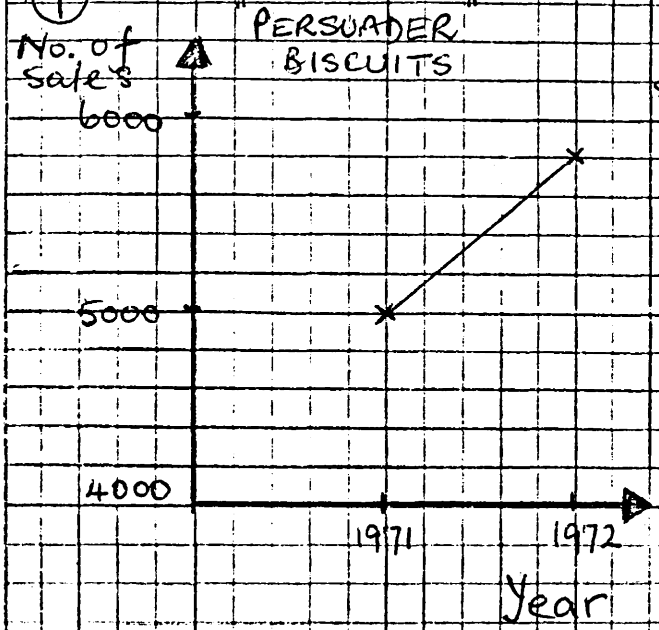
The shape this time is ____________

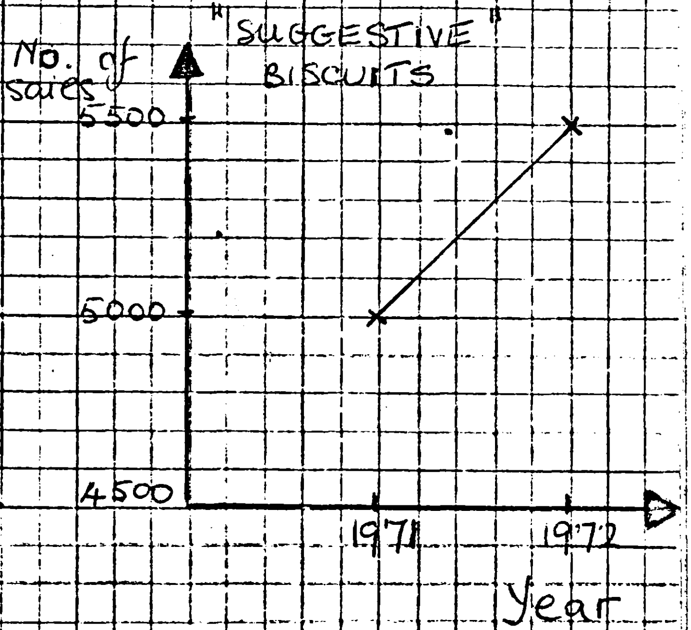
P ________ lie on the graph.

P's coordinates mean

I ________ have joined the points

(4)

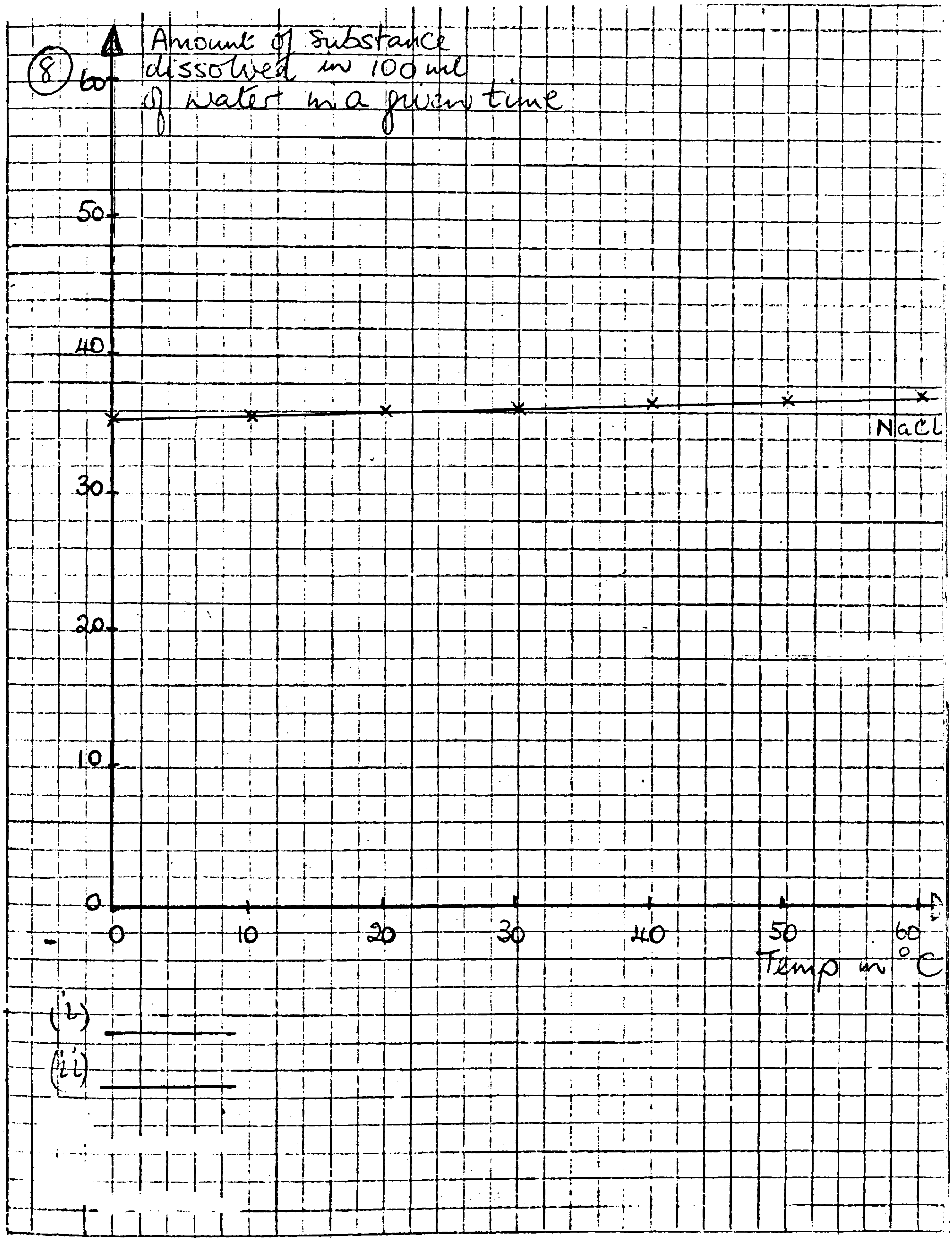


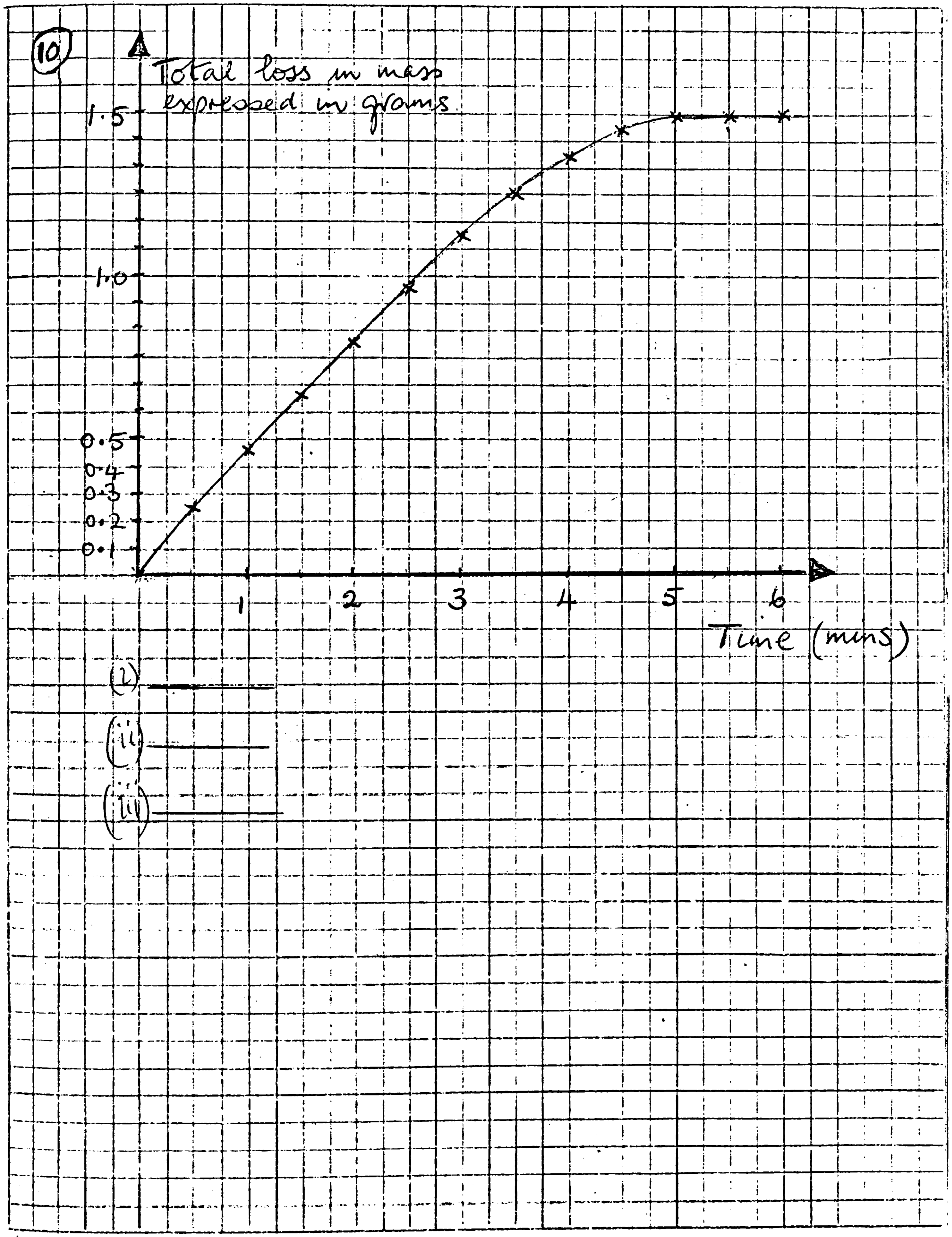


The change in no of sales for 1971 – 1972 is ________

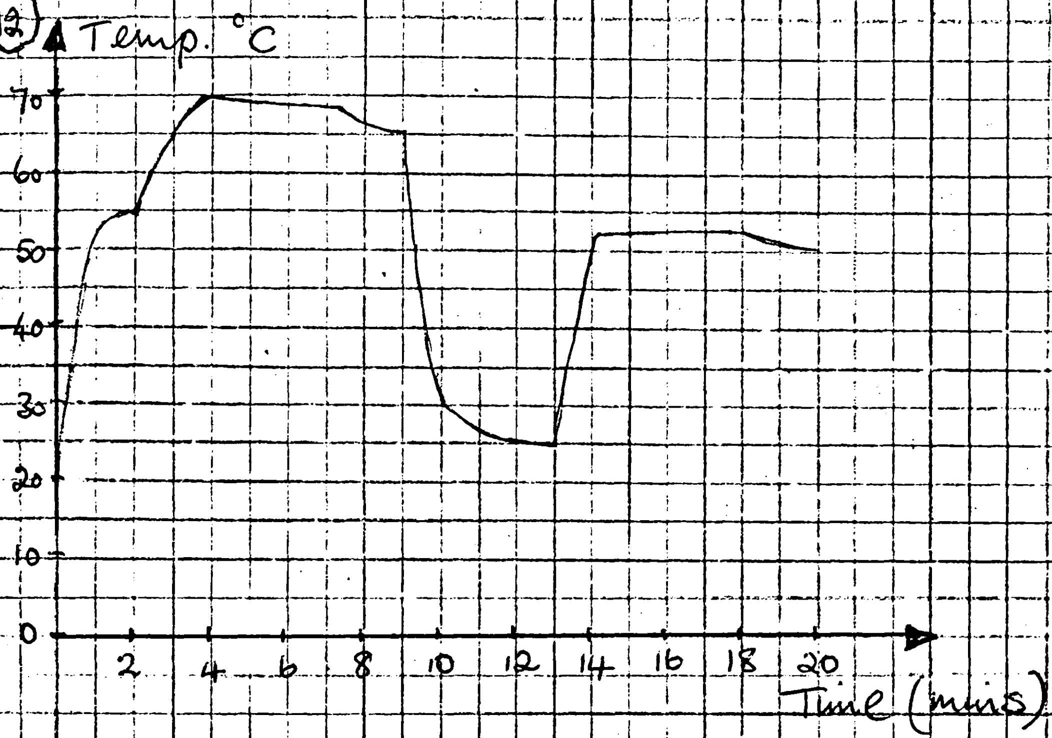
The change in no of sales for 1971 – 1972 is ________

________ is in fact more popular.


8
Amount of substance dissolved in 100 ml of water in a given time
60
50
40
30
20
10
0
NaCl
0
10
20
30
40
50
60
Temp in °C
(i)
(ii)


10
Total loss in mass expressed in grams
1.5
1.0
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
Time (mins)
(i)
(ii)
(iii)

(12)



(i) ______

(ii) ______

(iii) ______

(iv) ______

(v) ______

(vi) ______

QUESTION 1 RESULTS.

SCHOOL	NO OF PUPILS	+ve skew curve ending ≤ 50		+ve skew curve >50 and ≤60		+ve skew curve >60 and ≤70		SYMMETRIC CURVE		ODD-CURVE	
1	21	4		2		15					
2	44	5		5		28		2		4	
3	23			1		18		2		2	
4	38	9		1		15		8		5	
5	18	1		3		9		3		2	
6	55	8		6		33		2		6	
7	60	1		2		48		1		8	
8	40	4		3		24		2		7	
9	83	7		6		63		3		4	
10	40	6		4		28				2	
11	34	6		2		23				3	
TOTALS	456	51		35		304		23		43	

QUESTION 2 RESULTS.

SCHOOL	No of PUPILS	AXES WITH LABELS	NO AXES OR UNLABELLED	SCALES	No SCALES	POINTS	SOME POINTS	POINTS JOINED	GOT SHAPE	ANOTHER SHAPE	BLANK SHEET	COMPLETEY CORRECT
1	21	3	18	7	14	21		21	21			3
2	44	17	27	36	8	44		43	43			14
3	23	10	13	19	4	20	2	21	19	2		8
4	38	7	31	31	7	33		32	32			5
5	18	1	17	6	12	18		18	17			1
6	55	24	31	36	19	52		52	48			17
7	60	17	43	19	41	59		59	59			4
8	40	10	30	15	25	39	1	39	34			
9	83	10	72	35	48	72	6	75	63	3	1	3
10	40	14	26	19	21	39	1	40	39	1		2
11	34	9	24	9	25	32	1	32	31	1	1	1
TOTALS	456	122	332	232	224	429	11	432	411	7	2	58

12.7% CORRECT

QUESTION 3 RESULTS

SCHOOL	No OF PUPILS	DATA TABLE	MOST OF DATA	NO DATA	POINTS	SOME POINTS	POINTS JOINED	SHAPE A ST. LINE	ANOTHER SHAPE	'P' ON GRAPH	'P' NOT ON	P'S COORDS INTERPRETED CORRECTLY	ANOTHER INTERP. FOR P	JOINING POINTS VALID	BLANK SHEET	COMPLETELY CORRECT
1	21	17		4	21		17	20	1	21		14		10		9
2	44	40		3	39		25	39		37	2	29		16	1	12
3	23	14	4	3	18		17	17	1	18		12		14	2	6
4	38	33	2	1	33		22	24	6	27	6	27		10	2	14
5	18	10	2	6	14	1	13	12	1	13	1	3		14		
6	55	34	5	15	48		24	39	9	35	13	13	3	21	1	7
7	60	44	8	12	58		44	46	12	50	8	16	4	27	1	5
8	40	23	2	15	36	2	29	29	7	29	7	7	2	20		1
9	83	53	8	18	70	2	62	46	21	66	4	13	11	44	4	2
10	40	26	4	9	37		14	31	6	27	10	19	1	8	1	1
11	34	28		6	32		24	21	11	22	10	9	1	13		
TOTALS	456	322	35	92	406	5	291	324	75	345	61	162	22	197	12	57

12.5% CORRECT

QUESTION 7 RESULTS

SCHOOL	No OF PUPILS	CHANGE OF 800 FOR PERSUADER	ANOTHER No	CHANGE 500 FOR SUGGEST.	ANOTHER No.	PERSUADER MORE POPULAR	SUGGESTIVE MORE POPULAR	BLANK	COMPLETELY CORRECT
1	21	17	4	18	3	18	3		17
2	44	37	6	38	5	39	5		37
3	23	15	8	21	2	22	1		15
4	38	26	12	35	3	33	4		20
5	18	15	2	15	2	16		1	14
6	55	43	12	48	5	49	6		36
7	60	39	21	52	8	55	4		35
8	40	28	10	30	7	34	5	1	21
9	83	50	31	72	8	75	7	1	49
10	40	29	11	36	4	34	6		25
11	34	29	5	33	1	32	2		27
TOTALS	456	328	122	398	48	407	43	3	296
		71.9% CORRECT		87.3% CORRECT		89.3% CORRECT			64.9% CORRECT

QUESTION 5 RESULTS.

SCHOOL	No OF PUPILS	POINTS	SOME POINTS	POINTS JOINED	NO GRAPH	RATE 1"/WEEK	ANOTHER RATE	3" ESTIMATE	ANOTHER ESTIMATE	LABELS MISSING.	SOMETHING ELSE MISSING	BLANK	COMPLETELY CORRECT.
1	21	21		15		20	1	20	1	13			11
2	44	44		36		35	7	43	1	39	1		35
3	23	22	1	22		17	5	23		11	2		10
4	38	35	1	26		30	7	36	2	23	4		14
5	18	17		13		13	3	16	1	9	3	1	8
6	55	54		43	1	48	6	55		33	8		26
7	60	60		47		51	6	59	1	43	8		25
8	40	37		30	1	31	7	38	2	19	12		16
9	83	74		56	1	63	19	80	1	48	15	1	12
10	40	39		29		30	6	39	1	23	5		
11	34	33		27		28	5	33	1	21	1	1	9
TOTALS	456	436	2	344	3	366	72	442	11	282	59	3	166
						80.3% CORRECT		96.9% CORRECT					36.4% CORRECT

QUESTION 6 RESULTS

SCHOOL	No OF PUPILS	30°C	ANOTHER TEMP	≥25m	ANOTHER TIME	NO ANSWER	COMPLETELY CORRECT
1	21	21		3		18	3
2	44	43	1	24	15	3	
3	23	22	1	15	6		
4	38	34	4	27	11		
5	18	18		7	10		7
6	55	51	4	28	20	5	24
7	60	59	1	24	21	12	22
8	40	39	1	22	10	6	23
9	83	79	4	40	33	3	39
10	40	39	1	13	17	6	9
11	34	32	2	18	15		16
TOTALS	456	437	19	221	158	53	143

95.8% CORRECT (30°C)

31.3% CORRECT (COMPLETELY CORRECT)

QUESTION 7 RESULTS

SCHOOL	NO OF PUPILS	AXES WITH LABELS	NO AXES OR UNLABELLED	SCALES	SCALES AS X AND Y VALUES	POINTS	SOME POINTS	POINTS JOINED	(i) 45g	ANOTHER VALUE	(ii) 90	ANOTHER VALUE	(iii) 43	ANOTHER VALUE	(iv) 120	ANOTHER VALUE	BLANK	COMPLETELY CORRECT
1	21	19	2	21		19		19	20		15	1	18	2	12	4		
2	44	40	3	41	2	42		39	40		29	10	37	2	22	18	1	
3	23	22	1	23		20	3	22	20	2	16	6	20		10	11		
4	38	28	10	36		37		36	35	2	30	6	33	2	18	16		
5	18	16	2	16		16		15	17		15	3	13	5	8	8		3
6	55	51	3	52		49		45	53	1	40	12	37	11	14	35	1	6
7	60	54	6	60		58		54	59	1	52	6	44	12	28	27		11
8	40	31	8	36		34		30	35	2	26	8	28	5	13	20	1	1
9	83	75	6	67	8	68		58	76	5	63	14	60	12	29	41	2	7
10	40	33	6	39	1	38		34	36	4	29	11	23	12	11	26	1	6
11	34	27	7	33		32		28	30	3	25	8	26	7	18	10		
TOTALS	456	396	54	424	11	413	3	380	421	20	340	85	339	70	183	216	6	34
									92.3% CORRECT		74.6% CORRECT		74.3% CORRECT		40.1% CORRECT			7.5% CORRECT

QUESTION 8 RESULTS

SCHOOL	No OF PUPILS	POINTS	SOME POINTS	POINTS WITH COORDS INTERCHANGED	POINTS JOINED	LINE LABELLED	(i) KCl	ANOTHER ANSWER	(ii) KCl	ANOTHER ANSWER	BLANK	CORRECT BUT NO LABEL ON LINE	COMPLETELY CORRECT
1	21	20			20	9	15		10	3			
2	44	43			43	17	26		17	4	1		
3	23	23			23	16	10	3	11	1			
4	38	35			32	7	17	1	21		3	7	3
5	18	15			11	3	5	1	7		2		
6	55	53		1	47	15	32	2	26	2	1	5	7
7	60	57		3	55	14	34	2	24	6		8	7
8	40	35	1		32	5	18	3	8	3		4	1
9	83	68	3		60	15	35	1	27	2	11	5	3
10	40	37		1	33	11	25		16	1	2	5	6
11	34	32			29	10	17	1	16	1	1	3	3
TOTALS	456	418	4	5	385	122	234	14	183	23	21	37	30
							51.3% CORRECT		40.1% CORRECT				6.6% CORRECT

QUESTION 9 RESULTS.

SCHOOL	No of PUPILS	2 or 3 POINTS	POINTS JOINED	ROUGH LINE POINTS NOT CLEAR	SHAPE HYPERBOLA	SHAPE PARABOLA	SHAPE CURVE	SHAPE ST. LINE	ANOTHER SHAPE	For Rn SAME SHAPE	SAME ST. LINE	ANOTHER SHAPE	BLANK	COMPLETELY CORRECT
1	21	13	12	3	5	8	3	2		9			1	
2	44	21	19			6	15	11	2	7	6		7	
3	23	13	12	2	3	1	9	4	1	7	2		4	
4	38	15	14				22	11	1	7	8		3	1
5	18	4	3	1			6	6	1	3	2		3	
6	55	20	7	6	10	12	7	11	14	9	10	1	15	4
7	60	21	16	6			27	12		16	4	2	13	
8	40	27	24	2		4	21	3		9		1	5	
9	83	27	26	5	1		31	17	3	10	12	1	23	
10	40	19	14	2		1	19	7	3	7	3	4	8	
11	34	13	10	5		1	14	11	1	8	5	2	3	
TOTALS	456	193	157	32	19	33	174	95	26	92	52	11	85	5

QUESTION 10 RESULTS

SCHOOL	No OF PUPILS	CURVE 'ABOVE'	CURVE 'BELOW'	SAME CURVE	ANOTHER CURVE	(i) 5m	ANOTHER TIME	(ii) SAME TIME	TWICE AS FAST	ANOTHER TIME	(iii) FASTER	TWICE AS FAST	SLOWER	BLANK	COMPLETELY CORRECT
1	21	18	3			3	12	14	5	2	19				
2	44	35	3	2	2	9	14	20	9	9	32	3		2	
3	23	13	4		4	5	3	9	2	3	14			2	2
4	38	26	4	2	2	9	10	13	5	13	26	3		4	4
5	18	8	3	3	2	5	7	8	3	3	12			2	1
6	55	37	11	3	1	8	18	27	8	10	41	1		3	2
7	60	40	5	3	8	11	26	18	17	12	45	3		4	2
8	40	27	6		2	3	16	17	3	5	25	3		5	1
9	83	51	7	1	9	13	35	33	8	19	48	4		15	2
10	40	22	9	2	3	6	17	23	4	4	29	1	1	4	1
11	34	26	3	1	3	5	18	14	5	7	24		1	1	1
TOTALS	456	303	58	17	36	77	176	196	69	87	315	18	2	42	16
						16.9% CORRECT		43.0% CORRECT			69.1% CORRECT				3.5% CORRECT

QUESTION 11
RESULTS.

SCHOOL	NO OF PUPILS	(i) 1ST STROKE 4TH HOLE	5TH STROKE 4TH HOLE	ANOTHER	(ii) 1ST	ANOTHER	(iii) 4TH HOLE	ANOTHER	(iv) 2ND HOLE	1ST HOLE	ANOTHER	(v) 4TH STROKE 3RD HOLE	ANOTHER	(vi) 3RD HOLE	1ST HOLE	ANOTHER	BLANK	COMPLETELY CORRECT
1	21	11		6	20	1	19	2	4	11	5	5	7	10	7	3		
2	44	30	1	1	42	3	40	1	19	18	8	15	12	29	15			
3	23	10	2	3	16	4	15	3	2	10	8	5	7	7	6	5	3	1
4	38	23	1	2	33	5	32	6	9	10	19	9	5	21	12	5		1
5	18	12	1	2	12	4	13	3	3	9	4	6	2	8	4	3	1	1
6	55	32	1	2	48	7	43	11	10	27	15	19	9	29	16	5		9
7	60	35	7	2	56	4	56	3	19	25	14	23	11	36	20	3		4
8	40	26	1	2	32	3	34		9	23	4	9	9	20	7	7	4	2
9	83	35	15	1	65	8	58	13	20	27	25	15	14	29	32	10	7	
10	40	25	3	2	33	3	31	5	13	13	10	9	8	19	12	4	3	2
11	34	20	2	1	25	4	26	3	13	12	4	6	6	16	10	2		
TOTALS	456	259	34	24	382	46	367	50	121	185	116	121	90	224	141	47	18	20
		56.8% CORRECT			83.8% CORRECT		80.5% CORRECT		26.5% CORRECT			26.5% CORRECT		80% CORRECT				4.4% CORRECT

QUESTION 12 RESULTS.

SCHOOL	No OF PUPILS	(i) 1m	0m	2m	ANOTHER TIME	(ii) 2m	4m	ANOTHER TIME	(iii) 7m	4m	ANOTHER TIME	(iv) 9m	ANOTHER TIME	(v) 2m	ANOTHER TIME	(vi) 13m	ANOTHER TIME	BLANK	COMPLETELY CORRECT.
1	21	2	5	10	3	4	13	3	3	10	7	11	7	2	15	9	9		
2	44	3	3	18	13	5	22	14	9	13	10	20	22	9	30	25	26	1	
3	23	1	4	7	4	4	8	3	5	6	6	11	4	7	8	7	9	5	
4	38	4	2	12	13		18	12	7	10	15	21	6	8	21	16	14	1	
5	18	2		6	6	2	3	3	1	4	5	7	4	1	7	3	7	4	
6	55	14	5	18	4	6	30	5	5	23	16	27	15	8	38	36	11	4	
7	60	4	10	15	11	11	25	9	8	27	11	36	11	5	45	30	28	5	
8	40	4	3	16	4	4	19	2	3	13	12	22	8	5	26	14	14	6	
9	83	1	18	15	19	2	31	11	6	19	22	24	26	9	44	25	27	20	
10	40	4	10	11	4	7	18	3	12	13	6	27	6	11	20	22	10	4	
11	34	1	7	8	8	2	16	3	6	9	7	15	9	6	15	16	7	5	
TOTALS	456	40	67	136	89	47	203	68	65	147	117	221	118	71	269	203	162	55	0
		8·8% CORRECT				10·3% CORRECT			14·3% CORRECT			48·5% CORRECT		15·6% CORRECT		44·5% CORRECT			

QUESTION 13 RESULTS

SCHOOL	No OF PUPILS	POINTS	SOME POINTS	POINT TO POINT JOINING	ST. LINE OF BEST FIT	ROUGH LINE POINTS NOT CLEAR	(i) VOLUME OF H ∝ WEIGHT OF Ca	MORE Ca MORE H	EXPERIMENTAL ERROR	INACCURATE MEASURES	OTHER REASONS	(ii) 40g	ANOTHER VALUE	BLANK	COMPLETELY CORRECT
1	21	14		12								1	9		
2	44	31	12	26					2		3	2	16		
3	23	10	4	5						1			3	9	
4	38	20	12	4		1		3	4				19	5	
5	18	7	4	6							1		9	5	
6	55	31	17	27	2	1	2	3	5		1	2	26	2	
7	60	47	9	39	5				4	2	2	1	28	3	
8	40	23	10	18	1				1				4	5	
9	83	38	17	30				3			5	1	19	24	
10	40	28	6	18	2	1			5	1	6	1	24	5	
11	34	11	12	7	2			2	2			1	8	11	
TOTALS	456	260	103	202	12	3	2	11	23	4	18	9	165	69	0

CHAPTER 4

RATIO AND PROPORTION _ WHAT THE PUPILS CAN AND CANNOT DO.

4·1 Introduction - Conceptual development

Many topics in Mathematics which are linked to Chemistry appear to be conceptually difficult because there has been a shift of emphasis from the development of computational skills in Mathematics to conceptual or meaningful learning of the subject, and therefore it is imperative that development of the Mathematics is in a logical, practical and psychological order.

Piaget's developmental theory for intellectual growth can be used as a model for understanding educational processes. Shayer[27] suggests Piaget's stages correlate with mental age rather than chronological age. Lovell [28] suggests the following stages based on Piaget:-

1) Up to age of 6, the child interacts with persons and objects and experiences varied situations, i.e. his knowledge of the world is abstracted directly from objects, persons or events.

2) At 7 or 8, the child's thinking becomes more systematised and logical, i.e. he can classify and seriate and is entering the period of concrete operational thought.

3) At 8 - 12, the child's thinking is more flexible but he still makes exact relations between mental actions which bear directly on things. He forms first order relations which are inadequate for concepts required by science.

4) At 14 - 15, the child develops deductive ability in his thinking. He can form second order relations, i.e. can set up a hypothesis and deduce what would happen if it was held true. He is entering the stage of formal operational thought.

One /

One characteristic feature of this stage is that the pupil is restricted to relations with one variable at the beginning of formal thinking and later can work with one variable while others are held constant.

The research embodied in this chapter endeavours to find out if there is an absence of the hypothetical formal thinking required in Chemistry and Mathematics courses, in particular for the topic of proportionality - this being, perhaps, one of the reasons why this topic is conceptually difficult for pupils.

4·2 Difficulty Aspects in Ratio and Proportion

It is difficult to assess how far education can advance the onset of the stages in development stated above, and so it was decided to try and define areas of difficulty in Ratio and Proportion in terms of -

i) Mathematics involved	-	either by acquiring a technique or in understanding an idea
ii) Education involved	-	the teaching process
iii) Psychology involved	-	either a motivational problem or individual differences in ways of forming abstract ideas

Piaget[29] defined proportionality as a qualitative structure that facilitates the understanding of complex physical systems containing many compensating factors or forces.

Piaget and Inhelder[29] suggested that density and volume conservation are principal indices for concept of proportionality as both presuppose the same cognitive skill.

4·3 Topics in Chemistry requiring Mastery of the Technique of Ratio and Proportion

1) The gram, atom and mole require the concept of proportionality. The mole concept has been investigated by I.M. Duncan [6] and he has made the recommendation that the mole has too high a conceptual level for pupils in S3.

2) Atomic weights which are introduced as 'proportional' averages.

3) Processes of neutralisation and precipitation involve the use of proportion technique to calculate the volume of a given molar solution when a balanced equation is used.

4) Simple volumetric work involving acids and bases requires proportion in the calculation of an unknown molarity or of an unknown volume.

4·4 Design of the Test in Ratio and Proportion

It was decided that the test must :-

1) be relevant to the curriculum structure of the school

2) allow pupils of wide ability range to attempt answers which they felt were satisfactory

3) be designed to measure mental processes of the pupils' in relation to the immediate area of study since recall was no test of mental ability.

The test constructed was objective and had 54 items; 24 were mathematical, some of which involved the schema of ratio or arithmetic series or geometric series and the rest the schema of proportion; 20 were chemical, the majority of which involved proportion and some were analogous to some of the mathematical ones; the remaining 10 were physics, 9 were based on two Inhelder and Piaget experiments where the ability to translate visually and verbally was imperative before understanding could precede a solution involving ideas of Ratio and Proportion.

4.5 Aim of the test

The main aim of the test was to find out what the pupils could do and also to obtain an order of merit for the test as a whole, for the Mathematics 'proportion' items and for the Chemistry 'proportion' items, i.e. to obtain a measure of mathematical ability and related chemical ability. The secondary aim was from an item by item analysis to define a 'breakdown point' in the pupils' attempts to answer a proportion problem in Mathematics and in Chemistry.

4·6 Construction and Administration of the Test

Most forms of testing require an ability to read fluently with comprehension and an ability to hold the questions' information in mind while formulating an answer. Therefore, a pupil <u>must</u> be able to visualise mentally, read and write, or he must possess reading ability, visual imagery, recall and thought processes and writing ability. Research at Heriot Watt University[30] suggests that objective tests are possibly biassed towards students of high verbal ability.

To help eliminate most of these factors, the test would have to be given verbally, any apparatus should be there and operable, data called out and liberal use of simple diagrams provided. In this instance, any of these suggestions were not practical as schools used for the investigation covered a wide area and reliance was placed on the class teacher to administer the test.

Bearing all this in mind, the test was constructed so that items used simple language in the stem, responses were numerical whenever possible and diagrams were explicit. The test was an instrument for measuring ability to handle proportion and the necessary pre-requisite concepts of ratio, volume, area, and series. (The test is in the Appendix, p 118)

The test was given to a total of 345 S4 pupils in nine randomly selected schools. The pupils were pre 'O' grade Chemistry and 'O' grade Mathematics or Arithmetic. The time allowed for the test was one hour. Pupils answered items by writing A, B, C or D on an answer sheet. Their responses were then transferred to computer cards and a complete analysis was done by computer. A 'don't know' option was not provided for each item since the main aim of the test was to obtain an order of merit - if pupils did not know what a response was, they left a blank.

4·7 Results of the Test

The computer printout of the results of the test gave the following:-

For each pupil -

i) his score on the whole test

ii) his score on the items which were mathematical and involved ratio and proportion

iii) his score on the items which were chemical and involved ratio and proportion.

For each item -

i) the frequencies of responses for A, B, C and D and of number of responses

ii) the facility value, i.e. the fraction (expressed as a decimal) of the candidates choosing the key or correct answer

iii) the discriminating power, i.e. the difference between the facility value for the top third of the candidates (on the test as a whole) and the bottom third.

The item results were recorded on the test copy - see Appendix p 118.

4·8 <u>Analysis of the Results</u>

For each school, the mean score and standard deviation were calculated for the whole test for the Mathematics items involving ratio and proportion, and for the Chemistry items involving ratio and proportion. The table below shows the results for the nine schools.

School	Number of Pupils	Whole Test $(\overline{54})$	Maths Items $(\overline{15})$	Chem. Items $(\overline{15})$	Difference between Maths and Chemistry
1	16	$\bar{X}$ = 29·37	10·06	7·50	Significant at 1% level
		s = 6·12	2·82	2·48	
2	6	$\bar{X}$ = 30·00	9·83	8·17	Not significant
		s = 7·92	3·54	3·37	
3	50	$\bar{X}$ = 33·48	11·18	8·72	Significant at 1% level
		s = 6·54	3·03	2·64	
4	50	$\bar{X}$ = 37·42	12·50	9·72	Significant at 1% level
		s = 7·35	2·31	3·37	
5	55	$\bar{X}$ = 32·42	10·80	7·62	Significant at 1% level
		s = 6·45	2·84	2·33	
6	58	$\bar{X}$ = 33·76	11·43	8·76	Significant at 1% level
		s = 6·36	2·44	2·76	
7	44	$\bar{X}$ = 29·75	9·80	7·48	Significant at 1% level
		s = 10·20	3·66	3·53	
8	19	$\bar{X}$ = 40·47	12·58	12·32	Not significant
		s = 5·88	2·24	2·69	
9	47	$\bar{X}$ = 30·68	10·70	7·98	Significant at 1% level
		s = 6·85	2·87	3·01	
TOTAL	345	$\bar{X}$ = 33·21	11·11	8·57	Significant at 1% level
		s = 7·72	2·94	3·11	

<u>Table 4·1</u>

From /

From these statistics, it was possible to test the null hypothesis -

H_0 : There was no difference in the mean scores for the whole test for the nine samples used i.e. $\mu_1 = \mu_2 = \mu_3 = \dots\dots\dots = \mu_9$

against the alternative hypothesis -

H_1 : There was a difference in the mean scores for the whole test for the nine samples used i.e. $\mu_1 \neq \mu_2 \neq \mu_3 \neq \dots\dots\dots \neq \mu_9$

This test was done using a one-way analysis of variance technique. The result of the test showed that the calculated $F_{8,336}$ value was significant at the 1% value and so H_0 was rejected as a true statement and H_1 was accepted.

The test of H_0 was repeated using only the results for schools 3, 5, 6, 7 and 9 which were known to be comprehensive and where $N > 30$. In this case H_0 was accepted as true and H_1 was rejected. This meant that for the 'comprehensive' schools presenting samples with $N > 30$, the independent samples had been randomly drawn from a normal population with equal variances and there was no difference in the mean scores for these samples. i.e. The samples used with $N > 30$ were sufficiently representative of the total school population, in that they formed a homogeneous group. (Note that school 4 was omitted since it had only just changed to being comprehensive from being selective.)

The one-way analysis of variance test was made on the results for the Mathematics part of the test for schools 3, 5, 6, 7 and 9, and on the results for the Chemistry part of the test for schools 3, 5, 6, 7 and 9.

It was found that -

1) /

1) There was no difference in the mean scores for the Mathematics part of the test for schools 3, 5, 6, 7 and 9; i.e. these schools presented samples whose ability to do Mathematics proportion problems was approximately equal.

2) There was no difference in the mean scores for the Chemistry part of the test for schools 3, 5, 6, 7 and 9.

In making further analyses of the results, the following assumptions were thus made:-

1) Scores were sampled at random

2) From normal populations

3) With equal variances

4) The different samples from the nine schools were independent

5) For $N > 30$, the samples used had approximately equal ability in Mathematics and approximately equal ability in Chemistry.

Pupil scores on the whole test were compared with scores on the Mathematics part and on the Chemistry part by calculating for each school Pearson's product moment correlation coefficients. Results were as follows:-

School /

School	Number of Pupils	r for total v. Maths scores	r for total v. Chem. scores	r for Maths v. Chem. scores
1	16	0·84	0·76	0·39
2	6	0·96	0·88	0·87
3	50	0·83	0·73	0·43
4	50	0·79	0·88	0·59
5	55	0·87	0·65	0·44
6	58	0·83	0·79	0·61
7	44	0·89	0·91	0·72
8	19	0·74	0·805	0·47
9	47	0·77	0·74	0·42
TOTAL	345	Overall 0·86	0·83	0·58

Table 4·2

Values for r indicated that Mathematics scores and Chemistry scores were alike with respect to accuracy in predicting the total score for the test, i.e. Mathematics and Chemistry were of equal importance in prediction of the total score. For two schools, namely 1 and 8, the value of r for Mathematics v. Chemistry scores was not significantly different from r = 0 at 1% level using tables[31] but it was considered reasonable that this was due to sampling fluctuation since in both cases N was small (i.e. < 30). In all other schools the sample r values were significantly different from zero at the 1% level and so were overall values for r, therefore the chance explanation of the results was rejected. There was, however, a noticeable drop in the value for r in the last column compared with the other two for each school where $N > 30$ meaning that the 'tie-up' between Mathematics and Chemistry scores was not as good as each with the total score. i.e. A 'good' score in Mathematics did not necessarily imply a 'good' score in Chemistry. A scatter diagram - see p130 Appendix - showed more clearly the Mathematics/Chemistry scores relationship.

Consistency /

Consistency of measurement is the extent to which test scores were free from chance errors and this measure of reliability of the test was calculated from the figures in Table 4·2. The coefficient of reliability calculated was the split half coefficient of reliability. This measure of internal consistency indicated how the test placed each pupil relative to others in the sample. The formula used was :-

$$r_{11} = \frac{2r_{\frac{1}{2}\frac{1}{2}}}{1+r_{\frac{1}{2}\frac{1}{2}}}$$

r_{11} = measure of reliability of the whole test

$r_{\frac{1}{2}\frac{1}{2}}$ = correlation coefficient between the two 'half' tests, in this case the Mathematics and Chemistry parts

The value for r_{11} was 0·73

A further check was made on the reliability using Kuder Richardson method based on the consistency of performance on items which were scored dichotomously. This was done since there is often unreliability in measures obtained by using a multiple choice test. Here item statistics were used to calculate the reliability coefficient.

$$r_{KR} = \frac{n}{n-1}\left(\frac{\sigma_t^2 - \sum pq}{\sigma_t^2}\right)$$

n = number of items

σ_t = standard deviation of total scores on the test

p = proportion passing each item

q = 1 - p = proportion failing each item

The value for r_{KR} was 0·85

The values for r_{11} and r_{KR} showed close agreement and thus it was assumed that the test was a reliable measure of the pupil's ability to do problems /

problems involving proportionality. To establish the validity of the test, a correlation between test scores and an external criterion, e.g. 'O' grade scores, would have to be made. This was done in 4·9, for three out of the nine schools who provided the necessary information.

4·9 Within School Analysis of Results and Comparison with 'O' grade Preliminary Scores

The mean scores in Mathematics and Chemistry for pupils from the nine schools were compared using a 't' test,[32] where N < 30 or a 'z' test [33] where N > 30 - see Table 4·1 for data. In seven out of the nine schools the mean score for Mathematics was significantly better at the 1% level than the mean score for Chemistry (refer to Table 4·1). It looked as if the overall picture from the test results was that a significantly higher proportion of pupils had the Mathematics items correct than had the Chemistry items correct.

Three schools out of the nine provided enough information for the pupils' performance in the test to be compared with their school performance. The following table shows the results.

Paired Correlation Coefficients (product moment)

	Test Total Score	Test Maths Score	Test Chem. Score	Maths Exam Score	Chem. Exam Score
Test Total Score		0·79(0·74)[0·77]	0·88(0·805)[0·74]	0·60(0·61)[0·46]	0·46(0·44)[0·53]
Test Maths Score			0·59(0·47)[0·42]	[x] 0·42(0·71)[0·36]	
Test Chem. Score					(x) 0·54(0·23)[0·55]
Maths Exam Score					0·75(0·58)[0·58]
Chem. Exam Score					

Table 4·3

Unbracketed /

Unbracketed figures - school 4 N = 44

Figures in round brackets - school 8 N = 19

Figures in square brackets - school 9 N = 32

$[*]_r$ = 0·36 is significantly different from r = 0 at 5% level

$(*)_r$ = 0·23 is not significantly different from r = 0 at 5% level

The values obtained for r are significantly different from a true r of zero at the 1% level in all cases except for those indicated.

The results show -

1) Mathematics scores in the test and Chemistry scores in the test correlate highly with total scores in the test.

2) Mathematics 'O' grade preliminary scores and Chemistry 'O' grade preliminary scores correlate well with the total score on the test.

3) Mathematics scores in the test and Chemistry scores in the test correlate well with Mathematics preliminary scores and Chemistry preliminary scores. An investigation was also made into the relationship between the scores of boys and girls.

4) Boys' scores in the test were significantly higher than girls' scores but the samples involved were too small to make this a general conclusion - this was true for schools 4 and 9 only.

4·10 Conclusions

1. Verbal ability is not necessarily needed in mathematical thinking but appears necessary in translation of chemical terms.

2. Items involving the schema of ratio were done satisfactorily since this is a 'concrete' concept but those involving the schema of proportion, which is a 'formal' concept were not all done satisfactorily since the schema is not available in all situations at the same time.

3. Pupils who solved a mathematical problem using proportional reasoning did so quite mechanically using a technique like, "if you double this, you double that", or they multiplied and divided because this procedure gave them the correct response.

4. The level of understanding required in the proportionality concept is such that regardless of teaching method, many pupils will never fully grasp the topic by the time they reach sixteen years of age. [34]

5. In items where the solution required the application of inverse proportionality more serious demands on the pupils' understanding were made and results were poorer.

6. In 'proportion' problems where numbers were 'simple' performance was all right, but when numbers used in a multivariate situation were not easily imaginable or not within concrete experience the pupils' problems were great - this was most noticeable in stoichiometric problems where for constant molarity, volume $\propto$ number of moles, and for a given number of moles, volume $\propto \frac{1}{M}$

7. /

7. In failing to answer correctly a proportion problem there are the factors of reading ability, visual imagery and recall and thought processes all entering, therefore it is difficult to define one reason for pupils' inability in transferring the 'proportion' technique from Mathematics to Chemistry.

4·11 Modifications to the Test in the light of the Analysis of the Results

1. Items 1, 2, 35 and 52 have discriminating power $< 0 \cdot 1$ and therefore do not function as objective items in obtaining a good order of merit - therefore omit. In 35 and 52 the frequency of responses for A, B, C and D suggests that guessing has been the operative procedure in choosing a key, which means the items are not good ones.

2. Item 34 has a low facility value with good discrimination. Compared to the statistics for item 35, it might be suggested that pupils were not really familiar with the terms 'mole', 'gram' and 'volume'. To re-test this, either leave out the given equation or re-write in ionic form which is more familiar with pupils and obtain unbiassed results.

3. In 'proportion' problems make sure only one factor is changed at a time and gradually introduce multivariate problems in Mathematics as well as Chemistry so that the actual breakdown point in transfer of the proportion technique from Mathematics to Chemistry can be found.

4. In items where apparatus is used, for example 21 - 24 and 45 - 49 inclusive, describe the practicalities of operation more fully. For the Balance Experiment explain the Principle of Moments and hence relationships involving direct proportionality.

For the Shadows Experiment explain the inverse proportionality relationships and ensure calculations are done systematically from the screen or the light source.

By /

By so doing, the problem can be defined as one of verbal/visual or proportionality calculation.

These experiments have both been used by Piaget and Inhelder [35] - they found the Balance Experiment required concrete thinking 2A/B level and the Shadows Experiment required formal thinking 2B/3 level. If presented in a more perceptual form, then we could establish if direct or inverse proportionality is a sole measure of difficulty.

5. In items 40, 41, 42 and 43 change one distractor to include the answer that would be obtained by calculating using the inverse of the correct ratio,

   e.g. 41) What volume of 4M NaOH will neutralise 1 l of 1M H_2SO_4 ?

   A) 125 ml
   B) 500 ml
   C) 2 l
   D) 4 l

   From test results - in seven out of twenty-three problems involving proportion in Mathematics or a parallel chemical situation - there was a significant number of those wrong who chose the response obtained by using the inverse ratio of the correct one in the calculation.

6. In general, problems will be presented so that they can be clearly defined as concrete or formal. In the original test, problems which in descriptive terms were meant to be concrete, were to the pupils formal in terms of the process of visualising relationships between variables.

To sum up : It is obvious that Mathematics proportion problems are done by rule of thumb or using mechanical technique and it is thought that /

that similar chemical problems are difficult for pupils because they involve intensive properties, visualisation and verbal ability before the mechanical technique can be applied. In Chapter 5 a modified version of the test will be used for further investigation.

UNIVERSITY OF GLASGOW

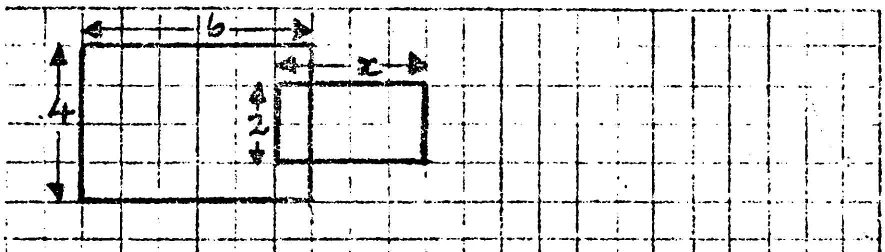
RESEARCH IN CHEMICAL EDUCATION

✱ indicates the key or correct response

What is the length of the missing side x in each of the following?

Frequenc of respo se

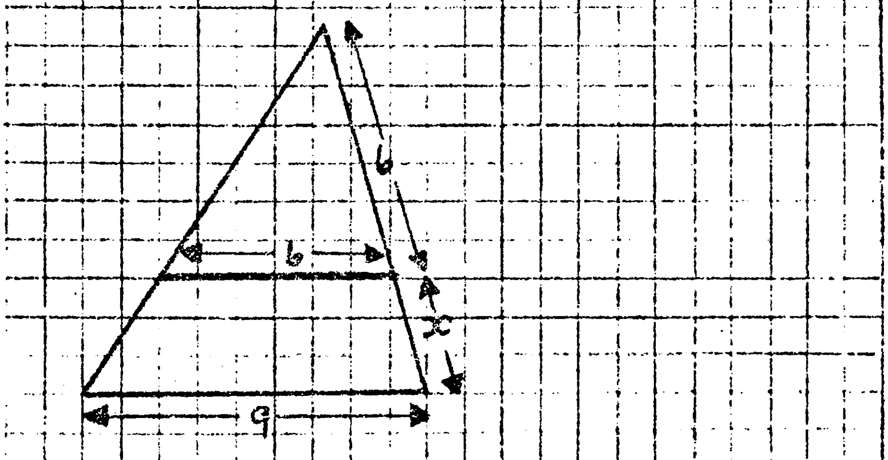
(1)



Is it	(A)	5	1
	(B)	$4\frac{1}{2}$	2
✱	(C)	4	310
	(D)	3	32

F.V.= 0.89
D.P.= 0.05

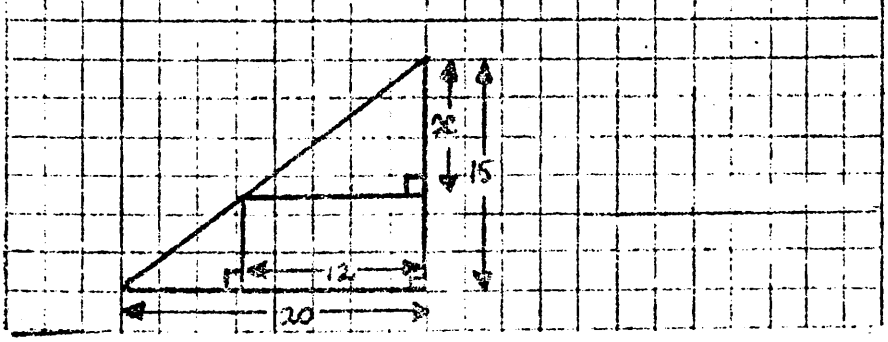
(2)



Is it ✱	(A)	3	295
	(B)	4	27
	(C)	6	4
	(D)	9	19

F.V.= 0.85
D.P.= 0.04

(3)

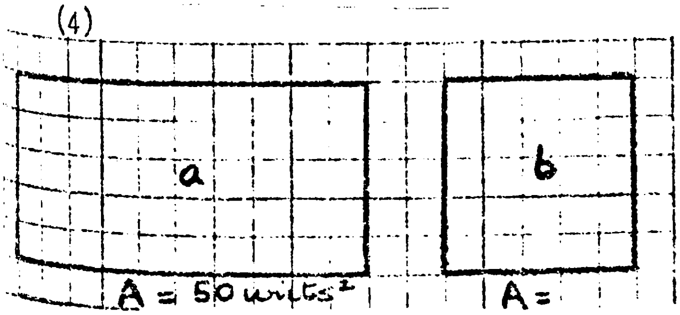


Is it	(A)	5	30
	(B)	6	58
	(C)	8	105
✱	(D)	9	152

F.V.= 0.44
D.P.= 0.34

By calculating the missing areas, what is the value of each ratio of areas stated?

(4)

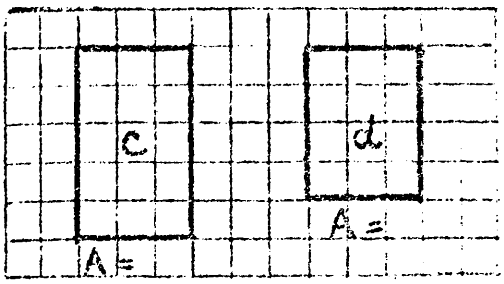


Is $\frac{\text{Area of a}}{\text{Area of b}}$ equal to

✱	(A)	2	228
	(B)	50/24	25
	(C)	24/50	10
	(D)	$\frac{1}{2}$	82

F.V.= 0.66
D.P.= 0.47

(5)



Is $\frac{\text{Area of c}}{\text{Area of d}}$ equal to

(A) 12/15 33
(B) 4/5 24
*(C) 5/4 284
(D) 1 4
F.V.= 0.82
D.P.= 0.32

Which pair of numbers is the next two numbers in each of the following series?

(6) 1 + 7 + 13 +   +

(A) 20, 27 4
(B) 19, 26 26
*(C) 19, 25 312
(D) 20, 26 3
F.V.= 0.90
D.P.= 0.11

(7) 1 + 5 + 25 + 125 +   +

*(A) 625, 3125 312
(B) 250, 500 28
(C) 129, 149 5
(D) 100, 95 0
F.V.= 0.90
D.P.= 0.23

(8) $\frac{1}{2} + \frac{1}{6} + \frac{1}{18} + \quad +$

(A) $\frac{1}{9}, \frac{1}{6}$ 1
*(B) $\frac{1}{54}, \frac{1}{162}$ 296
(C) $\frac{1}{22}, \frac{1}{36}$ 11
(D) $\frac{1}{36}, \frac{1}{72}$ 37
F.V.= 0.86
D.P.= 0.26

(9) 1 + 1 + 2 + 3 + 5 +   +

(A) 5, 6 23
(B) 7, 10 51
(C) 6, 8 10
*(D) 8, 13 260
F.V.= 0.76
D.P.= 0.26

(10) $2 + \frac{4}{3} + \frac{8}{9} + \quad +$

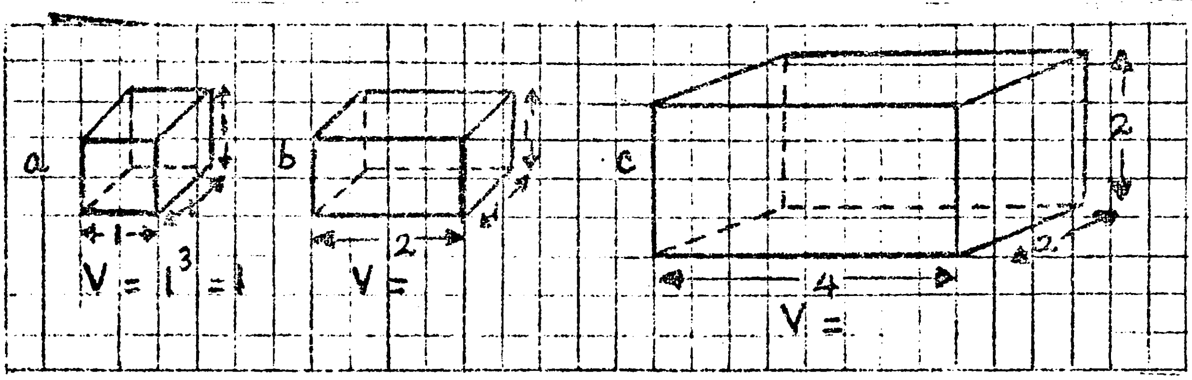
*(A) $\frac{16}{27}, \frac{32}{81}$ 260
(B) $\frac{10}{12}, \frac{12}{15}$ 15
(C) $\frac{10}{11}, \frac{14}{17}$ 9
(D) $\frac{16}{15}, \frac{32}{21}$ 60
F.V.= 0.76
D.P.= 0.14

(11) /

(11) 1 + 2 + 2 + 4 + 3 + 8 + 4 + 16 + +

(A) 7, 25 17
*(B) 5, 32 24
(C) 11, 41 42
(D) 6, 27 35
F.V.= 0.72
D.P.= 0.28

Given,



(12) Is $\frac{\text{Volume of a}}{\text{Volume of b}}$ equal to

(A) 2 24
(B) 4 18
(C) $\frac{1}{4}$ 15
*(D) $\frac{1}{2}$ 288
F.V.= 0.83
D.P.= 0.31

(13) Is $\frac{\text{Volume of b}}{\text{Volume of c}}$ equal to

(A) 8 22
*(B) $\frac{1}{8}$ 288
(C) 16 21
(D) $\frac{1}{16}$ 13
F.V.= 0.84
D.P.= 0.33

(14) The ticket for a 24 mile journey costs 40p. What should a ticket for a 60 mile journey cost?

(A) 16p 4
(B) 60p 18
*(C) £1 316
(D) £2 7
F.V.= 0.92
D.P.= 0.15

(15) If 1 mole of sodium chloride has mass 58·5 g, what is the mass of 0·2 moles?

(A) 1·17 g 32
*(B) 11·7 g 266
(C) 117 g 13
(D) 292·5 g 28
F.V.= 0.78
D.P.= 0.43

(16)/

(16) A train travels 45 miles in $\frac{3}{4}$ hour. If it maintains the same average speed, how long will it take to travel 60 miles?

*(A)	1 hour	322
(B)	$\frac{9}{16}$ hour	7
(C)	$\frac{6}{8}$ hour	10
(D)	$\frac{1}{2}$ hour	5

F.V. = 0.94
D.P. = 0.14

(17) An electron travels at $1 \cdot 5 \times 10^{8}$ m in 1 second. If it maintains the same average speed, how far would it travel in ten minutes?

(A)	$1 \cdot 5 \times 10^{9}$ m	33
(B)	90×10^{8} m	101
(C)	$1 \cdot 5 \times 10^{7}$ m	7
*(D)	9×10^{10} m	197

F.V. = 0.58
D.P. = 0.59

A 100 ml of 1M HCl requires 12 pellets of solid NaOH for neutralisation.

(18) How many pellets would 150 ml of 1M HCl require?

(A)	5	7
(B)	7½	5
(C)	8	11
*(D)	18	321

F.V. = 0.93
D.P. = 0.23

(19) How many pellets would 100 ml of 3M HCl require for neutralisation?

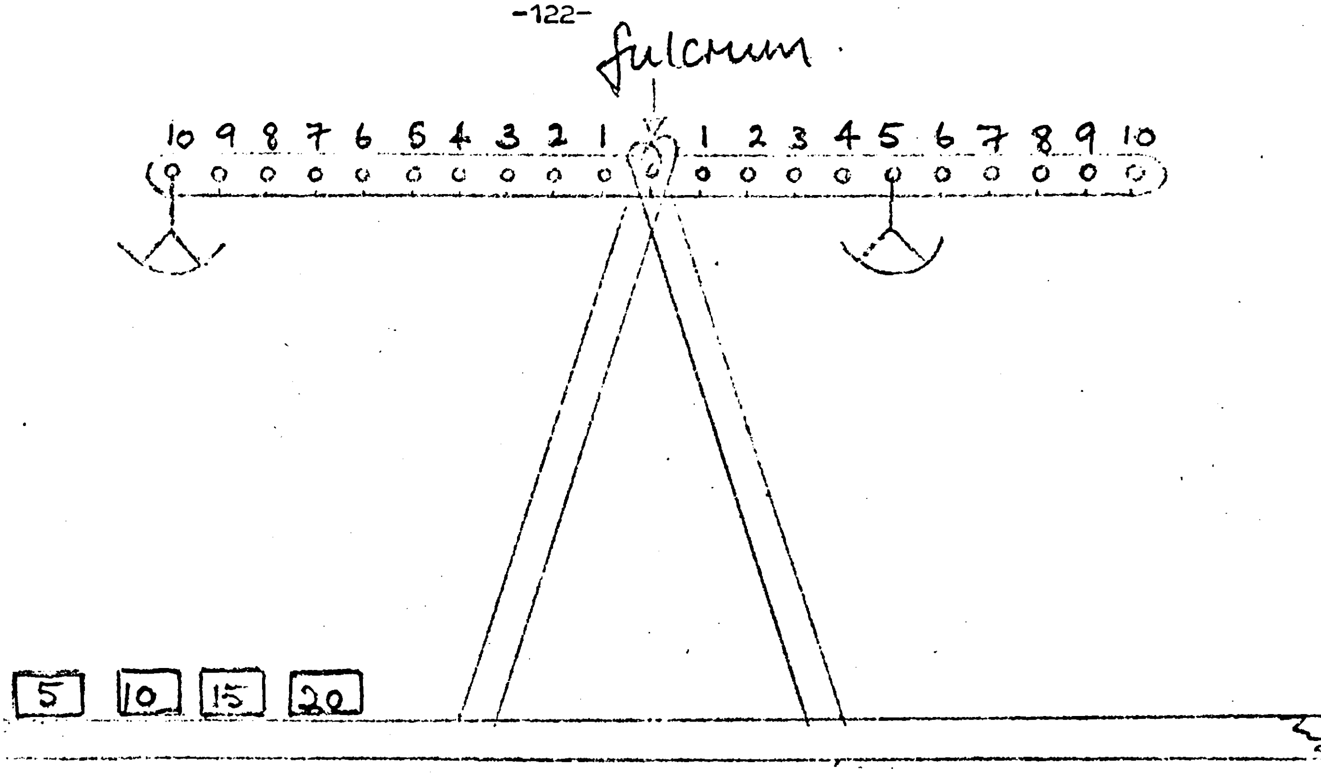
(A)	4	46
(B)	15	6
*(C)	36	284
(D)	24	9

F.V. = 0.83
D.P. = 0.34

(20) How many pellets would 25 ml of 5M HCl require for neutralisation?

(A)	3	35
*(B)	15	265
(C)	60	24
(D)	240	20

F.V. = 0.77
D.P. = 0.44



Let's suppose a balance type of this kind has been set up and we want to investigate by using detachable scale pans when balance is effected. Weights of 5 units, 10 units, 15 and 20 are available for use on scale pans of negligible weight.

(21) If a 10 unit weight is on left hand scale pan in the position shown, which weight would be required on the right hand scale pan in the position shown for balance to take place?

(A)	5	53
(B)	10	41
(C)	15	38
*(D)	20	213

F.V.= 0.62
D.P.= 0.53

(22) If the scale pans remain in the same positions and 5 units are on the left - what weight would be required on the right?

(A)	5	43
*(B)	10	274
(C)	15	20
(D)	20	8

F.V.= 0.79
D.P.= 0.41

(23) If we had one 5 unit weight on the left pan and one 15 unit weight on the right pan, where could the scale pans be placed to effect balance.
For ease in responding, holes are numbered from the fulcrum out.

(A)	5 at 7 and 15 at 3	49
(B)	5 at 10 and 15 at 5	54
(C)	5 at 8 and 15 at 2	38
*(D)	5 at 9 and 15 at 3	196

F.V.= 0.57
D.P.= 0.67

(24) /

(24) If we now had 2 scale pans on the left hand side, and only one on the right, how could balance be obtained when 5 units were in the pan at position 10 and 10 units were in the pan at position 5, both on the left. The right pan would need -

(A) 10 units in position 8 — 20

*(B) 20 units in position 5 — 187

(C) 15 units in position 7 — 78

(D) 10+15 units in position 5 — 54

F.V.= 0.56
D.P.= 0.49

Using a similar method of reasoning to that needed for -

Rome is to Italy as Paris is to France	OR	Rome is to Italy as Paris is to France
Oslo is to Norway as London is to _____		Norway is to Oslo as _____ is to London

What is the missing number in each of the following?

(25)

5	1
8	4
15	11
7	?

(A) 19 — 22
(B) 6 — 8
*(C) 3 — 303
(D) 4 — 12

F.V.= 0.88
D.P.= 0.27

(26)

5	15
4	12
3	9
?	18

(A) 54 — 7
*(B) 6 — 303
(C) 2 — 28
(D) 7 — 7

F.V.= 0.88
D.P.= 0.27

(27)

5	13
7	17
4	11
6	?

*(A) 15 — 270
(B) 16 — 47
(C) 7 — 16
(D) 13 — 11

F.V.= 0.78
D.P.= 0.28

(28)

2	5
7	20
5	14
?	26

(A) 11 — 43
*(B) 9 — 214
(C) 17 — 25
(D) 8 — 55

F.V.= 0.63
D.P.= 0.52

(29) /

(29)

3	9	(A)	21	29
5	25	(B)	34	8
2	4	(C)	47	8
7	?	*(D)	49	300

F.V.= 0.87
D.P.= 0.25

(30)

16	12	*(A)	18	219
8	6	(B)	2	25
10	5	(C)	5	45
?	9	(D)	16	46

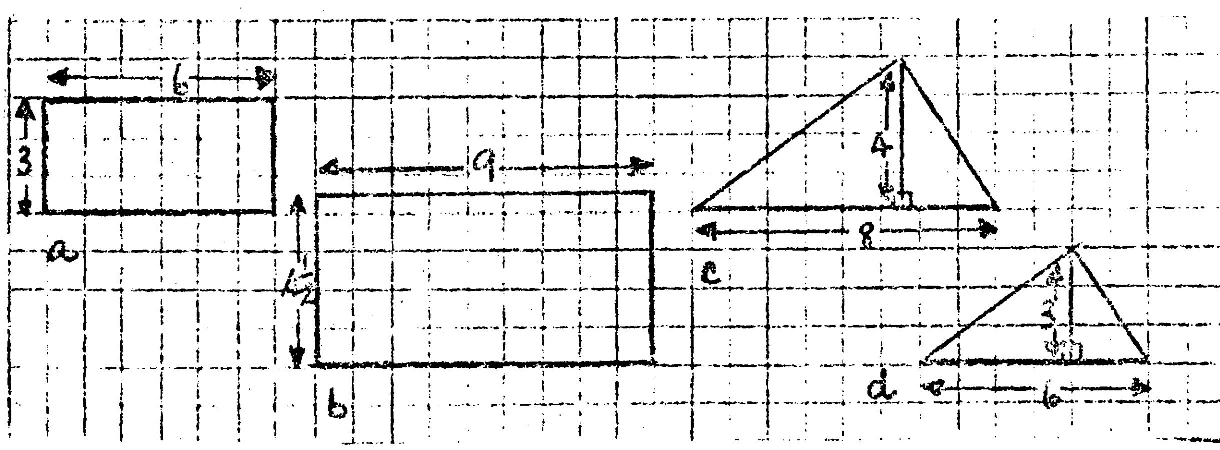
F.V.= 0.65
D.P.= 0.31

(31)

2	8	(A)	25	25
4	64	(B)	100	44
3	27	*(C)	125	238
5	?	(D)	625	29

F.V.= 0.71
D.P.= 0.38

Given



(32) Is $\frac{\text{Area of a}}{\text{Area of b}}$ equal to

(A) $\frac{9}{4}$ 27

(B) $\frac{36}{41}$ 73

*(C) $\frac{4}{9}$ 168

(D) $\frac{2}{3}$ 68

F.V.= 0.50
D.P.= 0.50

(33) Is $\frac{\text{Area of c}}{\text{Area of d}}$ equal to

(A) 2 24

(B) $\frac{9}{16}$ 29

(C) $\frac{4}{3}$ 76

*(D) $\frac{16}{9}$ 212

F.V.= 0.62
D.P.= 0.47

(34) If we take a known mass of Zn and stir it into an excess of copper sulphate solution, then which statement is correct for the reaction :-

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$$

*(A) Every mole of Zn gives a mole of Cu 116
(B) Every gram of Zn gives a gram of Cu 53
(C) You cannot tell from the given information. 88
(D) Every volume of Zn gives a volume of Cu. 84

F.V.= 0.34
D.P.= 0.32

(35) If we stirred a known mass of Zn into an excess of silver nitrate solution then which statement is correct?

Equation : $Zn + 2AgNO_3 \rightarrow Zn(NO_3)_2 + 2Ag$

(A) You cannot tell from the given information 52
(B) Every gram of Zn gives 2 grams of Ag 91
*(C) Every gram of Zn gives a fixed mass of Ag 86
(D) Every volume of Zn gives 2 volumes of Ag. 114

F.V.= 0.25
D.P.= 0.04

When a given 1M solution of NaOH is titrated against a given 1M solution of HCl, then,

$$NaOH + HCl \rightarrow NaCl + H_2O$$

(36) How many moles of NaOH are required to react with 1 mole of HCl?

(A) ½ mole 26
*(B) 1 mole 268
(C) 1½ moles 18
(D) 2 moles 30

F.V.= 0.78
D.P.= 0.40

(37) What volume of 1M NaOH will neutralise 2 l of 1M HCl?

(A) ½ l 45
(B) 1 l 41
(C) 1½ l 25
*(D) 2 l 231

F.V.= 0.68
D.P.= 0.47

Given

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

(38) How many moles of NaOH are required to react with 1 mole of H_2SO_4 ?

(A) $\frac{1}{2}$ mole 40
(B) 1 mole 44
(C) $1\frac{1}{2}$ moles 24
*(D) 2 moles 236
F.V.=0.69
D.P.= 0.49

(39) What volume of 1M NaOH will neutralise 1 l of 1M H_2SO_4 ?

(A) 500 ml 50
(B) 1 l 95
(C) $1\frac{1}{2}$ l 28
*(D) 2 l 159
F.V.= 0.48
D.P.= 0.48

(40) What volume of 1M NaOH will neutralise 2 l of 1M H_2SO_4 ?

(A) 500 ml 32
(B) 1 l 45
(C) 2 l 99
*(D) 4 l 163
F.V.= 0.48
D.P.= 0.48

(41) What volume of 4M NaOH will neutralise 1 l of 1M H_2SO_4 ?

*(A) 500 ml 154
(B) 1 l 44
(C) 2 l 67
(D) 4 l 74
F.V.= 0.45
D.P.= 0.49

(42) What volume of 4M NaOH will neutralise 250 ml of 2M H_2SO_4 ?

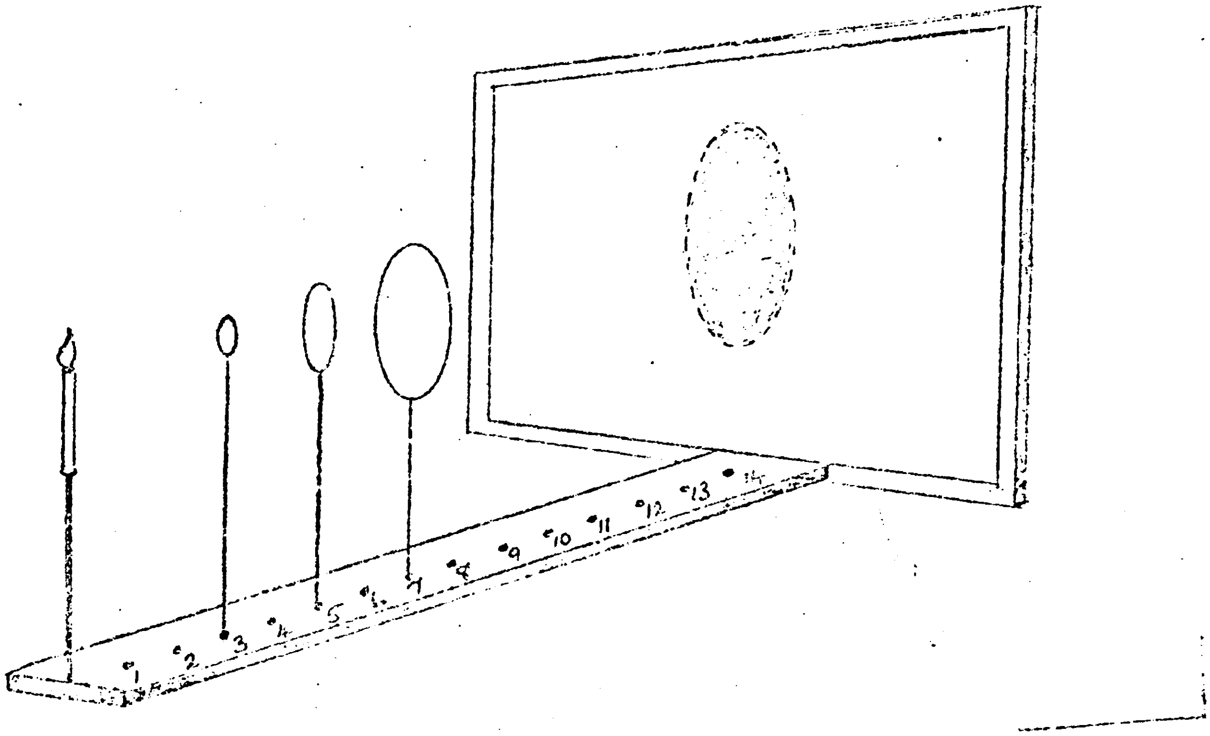
*(A) 250 ml 137
(B) 500 ml 109
(C) 1 l 57
(D) 2 l 37
F.V.= 0.40
D.P.= 0.34

(43) If 1 l of 1M NaOH neutralises $\frac{1}{2}$ l of H_2SO_4 what is the molarity of the H_2SO_4 ?

*(A) 1M 129
(B) 2M 152
(C) 3M 33
(D) 4M 25
F.V.= 0.38
D.P.= 0.41

(44) If 20 ml of 2M H_2SO_4 neutralises 100 ml of NaOH, what is the molarity of the NaOH ?

(A) $\frac{1}{5}$ M 107
(B) $\frac{2}{5}$ M 122
*(C) $\frac{4}{5}$ M 78
(D) 1M 33
F.V.= 0.23
D.P.= 0.18



Here is a piece of apparatus which consists of a screen attached to a strip of wood which has a light source and three moveable cardboard discs 1 cm, 2 cm and 4 cm in diameter. The cardboard discs produce shadows on the board and by moving the discs the size of shadow on the board can be altered.

(45) Leave only the disc diameter 1 cm in the position shown - note the shadow size. Where will the same disc have to be positioned to give a shadow whose diameter is two times the size in position shown?

*(A)	2	152
(B)	5	39
(C)	6	121
(D)	9	25

F.V.= 0.45
D.P.= 0.24

(46) Where will it have to be to give a shadow whose diameter is three times the size in position 3 ?

*(A)	1	132
(B)	6	28
(C)	9	154
(D)	12	26

F.V.= 0.39
D.P.= 0.31

(47) Where will it have to be to give a shadow whose diameter is one third the size in position 3 ?

(A)	12	30
*(B)	9	88
(C)	6	70
(D)	1	152

F.V.= 0.26
D.P.= 0.12

(48) /

Note: In item 45, there is no correct response given - it is $1\frac{1}{2}$ that is the answer so the nearest i.e. 2 was taken to be correct.

(48) If the disc diameter 1 cm is in position 6, where would the disc 2 cm diameter have to be positioned so that the diameters of shadows from the discs are equal?

(A) 3 147
(B) 4 35
(C) 8 61
*(D) 12 96

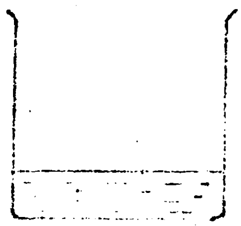
F.V.= 0.28
D.P.= 0.12

(49) How could you position the discs whose diameters are 1 cm and 4 cm respectively to obtain shadows whose diameters are equal?

(A) Disc 1 cm diameter in position 2 and disc 4 cm diameter in position 6 40
*(B) Disc 1 cm diameter in position 2 and disc 4 cm diameter in position 8 104
*(C) Disc 1 cm diameter in position 3 and disc 4 cm diameter in position 12 81
(d) Disc 1 cm diameter in position 12 and disc 4 cm diameter in position 3 112

F.V.= 0.55

One final experiment. Given



500ml of 1M HCl

At Wt H = 1
At Wt Cl = 35·5

(50) How many moles of HCl are there in the beaker?

*(A) ½ 159
(B) 1 125
(C) 2 36
(D) 0 19

F.V.= 0.47
D.P.= 0.41

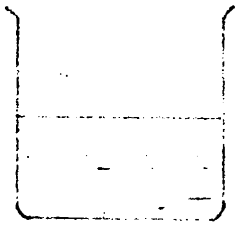
(51) What is the concentration in g/l of this solution?

(A) 73 36
*(B) 36·5 129
(C) can't tell 93
(D) 18·25 77

F.V.= 0.38
D.P.= 0.19

Now/

Now add 500ml of water, thus



500ml of 1M HCl + 500ml of water

(52) What now is the concentration in g/l of this solution?

(A) 36·5 76
(B) 73 30
* (C) 18·25 97
(D) can't tell 127

F.V.= 0.29
D.P.= 0.08

(53) What is the molarity of the solution?

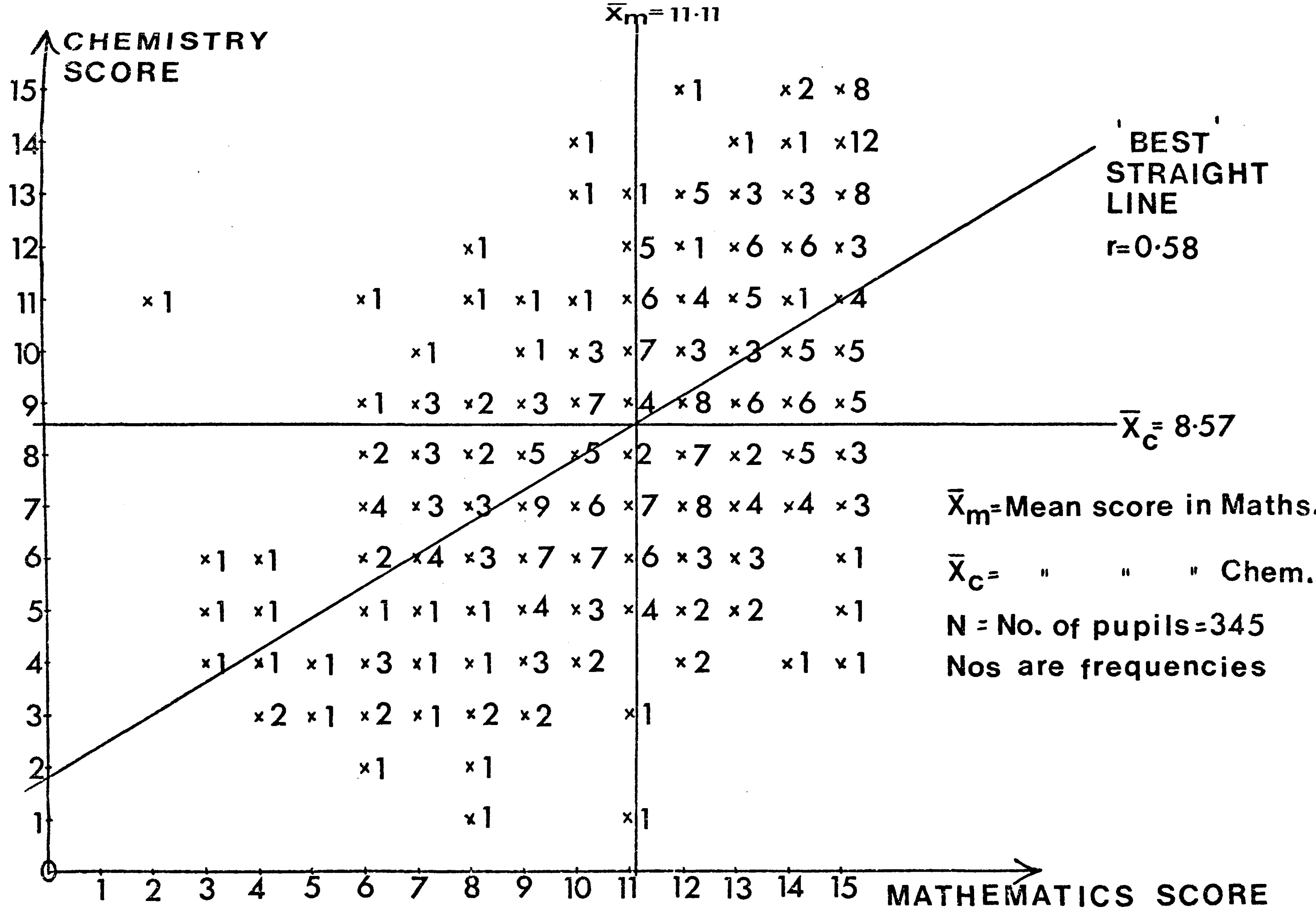
* (A) ½ 130
(B) 1 122
(C) 2 49
(D) 4 24

F.V.= 0.37
D.P.= 0.14

(54) How many moles of HCl are there?

(A) 0 20
(B) 1 143
(C) 2 29
* (D) ½ 138

F.V.= 0.42
D.P.= 0.18


CHEMISTRY SCORE
MATHEMATICS SCORE
$\bar{X}_m = 11{\cdot}11$
$\bar{X}_c = 8{\cdot}57$
'BEST' STRAIGHT LINE
r=0·58
$\bar{X}_m$=Mean score in Maths.
$\bar{X}_c$= " " " Chem.
N = No. of pupils=345
Nos are frequencies

CHAPTER 5

RATIO AND PROPORTION - WHY THE PUPILS HAVE DIFFICULTIES.

5.1 Introduction.

The research outlined in Chapter 4 described exactly where pupils in S4 have difficulties with topics in Chemistry and Mathematics 'O' grade which involve the concept of Ratio and Proportion. As a result of this, it was decided to investigate pupil difficulties much more closely by talking to some pupils while they attempted to solve some problems in this domain and find out why they had these difficulties.

As a result of this further more direct research, it was hoped that reasons for the inability to solve problems in both Maths. and Chemistry involving Ratio and Proportion could be clearly defined and possible recommendations for change in the syllabus or change in teaching method could be outlined as a result of observations in the classroom.

5·2 Experimental Design

It was decided to specify problems of graded difficulty in Mathematics and parallel ones in Chemistry and to interview pupils individually while they attempted to apply the technique of Ratio and Proportion in solving these problems. Pupils were thus encouraged to speak out loud and it became possible to categorise pupils into one of four types:-

1. Those who could see and do the problem instantly.
2. Those who could do the problem using a given format which they had been taught in Mathematics but did not really understand and certainly found their format difficult to apply to a similar chemical situation.
3. Those who floundered and tried to form relationships with the figures to obtain one of the distractors given.
4. Those who could not attempt to solve the problem even with help.

Thirty-one S4 mixed ability pupils from school 4 (see Chapter 4) and thirty-six S4 mixed ability pupils from school 5 (see Chapter 4) were used as subjects. These pupils were not the same S4 ones as used in Chapter 4 but those of the subsequent year.

As well as the interview part of the experiment, pupils not being observed individually at a given time were set a written test with objective items. This test included the items used for the interviews and was slightly modified for school 4 after use with school 5. The test is in the Appendix, p.157, and the instruction sheet and a sample of tick sheets used for recording responses in the interviews are in the Appendix, p.160. Questions and aids given to pupils who were interviewed were specified on the instruction sheet.

The written /

The written test was designed so that items were presented in pairs, with each Mathematics item followed by a closely parallel Chemistry one. The final two items were stoichiometry ones and they gave for the parallel situations of NaOH titrated with HCl and H_2SO_4 items of graded difficulty so that the point could be discovered where the pupils' ability to cope with a proportion problem broke down.

5·3 Results of the Interviews for items 2, 4, 6, 7 and 9h) in the Test

Pupils' responses in the interviews matched well their responses in the written test but from the interviews it was clear that in many cases there was absence of reasoning or faulty reasoning or use of a rule of thumb even when the correct response was selected. By recording a concise pupil method from a face to face interview several channels along which pupils travel in tackling 'proportion' problems can be specified.

Interview results with pupils in order of merit. School 4 results are first, school 5 in brackets and second:-

Item 2 — 12 pellets of solid NaOH are required for neutralisation of 100 ml of molar HCl; how many pellets will be required for neutralisation of 150 ml of molar HCl?

A. 8
B. 16
*C. 18
D. 62

F.V. = 0·97 (1·00)

D.P. = 0·09 (0·00)

Pupil /

Pupil Score on Test	School Year Section	Response in Written Test	Pupil Method and Comments
21	1	Correct	Used 1 to 1 correspondence method with format $\begin{matrix}A\leftrightarrow B\\ C\leftrightarrow ?\end{matrix}$
20	1	Correct	Changed format so that $\begin{matrix}A\leftrightarrow B\\ C\leftrightarrow ?\end{matrix}$ then easy $\begin{matrix}100\longleftrightarrow 12\\ 150\longleftrightarrow 12 \times \frac{150}{100}\end{matrix}$
20	1	Correct	$100\longleftrightarrow 12$ so half more again is 18
20	1	Correct	Difficult to write down. When given $\begin{matrix}100\longleftrightarrow 12\\ 150\longleftrightarrow ?\end{matrix}$ he said 6 more was the answer
19	1	Correct	Slow to start. $\frac{3}{2} \times \frac{12}{1} = \frac{36}{2} = 18$
12	1	Correct	Half as much again, so 18
10	5	Correct	Half as much again, so add 6 to 12
9	3	Correct	Half as much again, so add 6 to 12
9	5	Correct	$150 \leftrightarrow 12 \times \frac{150}{100} = 18$ Quite easy
6	5	Correct	$\frac{100}{150} = \frac{x}{12}$ $x = \frac{12 \times 150}{100} = 18$ Decide if bigger quantity - bigger number on top
3	5	Correct	No idea, so guessed it was 18
19	1	Correct	Find 6 for 50 then 18 for 150. Always look for a common factor.
14	4	Correct	Add on half as much again of pellets, but don't know why.
13	1	Correct	Reverse variables so that:- 100 ml 1M HCl needs 12 pellets NaOH; 150 ml 1M HCl needs 18 pellets NaOH.
13	1	Correct	Tried to use unitary method. Divide 100 by 12 then multiply.
12	4	Correct	Reverse presentation to get in Maths format. Really just half added on.
12	4	Correct	Think it is 18; $100 \div 12$, 24 get 200, $\frac{1}{2} = 6$
11	4	Correct	$100 + \frac{1}{2}(100) \Rightarrow 12 + \frac{1}{2}\times 12 \Rightarrow 18$
11	1	Correct	12 for 100 $\therefore$ half as much again, 18. Easy.

Several pupils obviously used a rule of thumb here but specified first the format has to be $\begin{matrix}A\leftrightarrow B\\ C\leftrightarrow ?\end{matrix}$. They could cope with the numbers given but when /

but when asked to calculate number of pellets for 160 ml HCl there was a great deal of confusion since a common factor was not so obvious. A rule of thumb was not so easily applicable and so it was clear that many who got the key did not understand the rule of thumb.

Item 4 A 100 ml of 1M HCl requires 15 pellets of NaOH for neutralisation; how many pellets will 100 ml of 3M HCl require?

A. 5
B. 17
C. 18
*D. 45

F.V. = 0·90 (0·81)
D.P. = 0·27 (0·25)

Pupil Score on Test	School Year Section	Response in Written Test	Pupil Method and Comments
21	1	Correct	3 times as strong ∴ 3 times as many pellets ∴ 45
20	1	Correct	Used 1 to 1 correspondence method
20	1	Correct	15 ↔ 100 1M; x ↔ 100 3M Same quantity ∴ 3 x 15 = 45
19	1	Correct	$\frac{3}{1} \times \frac{15}{1} = 45$
12	1	Correct	1 x x = 3 x 15 ∴ x = 45
10	5	Correct	Helped throughout, but eventually got 45.
9	3	Correct	Multiply 15 x 3 as a guess. M means concentration.*
6	5	Correct	M = 63 x $10^{\text{some power}}$. More pellets since more M ∴ 45. Did not really understand. *
3	5	Incorrect	Did not understand neutralisation and molarity. Completely stuck.
19	1	Correct	·1 for 15; ·3 for 45 where 0·1 = 100 ml x 1M. Always multiply volume in l by M to get number of moles.
14	4	Correct	Answer is 45; don't know why, just a guess; multiplied 15 by 3. *
13	1	Correct	Used 1 to 1 correspondence method; 3 times as strong - 3 times as many pellets.
13	1	Correct	Used 1 to 1 correspondence method after told the 100 ml was irrelevant.

12	4	Correct	100 common so M is the only variable. 1↔15, 3↔15 x 3. This type of problem is only difficult when presented in reverse.
12	4	Correct	1 ↔ 15, 3 ↔ 15 x 3. Big words like neutralise and requires, and awkward numbers confuse. Likes to use a rule of thumb but does not understand. *
11	4	Correct	Chose answer of 45 from those given and therefore spotted the relation in reverse. When given 1 ↔ 15, then no problem. *
11	1	Incorrect	3M takes $\frac{1}{3}$ less $\therefore \frac{1}{5}$ of 15 = 5. Thought 1M was stronger than 3M, but did not know what M really meant.

* Pupils' responses indicate that they had the correct answer but did not understand how to calculate it, mainly because chemical terms were confusing like M, neutralise and requires, but also because there is irrelevant data which made the necessary data appear 'awkward'.

Item 6 A "slow motion" camera takes pictures at 72 frames per second, and these are projected on a screen at 16 frames per second. How long will a shot of a golfer's swing take when projected if it actually takes 0·45 seconds to complete?

A. 0·10 secs.
B. 10 secs.
*C. 2·025 secs.
D. 25·20 secs.

F.V. = 0·77 (0·56)
D.P. = 0·45 (0·08)

Pupil Score on Test	School Year Section	Response in Written Test	Pupil Method and Comments
22	1	Correct	Straight through mentally
22	1	Correct	$16 = \frac{72}{4\frac{1}{2}}$ then $\frac{9}{2} \times 0{\cdot}45 = 2{\cdot}025$
20	1	Correct	Confused about frames - when first part cracked, she saw the rest.
19	3	Correct	Used 'Equal Products' method. If proportion format is used then there is a problem about which way up to put the ratio.
16 /			

16	1	Incorrect	72 frames/second taken in 0·45 secs. $\therefore \frac{72}{0\cdot45}$ frames taken - No! Try 72 ↔ 1 72 x 0·45 ↔ 0·45 = 32·40 $32\cdot40 \times \frac{72}{16}$ - No! Set out 72 ↔ 1 ↔ 32·40 * 16 ↔ 1 ↔ ? So the answer is 25·20 or 10 secs.
13	5	Correct	Hard. ·45 is confusing, could do for ½ second then guess the answer. *
12	1	Correct	Helped with first part, then she saw the rest.
11	5	Correct	$\frac{72}{16}$ is the number shown then multiply by 0·45 secs. = 2·025.
9	5	No answer	$\frac{72}{16}$ is the time to show 72 prints, then stuck. With a lot of help, reasoned out the answer by comparing the number taken and the number shown in a given time. *
19	1	Correct	72 x 1 = 16 x x $\therefore$ x = 4·5 4·5 secs for 72 frames to go; then 4·5 x 0·45 = 2·025
18	1	Correct	72 proper, 16 slower $\frac{72}{16} = 4\frac{1}{2}$ then $4\frac{1}{2}$ x ·45
16	1	Correct	No real idea, try $\frac{72}{16} = 4\frac{1}{2}$. 0·45 secs taking time, therefore 2·025
14	1	Correct	Divide 72 by 16 then multiply by ·45
13	4	Incorrect	$\frac{72}{16} = 4\cdot5$ - did not know why he did this. $\frac{\cdot45}{4\cdot5} = 0\cdot10$ So answer is 0·10 *
12	4	Correct	$72 \times \frac{0\cdot45}{16}$ Don't know why *
12	1	Incorrect	Try 16 x 0·45 then guess the answer is more than 2, therefore, 2·025 *
11	4	Incorrect	Slowed down by 56 when showed on the screen. $\frac{72}{16} = 4\cdot5 \times \cdot45 = 2\cdot025$. Did not understand ratio.
11	4	Correct	$\frac{72}{16} = 4\cdot5$ then 45 x 45 = 2025. Answer, 2·025. No idea why; found words difficult.

There were clearly pupils who solved the problem, i.e. had the key, but did not understand exactly what they calculated at each stage. Pupils marked /

marked * belonged to category 3) p 133. Most of them were obviously trying to reason from a chosen distractor backwards - randomly operating on data chosen at random, or were looking for an obvious pattern in the numbers.

It was surprising that in this item some pupils used a fairly sophisticated method of solution; they worked out the time taken to show compared to the time taken to photograph. This was a factor 1 to 4·5 or as some explained, it took $\frac{72}{16} = 4{\cdot}5$ seconds to show 72 frames. This times 0·45 seconds gave what was required. It seemed as if, particularly in school 5, the pupils had met a similar problem in class and had been taught a 'quick way' of getting the correct answer, with no depth of understanding.

<u>Item 7</u> What volume of 0·2M HCl is required to neutralise 30 ml of 0·3M NaOH solution?

A. 20 ml
B. 33 ml
*C. 45 ml
D. Need more information

F.V. = 0·48 (0·33)
D.P. = 0·63 (0·50)

Pupil Score on Test	School Year Section	Response in Written Test	Pupil Method and Comments
22	1	Correct	Knew M was moles/litre. From equation there was a 1 to 1 mole relationship but was doubtful whether to multiply or divide first.
22	1	Correct	Know from equation 1 to 1 mole relationship x ml 0·2M HCl neutralises 30 ml 0·3M NaOH $x \quad \frac{1}{5} \qquad\qquad 30 \quad \frac{3}{10}$ $\frac{x}{100} \quad 0{\cdot}2 \qquad\qquad \frac{3}{100} \quad 0{\cdot}3 = 0{\cdot}009$ $\frac{0{\cdot}2x}{100} = 0{\cdot}09$ Helped and managed to solve.
19	3	Correct	The numbers and the context put you off. M is about concentration and number of ions. $\frac{\cdot 3}{\cdot 2}$ = concentration. $\frac{\cdot 3}{\cdot 2} \times 30$ is required volume. Really finding how much more and adding to the original volume.

16 /

16	1	Correct	$0{\cdot}3 \leftrightarrow 30$ $0{\cdot}2 \leftrightarrow ?$ $\quad \frac{0\cdot3}{0\cdot2} \times 30 = 45$ *
13	5	Incorrect	M means moles. Chemical terms confusing; once she knew it was proportion, then, $0{\cdot}2 \leftrightarrow 30$ ml $0{\cdot}3 \leftrightarrow \quad 30 \times \frac{0\cdot3}{0\cdot2} = \frac{9}{0\cdot2} = 1{\cdot}8$
11	5	Correct	$\frac{30}{0\cdot2} \times 0{\cdot}3 = 45$
18	1	Correct	·2 to ·3 is a ratio, so you do it to 30, therefore, 45 is the answer.
16	1	Correct	30 ml 0·3M NaOH ⇒ 30 ml 0·3M HCl * More HCl is required if 0·2M $\therefore 30 \times \frac{3}{2} = 45$ ml
14	1	Correct	No idea. Told 1:1 mole relationship. $30 \times \frac{0\cdot3}{0\cdot2} = 45$ which is the answer.
13	1	Incorrect	Calculate $\frac{0\cdot2}{0\cdot3} \times 30$ to find how much HCl per mole? After given Molarity No. of mls $0{\cdot}3 \leftrightarrow 30$ then calculated $30 \times \frac{0\cdot3}{0\cdot2} = 45$.
13	4	Correct	No idea. Tried $30 \times \frac{2}{3}$. Words with no picture is difficult.
12	4	Incorrect	No idea at all. Would try to make ratios, but which ones?
11	4	Incorrect	Totally confused.
11	4	Incorrect	Did not know what ·2M meant or 'require' or 'neutralise'. If it had been M then same volume of 30. The arithmetic is quite different from that of Question 6.

In this item, pupils had real difficulties. Only 2 out of 14 (marked *) understood what they were calculating, the others had all sorts of problems but mainly chemical language and notation ones, as can be seen from the responses.

Item 9 h) When a given 1M solution of NaOH is titrated against a given 1M solution of H_2SO_4 then

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

h) If 20 ml of 2M H_2SO_4 neutralises 100 ml of NaOH what is the molarity of the NaOH?

A. $\frac{1}{5}$ M

B. $\frac{2}{5}$ M

*C. $\frac{4}{5}$ M

D. 1 M

F.V. = 0·45 (0·14)

D.P. = 0·90 (0·25)

Pupil /

Pupil Score on Test	School Year Section	Response in Written Test	Pupil Method and Comments
20	1	Correct	Assumed 1 to 1 mole relationship and did calculation mentally. When made to read the equation he knew relation was 2 to 1 but could not decide whether to multiply his answer by 2 or $\frac{1}{2}$. *
20	3	Correct	20 ml $\therefore \frac{1}{5}$ more molarity $= 1 - \frac{1}{5} = \frac{4}{5}$ M, but not sure. 20 ml 1M H_2SO_4 40 ml 1M NaOH " 2 " 80 " " " " " " 100 ml $\frac{4}{5}$M "
19	1	Correct	5 times volume $\therefore \frac{1}{5}$ of M $\therefore \frac{2}{5}$ M. When made to read the equation he knew relation was 2 to 1, $\therefore$ double molarity $\therefore \frac{4}{5}$ M *
15	1	Correct	Knew there was a 2 to 1 mole relation from the equation 20 ml 2M H_2SO_4 20 ml 4M NaOH then stuck.
10	3	Incorrect	2M = 2 molar 1M = solution in 1 l $\therefore$ 2M – made up to $\frac{1}{2}$ l. With help got $\frac{1}{5}$ M in 100 mls then stuck. Did not see any need for the equation. *
10	5	Incorrect	Found the chemical equation confusing. $\frac{20}{100} = \frac{1}{5}$ so solution is $\frac{1}{5}$ M. *
3	5	No answer	Did not know what molarity and mole meant. Had no idea how to start it. With a lot of help got 2 20 0·4 100 but really no idea.
18	1	Correct	20 ml 2M H_2SO_4 neutralises 20 ml 4M NaOH. But $20 = \frac{1}{5} \times 100 \quad \therefore \frac{4}{5}$ M
18	1	Incorrect	2 of NaOH and 1 of H_2SO_4. If 2M H_2SO_4 and 2M NaOH, then you would need 2 x 20 mls NaOH $\therefore < 2M$. No clear concept of M, but knew what neutralise meant.
15	1	Incorrect	No idea at all despite aids. *
13	1	Incorrect	No idea at all despite aids. *
11 /			

11	4	Incorrect	Compared 20 and 100, 20 is 5 times stronger than 100 ∴ Divide so $\frac{2}{5}$ M * She had no clear concept that M was Mass/litre.
10	1	Incorrect	No idea at all despite aids. *
8	4	Incorrect	No idea at all despite aids. *
8	4	Incorrect	No idea at all despite aids. *

* Pupils who failed so see the 2 to 1 mole relationship from the equation, or failed to see its relevance to the calculation.

There was again a lot of confusion about chemical terminology and only 2 out of 15 showed they understood the calculation they made correctly.

5·4 Results of the 'Written Test'

A computer printout gave for each item in the test, the frequency of each response, facility value and discriminating power.

Schools 4 and 5 results for N = 31 and N = 36 respectively were as follows:-

ITEM	FREQUENCY OF RESPONSE A		FREQ. OF RESPONSE B		FREQ. OF RESPONSE C		FREQ. OF RESPONSE D		FACILITY VALUE		DISCRIMINATING POWER	
1	0	(0)	1	(0)	30*	(36*)	0	(0)	0·97	(1·00)	0·09	(0·00)
2	0	(0)	0	(0)	30*	(36*)	0	(0)	0·97	(1·00)	0·09	(0·00)
3	4	(2)	0	(0)	0	(0)	27*	(34*)	0·87	(0·94)	0·27	(0·08)
4	3	(6)	0	(0)	0	(0)	28*	(29*)	0·90	(0·81)	0·27	(0·25)
5	2	(1)	6*	(17*)	1	(1)	21	(17)	0·19	(0·47)	0·03	(0·08)
6	2	(10)	2	(2)	24*	(20*)	0	(2)	0·77	(0·56)	0·45	(0·08)
7	8	(6)	1	(2)	15*	(12*)	6	(14)	0·48	(0·33)	0·63	(0·50)
8a	1	(2)	28*	(30*)	0	(0)	1	(4)	0·90	(0·83)	0·27	(0·33)
8b	0	(7)	3	(1)	0	(2)	25*	(26*)	0·81	(0·72)	0·16	(0·33)
8c	23*	(23*)	1	(1)	0	(1)	4	(11)	0·74	(0·64)	0·55	(0·33)
8d	25*	(23*)	4	(7)	0	(0)	1	(6)	0·81	(0·64)	0·55	(0·33)
8e	25*	(21*)	5	(13)	0	(2)	0	(0)	0·81	(0·58)	0·55	(0·75)
8f	9	(12)	1	(9)	0	(1)	17*	(14*)	0·55	(0·39)	0·71	(0·58)
8g	3	(5)	18*	(16*)	2	(9)	5	(6)	0·58	(0·44)	0·91	(0·67)
9a	0	(5)	3	(5)	0	(0)	25*	(26*)	0·81	(0·72)	0·55	(0·33)
9b	1	(8)	5	(4)	0	(3)	21*	(21*)	0·68	(0·58)	0·82	(0·58)
9c	1	(0)	1	(4)	4	(10)	20*	(22*)	0·65	(0·61)	0·82	(0·50)
9d	7	(2)	15*	(19*)	1	(4)	2	(9)	0·48	(0·53)	0·91	(0·33)
9e	10	(17)	14*	(3*)	0	(8)	2	(7)	0·45	(0·08)	0·91	(0·25)
9f	1	(10)	9	(10)	12*	(9*)	4	(6)	0·39	(0·28)	1·00	(0·17)
9g	3*	(12*)	14	(14)	8	(3)	1	(6)	0·45	(0·33)	0·90	(0·08)
9h	6	(16)	3	(11)	14*	(5*)	4	(1)	0·45	(0·14)	0·90	(0·25)

Table 5-1

* indicates the key or correct response for each item

Individual /

Individual pupils' scores on the test were also obtained and these were compared with their scores or grades from S3 Mathematics and Chemistry. For school 4, Mathematics and Chemistry scores in S3 were provided and r, the product moment correlation coefficient was calculated for the scores. For school 5, Mathematics and Chemistry grades in S3 were provided and ρ, the rank correlation coefficient was calculated for the ranks of grades. Results were as follows:-

SCHOOL	Correlation between Maths in S3 and TEST SCORE	Correlation between Chem. in S3 and TEST SCORE	Correlation between Maths in S3 and Chem. in S3
4	0·717	0·755	0·773
5	0·805	0·612	0·690

These figures indicate that in each school there was a degree of relationship between Mathematics and Chemistry performance and the test performance. All correlation coefficients are significantly different from a true correlation of 0 and of 1 - this means we can say with a high degree of confidence that population correlation coefficients, i.e. the correlation coefficients for the same variables for all school pupils about to sit 'O' grade Mathematics and Chemistry, will be of the same order. In fact, the 95% confidence limits for the coefficients as they appear in the table are:-

0·484 - 0·717 - 0·853	0·548 - 0·755 - 0·875	0·577 - 0·773 - 0·885
0·648 - 0·805 - 0·896	0·354 - 0·612 - 0·782	0·468 - 0·690 - 0·830

As an overall picture, themean scores and standard deviations on the test for schools 4 and 5 respectively were:-

$\bar{X}$ = 14·71 (s = 5·69) (N = 31)

$\bar{X}$ = 12·64 (s = 3·23) (N = 36)

The scores forschool 4 were negatively skewed and for school 5 were close enough (from a goodness of fit test) to a normal distribution.

5·4 Pupils' Wrong Responses in the Written Test

The pupils from each school were divided into a top, a middle and a bottom third on the strength of their test score. The frequencies of actual wrong responses for all pupils in these categories were then recorded in the following table for all items in the written test.

A - denotes a pupil who responded wrongly by choosing the distractor A;

B, C and D - denote a pupil who responded wrongly by choosing the distractor B, C or D respectively;

NA - denotes a pupil who gave 'no answer' to an item.

Figures appearing in front of A, B, C, D or NA are coefficients and denote the frequency of occurrence of that response.

Frequencies of Wrong Responses /

Frequencies of Wrong Responses

Item	1	2	3	4	5	6	7	8a	8b	8c	8d	8e	8f	8g	9a	9b	9c	9d	9e	9f	9g	9h	
Top third scoring 20 - 22					2A 5D		1A		2B				2A								1D	1A	School 4 N = 10
Top third scoring 14 - 19				1A	6D	3A 1B 1NA	3D 1NA		1B	2D	2B	1B	2A 1B	1A 1C 1D	1A 1B	3A	1B 1C	1A 3C	7A 1C 1D	4A 2C	4B 4D	4A 4B 1NA	School 5 N = 12
Middle Third scoring 12 - 19			1A		1C 9D	1A 1B	6A 1D			1B 1D			3A	2A 2D	1NA	1B 1NA	1C 2NA	4A 1D 2NA	4A 2D 2NA	4B 3D 2NA	4C 2NA	2A 2B 1D 1NA	School 4 N = 11
Middle Third scoring 12 - 13			1A	2A	6D	4A 1D	4A 5D 1NA	1A 1D	3A 1C	5D	1B 4D	3B 1C	6A 3B	2A 4D	2B	1A 1B	1B 3C	1C 4D	5A 3C 4D	4A 4C 4D	8B 1C	4A 5B 1NA	School 5 N = 12
Bottom Third scoring 3 - 11	1B	1NA	3A	3A	7D 1NA	1A 1B 3NA	1A 1B 5D 1NA	1A 1D 1NA	1B 3NA	3D 3NA	4B 1D 1NA	5B 1NA	4A 1B 4NA	1A 2C 3D 3NA	3B 2NA	1A 4B 3NA	1A 1B 3C 3NA	3A 1C 1D 4NA	6A 3NA	1A 5B 1D 3NA	3A 4C 3NA	3A 1B 3D 3NA	School 4 N = 10
Bottom Third scoring 6 - 11			1A	3A 1NA	1A 1C 5D	3A 1B 1D 1NA	2A 2B 6D	1A 3D	4A 1C	1B 1C 4D	4B 2D	9B 1C	4A 5B 1C	2A 8C 1D	4A 2B	4A 3B 3C	2B 6C	1A 5D 2NA	5A 4C 2D 1NA	2A 3C 2D 1NA	2B 2C 3D 1NA	8A 2B 1D 1NA	School 5 N = 12
Totals including	1	1 1NA	4	3	25 1NA	7 3NA	16 1NA	3 1NA	6 3NA	8 3NA	6 1NA	6 1NA	14 4NA	13 3NA	6 3NA	10 4NA	11 5NA	16 6NA	17 5NA	19 5NA	17 5NA	17 4NA	School 4 N = 31
Totals including			2	7 1NA	19	16 2NA	24 2NA	6	10	13	13	15	22	20	10	15	14	17 2NA	33 1NA	26 1NA	25 1NA	31 3NA	School 5 N = 36

Table 5-2

By observation from this, Table 5-2, pupils in the top third had most difficulty with items 5, 6, 7 and 9d-h in the test; pupils in the middle third had most difficulty with items 5, 6, 7, 8c,d,f,g and 9d-h; and pupils in the bottom third found items 5, 6, 7, 8c,d,e,f,g and 9a-h difficult.

The percentages in each third in each school who responded incorrectly in each item were used to rate items for difficulty. An item rated 0 was one which caused no difficulty, or 0% had it wrong, and an item rated 1 had $>$ 0% of pupils responding wrongly. The ratings were "ranks" of the percentages who responded wrongly in items and so items where a large percentage responded wrongly were rated $\sim$ 21.

By using this method of rating items for difficulty a comparison could be made between the responses for thirds of each school sample more easily, and so it was possible to see exactly which pupils were struggling with which items.

The table below shows ratings:-

Item	1	2	3	4	5	6	7	8a	8b	8c	8d	8e	8f	8g	
Top Third	0	0	0	0	6	0	2	0	4½	0	0	0	4½	0	School 4
	0	0	0	0	11½	10	8½	0	0	2½	2½	0	6	6	School 5
Middle Third	0	0	1½	0	15	4	11½	0	0	4	0	0	6½	8	School 4
	0	0	1	3½	13½	10½	17½	3½	7	10½	10½	7	15½	13½	School 5
Bottom Third	1½	1½	4	4	14½	7½	14½	4	6	10½	10½	10½	10½	18	School 4
	0	0	1	2½	9	6½	15½	2½	4	6½	6½	15½	15½	18	School 5

Item /

Item	9a	9b	9c	9d	9e	9f	9g	9h	
Top Third	0	0	0	0	0	0	2	2	School 4
	2½	6	2½	8½	14½	11½	13	14½	School 5
Middle Third	1½	4	6½	11½	13	14	9½	9½	School 4
	3½	3½	7	10½	19½	19½	15½	17½	School 5
Bottom Third	7½	14½	14½	18	18	21	21	21	School 4
	6½	15½	11½	11½	19½	11½	11½	19½	School 5

Table 5-3

Questions 5, 6, 7 and 9e-h were found equally difficult by all thirds of the class, while other items caused most difficulty to the poorer pupils, as would be expected.

5·5 An Analysis of Wrong Responses

a) Use of the "Inverse Ratio"

A survey was made to see how many pupils in schools 4 and 5 responding wrongly in an item chose the distractor obtained if the inverse ratio of the correct one was used in calculation, i.e.

$$\begin{matrix} A \leftrightarrow B \\ C \leftrightarrow B \times \frac{A}{C} \end{matrix} \quad \text{Instead of} \quad \begin{matrix} A \leftrightarrow B \\ C \leftrightarrow B \times \frac{C}{A} \end{matrix}$$

Refer to Table 5-1 which shows the response pattern for each item. Results were tabulated for the items involved:-

Item	'Inverse Ratio' Response	Number choosing this response	Total number responding incorrectly	z value for difference in proportions choosing this response and expected to choose it
3	A (A)	4 (2)	4 (2)	2·00 (1·42)
4	A (A)	3 (6)	3 (6)	1·74 (2·46)
7	A (A)	8 (6)	12 (24)	0·98 (-0·61)
8b	A (A)	0 (7)	6 (10)	-1·54 (1·65)
8c	D (D)	4 (11)	8 (13)	0·69 (3·82)
8d	D (D)	1 (6)	6 (13)	-0·64 (0·96)
8e	B (B)	5 (13)	6 (15)	1·75 (3·02)
8f	A (A)	9 (12)	15 (22)	1·48 (1·47)
8g	D (D)	5 (6)	13 (20)	0·27 (-0·20)
9a	A (A)	0 (5)	6 (10)	-1·54 (0·77)
9b	A (A)	1 (8)	10 (15)	-1·25 (1·10)
9c	B (C)	4 (10)	11 (14)	0·15 (2·01)
9d	- (A)	- (2)	- (17)	- (-1·47)

Table 5-4

Chi- squared:

$\chi^2 = \sum z^2 = 20{\cdot}53 \quad (46{\cdot}00)$

for 12 (13) **degrees of freedom**

χ^2 is a measure of the difference between actual numbers of pupils choosing the 'inverse ratio' response and numbers of pupils expected to choose this response.

If results for schools 4 and 5 are summed then $\chi^2 = 66{\cdot}53$ for 25 degrees of freedom. This value is significant at the 1% level which means that when we compare the proportion of pupils we would expect to choose the 'inverse ratio' response with the actual proportion of pupils who do choose it, then this difference is significant at the 1% level.

The pupils involved range from the top third to the bottom third of each school; they spot a relationship between figures but do not know which way round to put it - is it 2 to 1 or 1 to 2?

b) An Easy Option

In item 5, 21 (17) out of 25 (19) who responded wrongly chose D - the distractor that suggested more information was required. In item 7, 6 (14) out of 16 (24) who responded wrongly chose D - again the distractor suggesting a lack of information. Applying the same test as in (a) it was found that a significant number of pupils in doubt choose the easy option response, $\chi^2 = 29{\cdot}14$ for 4 degrees of freedom, which is significant at the 1% level.

c) Number Pattern Seeking

In item 6, which involved essentially two direct proportion calculations, 2 (10) out of 7 (16) wrong chose A; 2 (2) chose B; and (2) chose D. A, B and D are responses obtained by operating incorrectly on given data, e.g. $72 \div 16 \div 0{\cdot}45$ gives A when one should have $72 \div 16 \times 0{\cdot}45$. The idea of pupils juggling with figures to obtain a suitable response was also evident from the interviews and from some of the items on stoichiometry - there is no real understanding of the unknown variable and its calculation.

d) /

d) Chemical Concept(s)

In item 8a), 2 (6) out of 3 (6) who responded incorrectly chose a distractor which indicated they had no clear understanding of the mole concept or were unable to interpret the given chemical equation in terms of the mole. Also in item 9a), (5) out of (10) wrong chose response A; 3 (5) out of 6 (10) wrong chose B; and 3 out of 6 wrong gave no answer. Response A is the 'inverse ratio' response indicating pupils do know there is a 2 to 1 mole relationship but do not know which way to express it, so they clearly do not understand the mole concept. Pupils responding B also clearly did not understand the mole concept since they must have made the ass umption of a 1 to 1 mole relation. The responses in the other parts of item 9 also reflect this concept lack since it was clear that certain responses would not be chosen if the 2 to 1 mole relationship was taken into account.

The responses in the interviews indicated as well as difficulty with the mole concept, some pupils also found the words 'neutralise', 'required' and 'molarity' contributing factors to their inability to recognise and tackle problems of the type in the test.

5.6 Conclusions, Recommendations and Future Scope

From the results of observations in the interviews and of the written test there are clearly pupils who

1) have difficulty in recognising the 'type' of problem

2) like to be able to visualise the problem

3) recognise the key from a given distractor

4) solve problems in ratio and proportion mentally

5) merely guess an answer, after trying to operate logically on the data but they really lack reasoning

6) must have the data in the 'Mathematics' format $\begin{matrix} A \leftrightarrow B \\ C \leftrightarrow ? \end{matrix}$ and if it is not presented like this then they reverse the data to follow this format before solving the problem

7) have difficulty in isolating relevant data and in getting the format $\begin{matrix} A \rightarrow B \\ C \rightarrow ? \end{matrix}$ particularly if there is irrelevant data in the problem

8) avoid use of the format $\begin{matrix} A \leftrightarrow B \\ C \leftrightarrow ? \end{matrix}$ because it presents the problem as to which way up the ratio goes

9) have difficulty with numbers other than whole numbers - see item 6

10) must have whole numbers because they look for a common factor and solve from there

11) have difficulty when Chemical concepts like mole, molarity, neutralisation concentration and ions interfere with the mechanical technique they use in a Maths. example for solution

12) cannot translate a Chemical equation into real terms and understand it thus discount it when doing a stoichiometric calculation

13) have difficulty calculating an unknown molarity - see items 8f,g and 9g,h and in calculating an unknown volume in a 2 to 1 mole situation when the known molarities are different - see items 9d,e and f

There was a variety of methods of solution used by pupils. Some pupils showed clear understanding and reasoning but many merely followed a recipe /

recipe after recognising the problem 'type'. Pupils in the interviews confirmed that recognition was often difficult and this meant that thinking can only be done by some in terms of visualising what the set up is. Spatial ability has already been shown to be an asset to a pupil in obtaining mastery over skills in Mathematics.[36] Myers has said, "We believe that the person with this ability or these abilities will characteristically reason in a different manner from the people who have little of these abilities."[36]

The work covered in this report suggests there are areas of difficulty in the 'O' grade Chemistry course which are clearly linked to Mathematics. Teachers must be informed and be prepared to amend their methods and timing, but this can only be done satisfactorily if <u>all</u> Science teachers agree that there are areas of difficulty common to their syllabuses and that of Mathematics, and they <u>all</u> discuss new teaching methods with mathematicians advising. A recent report[37] on the relationship between Mathematics and Physics at 'O' grade suggested that pupils had little difficulty with graph interpretation. From research done in Chapter 3, pupils of Chemistry, even at S4 level, have considerable difficulty. Real problems no matter how fundamental and simple to the observer must be faced at the earliest stage possible.

Mathematicians, who have to provide pre-requisite skills for so many subjects must meet the needs of scientists after discussion. There is at the moment a great deal of discussion and confusion about the 'new Mathematics' - new in the sense that it is an internal consistency with itself - but it must also be new in the sense of being an external consistency for all the other subjects. Courses must be brought into line with each other and complement each other where possible.

Teachers and curriculum planners must form a close liaison and make the right decisions about timing and teaching methods if each pupil is to gain /

gain maximum benefit from studies at the correct stage in his mental development.

As a follow-up to the research described in Chapters 1 - 5 and the conclusions made, it is suggested that further research should centre round some of the following areas of interest:-

1. Ways in which 'O' grade Chemistry and Mathematics courses can be brought more into line.
2. An extension of face-to-face investigations rather than external testing for other areas of difficulty which are to be helped - this is the most direct way of getting a lot of information from pupils about the methods they use.
3. An attempt to discover why so many pupils must have a good spatial ability for problem solving if they do not apply a rule of thumb. Many tests for measuring spatial ability have been designed for various levels and can be obtained for use.
4. Work to find out if 'alternative' teaching methods are more suitable for some of the difficulty areas already defined. Some pupils learn more easily when interacting with a computer and of course they can be recorded, and Computer Aided Instruction could prove to be useful as a diagnostic. Audio Visual material to supplement formal teaching, which pupils can work at in their own time, might ensure 'mastery' of many topics not otherwise achieved. Teachers themselves can invent novel ways of teaching difficult topics if they always try to remember what the learners' position is like. A self-teach written linear or branched programme on a specified topic might be all that is necessary. It is, of course, important to indicate to the pupil the topic being studied - pupils like to know /

know what they are learning about and everything then becomes more meaningful. In the new Mathematics pupils tend to learn techniques in the abstract and context is often not clear to them.

5. A critical study of school text-books after discussion between colleagues about common problems to Science and Mathematics courses.

It is of interest that after a one-day conference to discuss the "hows" and "whens" of teaching the various mathematical skills required of students of Chemistry at school and university level, arranged by the Tayside Section of the Chemical Society, many Mathematics and Chemistry teachers were more aware of real problems necessitating communication between departments and they were willing to face these and try and solve them. They appreciated each others point of view. It may be that regional conferences of this type would be as beneficial to teachers as in-service courses. Someone must take the initiative in arranging one or other of these alternatives - there is an obvious need for more opportunities for Chemistry teachers to discover what is going on in Mathematics departments and to learn about the current jargon of Mathematics which once understood is found to be far from terrifying.

PLEASE ANSWER ALL QUESTIONS ON THE PAPER PROVIDED, SHOWING YOUR ANSWERS CLEARLY

1) The ticket for a 100 yard journey costs 45p; what should the cost of a 150 yard journey be?

A. 30p
B. 60p
C. $67\frac{1}{2}$p
D. 95p

2) 12 pellets of solid NaOH are required for neutralisation of 100 ml of molar HCl; how many pellets will be required for neutralisation of 150 ml of molar HCl?

A. 8
B. 16
C. 18
D. 62

3) What is the weight, in lbs., of 1 cubic foot of lead if we know that 1 cubic foot of water weighs 62·5 lbs. and lead is 10 times as dense as water is?

A. 6·25 lbs.
B. 71·5 lbs.
C. 72·5 lbs.
D. 625 lbs.

4) A 100 ml of 1M.HCl requires 15 pellets of NaOH for neutralisation; how many pellets will 100 ml of 3M HCl require?

A. 5
B. 17
C. 18
D. 45

5) If we stirred a known mass of Zn into an excess of silver nitrate solution, then which statement is correct?

A. Every gram of Zn gives 2 grams of Ag
B. Every gram of Zn gives a fixed mass of Ag
C. Every volume of Zn gives 2 volumes of Ag
D. You cannot tell from the given information

6) A "slow motion" camera takes pictures at 72 frames per second, and these are projected on a screen at 16 frames per second. How long will a shot of a golfer's swing take when projected if it actually takes 0·45 seconds to complete?

A. 0·10 secs.
B. 10 secs.
C. 2·025 secs.
D. 25·20 secs.

7) What volume of 0·2M HCl is required to neutralise 30 ml of 0·3M NaOH solution?

A. 20 ml
B. 33 ml
C. 45 ml
D. Need more information

8) When a given 1M solution of NaOH is titrated against a given 1M solution of HCl, then

$NaOH + HCl \rightarrow NaCl + H_2O$

a) How many moles of NaOH are required to react with one mole of HCl?

A. $\frac{1}{2}$ mole
B. 1 mole
C. $1\frac{1}{2}$ moles
D. 2 moles

b) What volume of 1M NaOH will neutralise 2 l. of 1M HCl?

A. $\frac{1}{2}$ l.
B. 1 l.
C. $1\frac{1}{2}$ l.
D. 2 l.

c) What volume of 4M NaOH will neutralise 1 l. of 1M HCl?

A. 1/4 l.
B. $\frac{1}{2}$ l.
C. 2 l.
D. 4 l.

d) What volume of 4M NaOH will neutralise 500 ml of 1M HCl?

A. 125 ml
B. 250 ml
C. 1 l.
D. 2 l.

e) What volume of 4M NaOH will neutralise 250 ml of 2M HCl?

A. 125 ml
B. 500 ml
C. 1 l.
D. 2 l.

f) If 1 l. of 1M NaOH neutralises 500 ml of HCl, what is the molarity of the HCl?

A. $\frac{1}{2}$ M
B. 1 M
C. $1\frac{1}{2}$ M
D. 2 M

g) If 20 ml of 2M HCl neutralises 100 ml of NaOH, what is the molarity of the NaOH?

A. 1/10 M
B. 2/5 M
C. 2·5 M
D. 10 M

9) When a given 1M solution of NaOH is titrated against a given 1M solution of H_2SO_4 then

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

a) How many moles of NaOH are required to react with 1 mole of H_2SO_4?

A. $\frac{1}{2}$ mole
B. 1 mole
C. $1\frac{1}{2}$ moles
D. 2 moles

b) What volume of 1M NaOH will neutralise 1 l. of 1M H_2SO_4?

A. 500 ml
B. 1 l.
C. $1\frac{1}{2}$ l.
D. 2 l.

c) What volume of 1M NaOH will neutralise 2 l. of 1M H_2SO_4?

A. 500 ml
B. 1 l.
C. 2 l.
D. 4 l.

d) What volume of 4M NaOH will neutralise 1 l. of 1M H_2SO_4?

A. 250 ml.
B. 500 ml
C. 1 l.
D. 4 l.

e) What volume of 4M NaOH will neutralise 500 ml of 1 M H_2SO_4?

A. 125 ml
B. 250 ml
C. 1 l.
D. 2 l.

f) What volume of 4M NaOH will neutralise 500 ml of 2M H_2SO_4?

A. 125 ml
B. 250 ml
C. 500 ml
D. 1 l.

g) If 1 l. of 1M NaOH neutralises $\frac{1}{2}$ l. of H_2SO_4 what is the molarity of the H_2SO_4?

A. $\frac{1}{2}$ M
B. 1 M
C. 2 M
D. 4 M

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

A. 1/5 M
B. 2/5 M
C. 4/5 M
D. 10 M

Solution of Questions 2, 4, 6, 7 and 9 h) to be investigated

Instructions:-

1. Let the pupil read the problem and then ask him to identify the problem topic. 'Which topic have you studied that this is a problem in?' Indicate on the answer sheet.

2. Ask the pupil to 'think aloud' while writing down a solution to the problem, and as far as possible to explain why he writes what he does. Note the pupil comments.

3. Tick on the answer sheet -
   1) the method of solution the pupil uses;
   2) the steps in the solution process done correctly.

4. Cross on the answer sheet the steps in the solution process done incorrectly.

5. If the pupil cannot start to solve the problem, tell him it is a problem on Ratio and Proportion - if this does not help, give him the first two lines of the solution using one-to-one correspondence method.

6. If the pupil has two consecutive lines wrong, or mistakes, stop him and help him reason the steps aloud - when corrected, let him go on.

7. If the pupil has difficulty in forming ratio(s) the right way up, for example at line 3 in one-to-one correspondence method; at line 2 in equivalent ratios method; at lines 3, 4 in unitary method; then make him reason out loud and decide whether he wants a bigger/smaller quantity.

8. If the pupil has difficulty in isolating a variable in an equation, for example at line 3 in equivalent ratios method; at line 3 in equal products method; then explain the process by cross multiplication or otherwise.

   Indicate all aids required on the answer sheet.

9. If the pupil fails to solve the problem would you say the difficulty he had was due mainly to his inability in -
   (i) stating variables
   (ii) obtaining relations between variables
   (iii) isolating the unknown variable
   (iv) arithmetical manipulation

   Indicate on the answer sheet

NAME

QUESTION 4 - ANSWER SHEET

Equivalent Ratios	One-to-one correspondence or unitary method	Equal Products	Slide Rule	Identified Topic :- Tick method used - if another, state
1) Molarity No. of pellets	2) Molarity No. of pellets	1) $1 \times x = 3 \times 15$	1) Molarity No. of pellets	Tick each stage done correctly Cross " " " incorrectly
2) $\frac{1}{3} = \frac{15}{x}$	2) $1 \longleftrightarrow 15$ 3) $3 \longleftrightarrow 15 \times \frac{3}{1}$		2) $1 \rightarrow 1{\cdot}5$ $\uparrow$ $\downarrow$ 3 $4{\cdot}5$	Pupil's comments :
3) $x = 3 \times 15$ 4) $= 45$	4) $= 45$	2) $x = 45$	3) Answer $= 45$	
5) No. of pellets = 45	5) No. of pellets = 45	3) No. of pellets = 45	4) No. of pellets = 45	Aids required:-
				Failure to solve due to difficulty in:- 1) stating variables 2) obtaining relations between variables 3) isolating the unknown variable 4) arithmetical manipulation

NAME

QUESTION 7 - ANSWER SHEET

Equivalent Ratios	One-to-one correspondence or unitary	Equal Products	Slide Rule	Equivalent Moles method	Identified Topic: ; Tick method used - if another, state
1) Molarity / No. of mls.	1) Molarity / No. of mls.	1) $30 \times 0{\cdot}3 = x \times 1$	1) Molarity / No. of mls.	1) $NaOH + HCl \rightarrow NaCl + H_2O$	Tick each stage done correctly Cross " " " incorrectly
2) $\frac{1}{0{\cdot}3} = \frac{30}{x}$	2) $0{\cdot}3 \longleftrightarrow 30$ 3) $1 \longleftrightarrow 30 \times \frac{0{\cdot}3}{1}$		2) $\frac{1}{3}$ (↑) → $\frac{3}{9}$ (↓)	2) 1 mole NaOH requires 1 mole HCl	Pupil comments ;
3) $x = 30 \times 0{\cdot}3$ 4) $= 9$	4) $= 9$	2) $x = 9$	3) Answer = 9	3) NaOH: 30 ml, 0·3M | HCl: x ml, 0·2M	
5) Molarity / No. of mls	5) Molarity / No. of mls	3) $9 \times 1 = y \times 0{\cdot}2$	4) Molarity / No. of mls	4) $\frac{30}{1000} \times 0{\cdot}3$ moles | $\frac{x}{1000} \times 0{\cdot}2$ moles	Aids required:-
6) $\frac{0{\cdot}2}{1} = \frac{9}{y}$	6) $1 \longleftrightarrow 9$ 7) $0{\cdot}2 \longleftrightarrow 9 \times \frac{1}{0{\cdot}2}$		5) $\frac{2}{1}$ (↑) ⟶ $\frac{9}{4{\cdot}5}$ (↓)		
7) $0{\cdot}2y = 1 \times 9$ 8) $y = \frac{9}{0{\cdot}2}$ 9) $= 45$	8) $= 45$	4) $y = \frac{9}{0{\cdot}2}$ $= 45$	6) Answer = 45	5) $\frac{30 \times 0{\cdot}3}{1000} = \frac{x \times 0{\cdot}2}{1000}$	Failure to solve due to difficulty in:- 1) stating variables 2) obtaining relations between variables 3) isolating the unknown variable 4) arithmetical manipulation
10) No. of mls = 45	9) No. of mls = 45	5) No. of mls = 45	7) No. of mls = 45	6) $x \times 0{\cdot}2 \times 1000 = 30 \times 0{\cdot}3 \times 1000$ 7) $x = \frac{30 \times 0{\cdot}3}{0{\cdot}2}$ 8) $= 45$ 9) No. of mls = 45	

CHAPTER 6

CRYSTAL STRUCTURES.

6·1 Introduction

The first year Chemistry course at the University of Glasgow includes five lectures which give an introduction to crystal structures of metallic and ionic solids. As this lecture course is the foundation for work done in subsequent years on crystal structures, it is particularly important that students should obtain 'mastery' of the topic in their first year.

In this instance as is the case for other topics taught as part of the first year Chemistry course, the lecture method alone is inadequate for the following reasons:-

1) Very little feedback from students can be obtained - this means the lecturer cannot pace his presentation of the material.
2) The student has little opportunity to rehearse his learning by -
   (i) consolidating material,
   (ii) developing concepts by frequent use,
   (iii) relating different items of information to obtain a view of the whole topic being studied.
3) Lecturing is a relatively passive form of learning and passive methods of learning are less effective than active ones involving the desired behaviour.
4) Lecturing is poor for maintaining attention and stifles self expression.
5) Retention of information presented in lectures is inferior in delayed tests of recall - this has been shown by Bane.[38]
6) It is impossible to communicate 3D ideas to large groups of students in lecture theatres. Beyond a few yards even the best 3D models become 2D.

A questionnaire/

A questionnaire completed by thirty-three first year students in June, 1973, showed for which topics in the first year course, lecturing as a sole teaching medium was inadequate - in other words, for which topics some form of supplementary material was requested.

Results of the questionnaire

Supplementary material requested on:-	No. of students intending one year of Chemistry	No. of students intending two years of Chemistry	No. of students intending three years of Chemistry	No. of students intending four years of Chemistry	TOTAL
1) Gas Laws	4	6	-	2	12
2) Structures of molecules	4	3	1	6	14
3) Interpretation of graphs	1	1	-	3	5
4) Rates of Chemical Reactions	8	4	4	1	17
5) Thermodynamics	4	6	1	3	14
6) Chemical Equilibrium	6	3	2	4	15
7) Crystal Structures	10	7	4	9	30
Total number of students in each category	11	9	4	9	33

The students who completed the questionnaire were randomly selected, nineteen were in the top third of the class, eleven were in the middle third and three in the bottom third on the strength of diagnostic test /

test and class examination scores.

Having obtained this information from the students, the problem was what to use either along with lectures or as supplementary material to the lectures. Various teaching methods were available:-

1) Buzz groups
2) Problem Centred Groups
3) Controlled Discussion
4) Lecture Discussion
5) Case Discussion
6) Short Talks by Students
7) Audio Tapes
8) Lecture Demonstrations
9) Tutorials
10) Practical Sessions
11) Programmed Learning
12) Projects
13) Simulation and Games

Combinations of these teaching methods can of course be used. Although previous research[39] suggests there is no significant difference between knowledge gained from lecture and from a variety of other teaching methods, research in Glasgow University suggests it is better to use a variety of teaching methods even in a 'lecture' period.[40]

Educational Reasons for the use of varied Teaching Methods:-

1) Different kinds of objectives are best achieved by different methods.
2) Teachers usually have a number of different kinds of objectives in any one lesson.
3) Therefore, the objectives of any one lesson are usually best achieved by different methods.

6·2 Supplementary Material on Crystal Structures

The type of material to design as a 'back-up' for the lectures on Crystal Structure was the first and most important decision to be made for the project in hand.

Since students had to be able to visualise structures in 3D, presentation of any material had to involve good 3D models of structures. Recognising distinctive features of each type of structure and distinguishing one type of structure from another would then be easier.

In previous years the students had attended two practical sessions, each of three hours duration, when they constructed their own models of structures. In practice, this proved to be unsatisfactory mainly due to badly designed 'Catalin' ionic model kits being provided, but also to the time limits. Also, students inevitably required individual help and therefore it seemed more feasible to produce some form of audio-visual self-teach programmed material on this topic that could also be used for revision before examinations and before subsequent study of the topic in third year.

6 ·3 Function of the self-teach material

Since the material was required to supplement a lecture course and not to provide an alternative for it, the function was to aid the students achieve 'mastery' of the objectives of the lecture course.

The content of the material was outlined after consultation with lecturers of the course and examination of objectives specified by them. The supplementary material and lecture course material, itwas felt, should be compatible and so objectives for both were the same. Extra background information could be given in self-teach material and points made in lecturse could be explained in more detail in the self-teach course.

6·4 Reasons for Preparing Self-Teach Programs

1. Large numbers of mixed ability students can learn effectively.
2. Instruction is learner controlled.
3. Multi-media used
4. Popular with students
5. Easy to run
6. Criterion testing gives a measure of the achievement of the objectives of the course.

6•5 Design of the Self-Teach Material

The amount of material was divided into seven units entitled Programs 1 - 7 under the following headings:-

A. Close Packing of Spheres - Programme 1

B. Features of Close Packing

(i) Interstitial sites - Programme 2

(ii) Unit cells - Programme 3

C. Ionic Crystal Structures

(i) MX type - NaCl - Programme 4

(ii) MX type - CsCl and ZnS; - Programme 5

MX_2 type - CaF_2 and TiO_2

D. Effect of Radius Ratios on Structures - Programme 6

E. Identification of some MX and MX_2 type structures - Programme 7

The content and preparation of Programmes 1, 2, 3 and 7 is described here - Mrs. N.C. Kellett will report on Programmes 4, 5 and 6.[7]

6·6 Aims in Designing the Programmes

1. The models used should be simple and cheap to construct, but adequate to illustrate the properties being defined.
2. Two types of models should be used:-

   i) Space filling models

   ii) Ball and stick 'Beevers'[41] type of model
3. Students should wherever possible be able to handle the models shown in slides and referred to on tape so that they can identify for themselves properties of the structures which the models represent.
4. Students should be shown slides of the actual models and clearly labelled perspective drawings of actual models so that they can learn to interrelate a 3D structure and a 2D representation.
5. Students should be given an opportunity to build their own models of close packed structures at least.

6.7 Justification for the Use of Models

1. A fundamental understanding, rather than mere familiarity with descriptive facts, can be acquired from using models as the method of representation.
2. Students can predict accurately from good models many of the physical and chemical properties of the compounds.
3. Spheres reproduce the true physical picture to the extent that they occupy space when their sizes are, in fact, relative sizes of the atoms they represent.

6·8 Objectives of the Programmes

Programmes 1, 2 and 3 were concerned with features of close packing arrangements of spheres of equal size and the make-up of the arrangements themselves namely hexagonal close packing, face-centred cubic packing and body-centred cubic packing.

The objectives relevant to the programmes and to this section of the lecture course were:-

1. Pack one layer of equal spheres in the most economical way.
2. Pack layers of equal spheres in 3D to show -
   a) hexagonal close packing,
   b) face-centred cubic packing,
   c) body-centred cubic packing.
3. Pack layers of equal spheres in hexagonal form to show -
   a) ABAB sequence,
   b) ABC ABC sequence.
4. Identify face-centred cubic packing in hexagonal ABC ABC close packing.
5. Identify tetrahedral and octahedral sites in each of the close packed structures in 2.
6. Identify the unit cell for each of the close packed structures in 2.

Programme 7 which was designed to be an assessment of Programmes 1-6 involved the students in identifying several unknown models by deductive method. The models consisted of some MX type structures and some MX_2 type structures.

The objectives relevant to Programme 7 were:-

Students should be able to -

1. /

1. State the coordination number of each ion species in a given model.
2. State the ratio of coordination numbers of the cation to anion.
3. State the stoichiometry of the compound.
4. With information on ionic radii and names of some compounds forming MX and MX_2 type structures studied in Programmes 4 and 5, identify the given models.

6·9 The Design of the Individual Programmes

Various ways of programming material exist:-

(i) Linear Programmes

(ii) Branched type of Programme

(iii) Structural communication type of programme [42]

(iv) Audiotape

(v) Film-strip with accompanying script

(vi) Tape-slide type of programme

(vii) Film-loop

Since much of the material for Crystal Structures was suitable for discussion and description and simultaneously involved the use of models it was decided that "traditional" programming methods were not appropriate. Instead a tape slide type of program was designed.

Programmes 1, 2, 3, 4 and 5 consisted of a set of 35 mm slides along with an Emi-type cassette. Programme 6 consisted of a workbook and a cassette and Programme 7 consisted of a detailed question and answer sheet, information sheets, a set of slides and a cassette.

Both slides and tapes are relatively cheap and easy to produce and can be easily altered or reproduced.

Programme 1

Metals were used as an example of solids which pack to form a 3D arrangement of equal spheres.

Two ways of packing circles in 2D $\Rightarrow$ several different ways of packing layers of spheres in 3D.

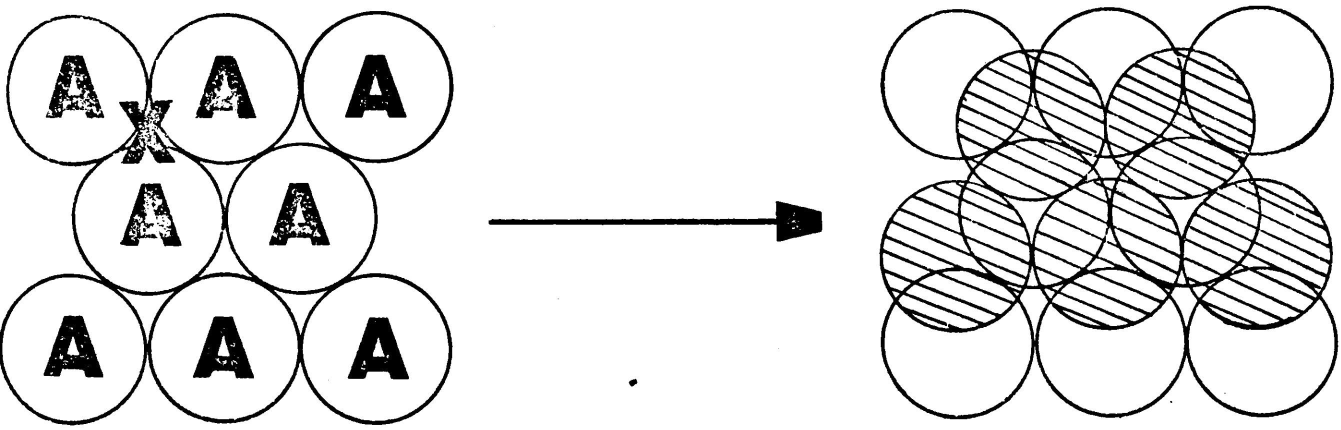
If /

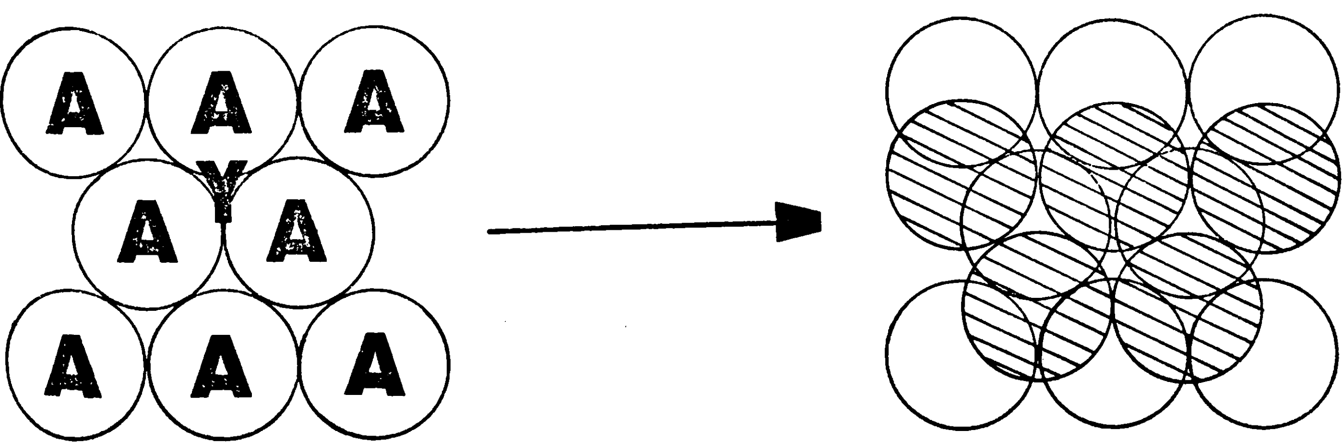
If equal layers of hexagonally close packed spheres are packed together then there are two <u>alternative</u> positions for the third layer to be placed above two below:-

a) directly over the first layer spheres → AB AB hexagonal close packing;

b) over the spaces between first layer spheres → ABC ABC face-centred cubic packing.

The two alternative positions are shown in the diagrams below.



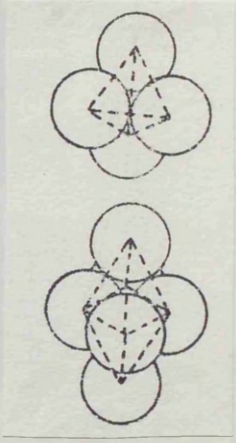


Students /

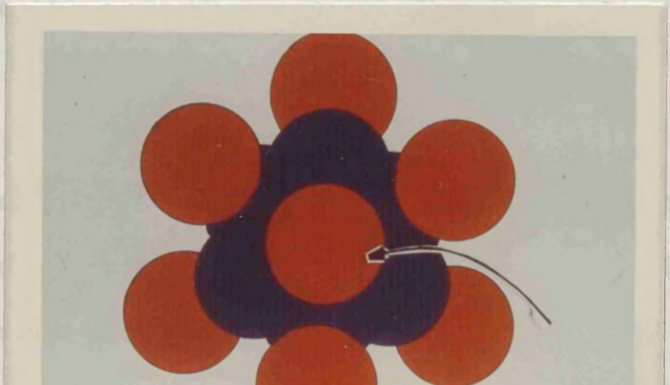
interstitial sites by examination of individual arrangements of -

(i) 4 close packed equal spheres, the centres of which are corners of a regular tetrahedron

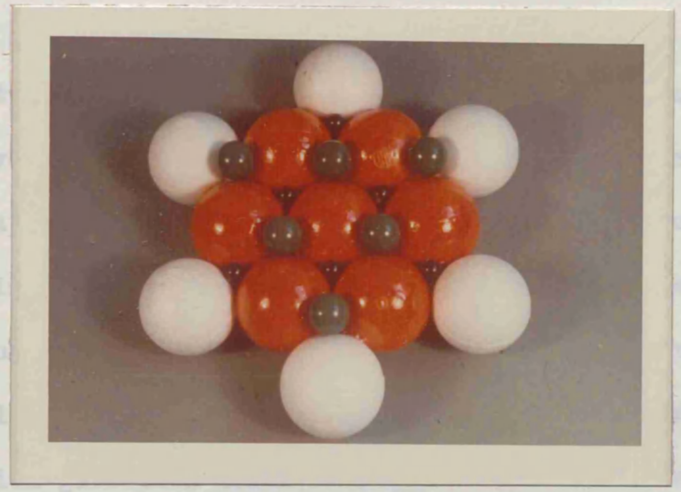
(ii) 6 close packed equal spheres, the centres of which are corners of a regular octahedron.



The emphasis then was placed on the ability to identify each type of site, tetrahedral and octahedral, in each of the models of close packed arrangements studied in Programme 1. Diagrams of models with clearly labelled sites were shown on slide, e.g.



In conclusion, the relationship in positions of each type of site was explained by the use of a model where close packed layer spheres were hexagonally arranged and tetrahedral and octahedral sites were filled with an appropriate size of different coloured spheres. (Colour print from slide)



The students were encouraged to refer to the spaces as 'sites' and not 'holes' in case there was a tendency for them to think of the actual shape of the spaces or holes as tetrahedral and octahedral rather than the disposition of spheres surrounding the spaces.

Programme 3

The main aim of this program was clearly to define a unit cell and then explain how to construct one for each of the close packed arrangements studied in Programme 1.

The sequence adopted was to work from body-centred cubic (where there was a one to one relationship between the corner and centre spheres) move to face-centred cubic (where there was a one to three relationship) and finally to study the more complex hexagonal arrangements.

The students were asked to look at models used in Programme 1, where all spheres were whole and from these to work out what the unit cell consisted of - their response was confirmed in the tape slide sequence. The 'cut-away' models were available for close examination.

Programme 7 /

Programme 7

The students worked 'deductively' through the process of identifying seven models by answering questions on the question/answer sheets in the appendix, p 208. Two methods of identification were suggested and information sheets (see appendix p211½) were advised for consultation during the process of identification. After answering (on the sheets) all questions relevant to all models, the students listened to the tape which gave them correct responses for the questions and simultaneously looked at slides of the models, comparing them with slides of the models of structures studied in Programmes 4 and 5. The students finally left their question/answer sheets in an answer box which was provided. The results of this programme are summarised on p 190.

6·10 Use of the Programmes

The programmes were available for use immediately after the lecture course was completed. Two sets of each programme were located in a self-teach laboratory and the necessary hard-ware for their use was provided :-

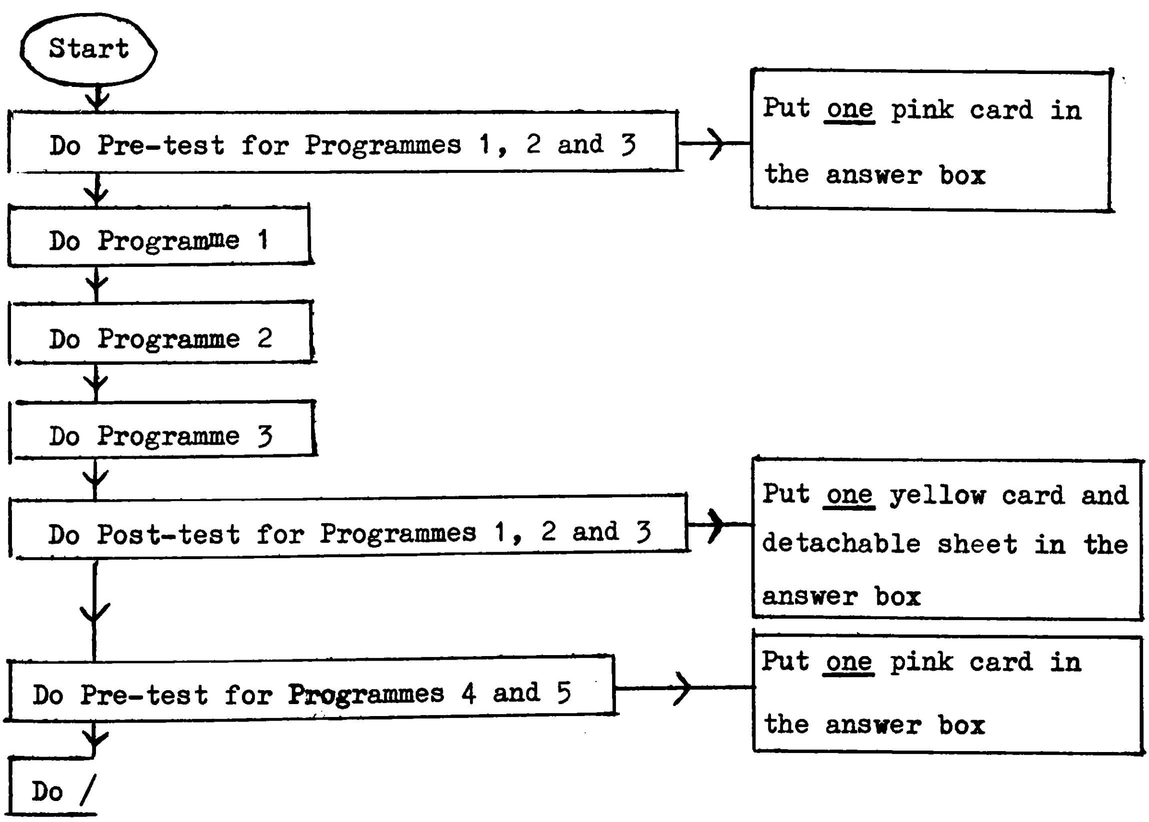
6 sets of one Phillips N 200 Cassette Recorder

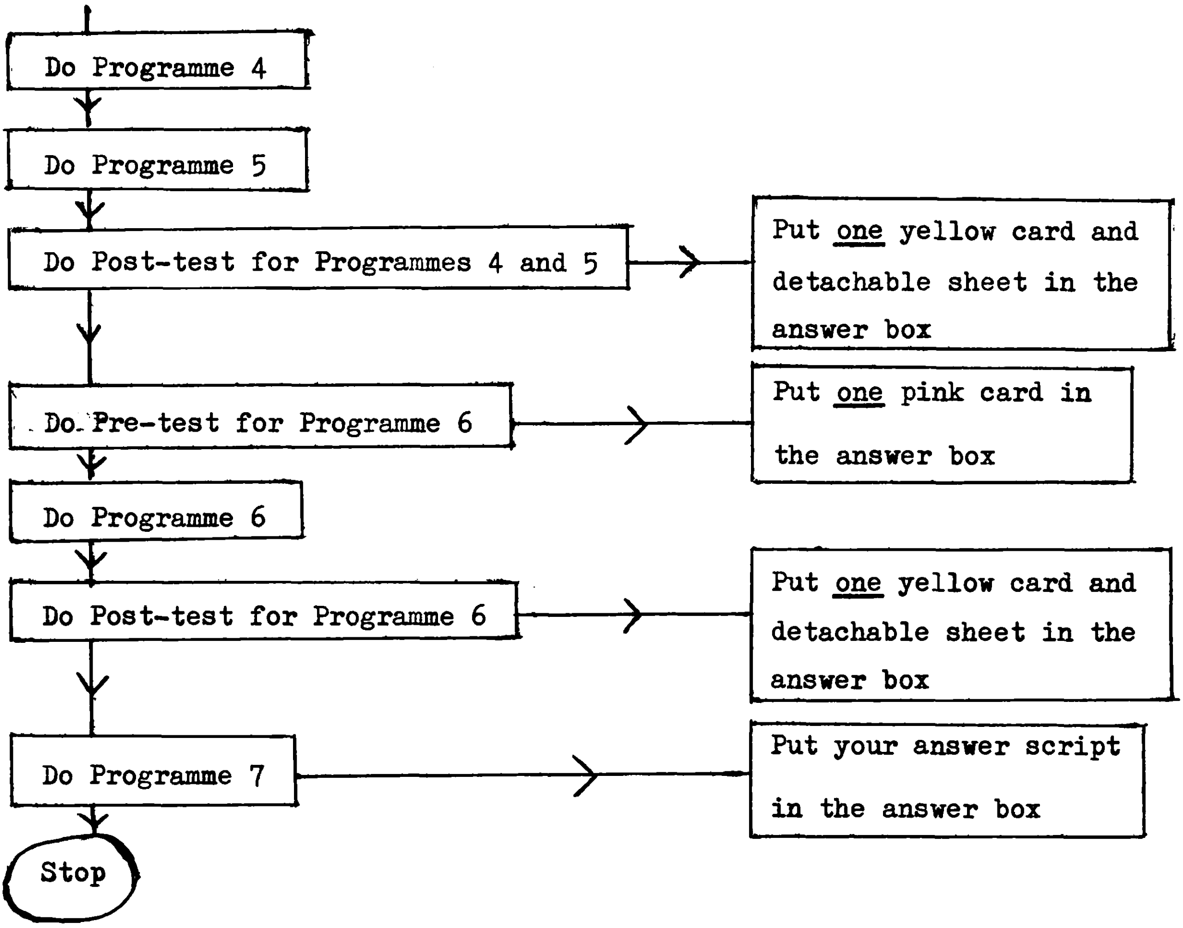
6 sets of one Agfascop 20 Slide Viewer

6 sets of one pair Eagle International SE 5 Headphones

A route was suggested for working through the programmes but it was obviously possible to select one or more programmes at random for studying particular weaknesses. Students would work through any programme at their own pace and, if necessary, use any program any number of times.

A 'Suggested' Route for doing the Programmes on Crystal Structures




Do Programme 4
Do Programme 5
Do Post-test for Programmes 4 and 5
Put one yellow card and detachable sheet in the answer box
Do Pre-test for Programme 6
Put one pink card in the answer box
Do Programme 6
Do Post-test for Programme 6
Put one yellow card and detachable sheet in the answer box
Do Programme 7
Put your answer script in the answer box
Stop

6·11 Assessment of the Programmes

This session 1973-74 was the first one when the self-teach material on Crystal Structures was available and so it was decided that the assessment should be diagnostic of the programme :-

a) to show weaknesses or misleading parts,

b) to assess the 'mastery' value.

and not solely diagnostic of the student.

It was decided that any form of test had to be concise, be quick for the student to do, and that the same test should be used for pre and post assessment otherwise differences may be due to different tests.

The tests were related to the objectives of the course and were designed so that -

Question Sheet 1 was pre and post Programmes 1, 2 and 3

Question Sheet 2 " " " "	Programmes 4 and 5	} Mrs. N.C. Kellett [7]
Question Sheet 3 " " " "	Programme 6	} will report

Programme 7 was, of course, self assessing and really an assessment in its own right of Programmes 1-6.

The items in the tests were scored on a 0, 1 basis and students were encouraged not to guess by inserting in each item a 'Don't know' option. It was possible from the results to measure the difference in performance of each student. When tests are related to specific objectives based on a course, are the total scores and differences in performance really meaningful? When 1 or 0 was allocated to an item, this was not the same as 1 or 0 for another item and therefore score increase of 6 to

10 /

10 was not the same as 10 to 14.

Deterline (1971)[43] pointed out that each item in a test is a stimulus response system and the test is a collection of such items - he also pointed out that a score of 75% tells little about the student's performance - what is needed instead is to know which items a student had wrong and relate those to the objectives of the course. In other words, the item gains are more useful than the total gains.

Also, differences in total scores are often statistically indeterminant due to -

a) small numbers of students,

b) expected large spread of scores in either pre or post test.

An attitude questionnaire was attached to each post test and it gave an indication of ease, interest and use of programmes and time taken to do each programme.

6·12 Item by Item Analysis for Question Sheet 1

The test which had 15 objective items can be found in the appendix p213. Results were as follows:-

Question Sheet 1 : figures show frequency of responses for A, B, C, D and E for questions 1 - 15

Qu.	A		B		C		D		E		Facility Value		Difference in Facility Values
1	18	[7]	*38	[35]	8	[1]	7	[1]	3	[-]	0·51	[0·80]	significant
2	5	[5]	14	[3]	1	[-]	*53	[36]	1	[-]	0·72	[0·82]	not significant
3	4	[1]	6	[3]	11	[1]	*51	[39]	2	[-]	0·69	[0·89]	significant
4	*46	[21]	14	[2]	3	[1]	7	[20]	4	[-]	0·62	[0·48]	not significant
5	1	[2]	8	[1]	20	[9]	*35	[31]	10	[1]	0·47	[0·70]	significant
6	12	[3]	2	[-]	21	[12]	*25	[28]	14	[1]	0·34	[0·64]	significant
7	5	[4]	10	[-]	*42	[33]	8	[6]	9	[1]	0·57	[0·75]	significant
8	8	[1]	*23	[37]	19	[3]	10	[2]	14	[1]	0·31	[0·84]	significant
9	14	[3]	17	[8]	*17	[23]	18	[10]	8	[-]	0·23	[0·52]	significant
10	*24	[15]	20	[17]	13	[6]	3	[5]	14	[1]	0·32	[0·34]	not significant
11	*27	[30]	11	[5]	5	[2]	4	[3]	27	[4]	0·36	[0·68]	significant
12	7	[1]	4	[-]	6	[3]	*46	[38]	11	[2]	0·62	[0·86]	significant
13	18	[11]	2	[1]	8	[1]	*43	[31]	3	[-]	0·58	[0·70]	not significant
14	16	[9]	2	[3]	*46	[31]	2	[1]	8	[-]	0·62	[0·70]	not significant
15	8	[-]	12	[6]	*36	[36]	3	[-]	15	[2]	0·49	[0·82]	significant

Table 6-1

* indicates the correct response for each item or the key

Post test figures in brackets after pre-test figures

74 students /

74 students did the pre test and 44 the post test. A test of significance involving sample facility values [44] showed that in ten items in the test the difference between pre and post test facility values was significant at the 5% level. (The facility value is the percentage of students who had the correct response for the item.) Students answered the items on a computer card which made an analysis easier than marking by hand.

The pre test was done after the lecture course, so measured differences were a direct result of using the programmes.

Previous research has suggested various ways of dealing with gain scores from pre and post tests using total scores, but for criterion referenced testing, item gains are more useful than total gains. Criterion referenced tests are designed to ascertain the status of a group or an individual with respect to specified criteria.

Popham and Husek (1969) [45] discussed in detail the concepts of variance, reliability, validity and item analysis procedures in relation to criterion referenced tests - they warned that most of these measures are not really applicable.

The item analysis of Question Sheet 1 involved an examination of student responses in pre and corresponding post test and results were as follows:- (Students responded in nine ways)

PRE/POST TEST RESPONSE COMPARISON

Qu.	Wrong ↓ Right	Right ↓ Right	Don't know ↓ Right	Right ↓ Don't know	Wrong ↓ Wrong	Right ↓ Wrong	Don't know ↓ Wrong	Wrong ↓ Don't know	Don't know ↓ Don't know	TOTAL
1	17	17	-		7	1	1			
2	4	30	1		8					
3	7	29	2		5					
4	5	15	1		8	13	1			
5	12	13	5		8	4			1	
6	13	11	3	1	10	1	4			
7	12	18	3		3	4	2		1	
8	20	9	6		4	-	3		1	
9	12	5	4		17	4		1		
10	5	9	1		15	7	5	1		
11	3	18	8	2	4	1	5		2	
12	8	26	2	1	2	1	1	2		
13	4	25	1		12	1				
14	4	24	3		10	1	1			
15	9	22	5		4	2			1	
TOTAL	135	271	45	4	117	40	23	4	6	/645
	20·9%	42%	7%	0·6%	18·1%	6·2%	3·6%	0·6%	1%	/100%

Table 6-2

Using accumulated figures -

∿70% gave the correct response when they did the post test

28% /

~28% gave a wrong response when they did the post test, and

~2% gave a 'Don't know' response when they did the post test.

Some students attempted items correctly before using the programmes and then answered them incorrectly after using the programmes. The items where this occurred, namely 4, 5, 7, 9 and 10, required investigation.

Item No.	Facility Value PRE	Facility Value POST	Possible Reason(s) for choosing a Distractor in the post test
4	0·62	(0·48)	The item depended on the interpretation of the word 'different'. Students who did not have A had D which was perfectly feasible.
5	0·47	(0·70)	The ability to visualise in 3D was necessary in this item. Students who considered only one layer of spheres chose the distractor C.
7	0·57	(0·75)	The few who did not have C in the post test chose A or D.
9	0·23	(0·52)	In this item a large percentage of those who were wrong chose D - the misconception that an octahedral site is the centre of an arrangement of 8 spheres was obvious in class examination results too.
10	0·32	(0·34)	In this item, students responded after looking at a two layer model and counting - it was obvious from the number who chose B that the model was looked at in one direction only.

Points misunderstood or not made clear enough would have to be modifications for

6·13 Overall Analysis of Question Sheet 1

The student identifier provided on the computer card enabled pre and post tests to be matched. The following table shows the students' total scores for pre and post tests.

PRE AND POST TEST SCORES

Student Number	Pre Score	Post Score	Diff.
1	6	12	+6
2	7		
3	7		
4	11	12	+1
5	3		
6	8	14	+6
7	7	14	+7
8	9		
9	3		
10	6	10	+4
11	12		
12	8	14	+6
13	6	7	+1
14	6	11	+5
15	9	10	+1
16	5	12	+7
17	11	13	+2
18	10	13	+3
19	11	14	+3
20	10		
21	6	12	+6
22	9	12	+3
23	6		
24	13	12	-1
25	2	9	+7
26	3	8	+5
27	12	13	+1
28	4		
29	10		
30		12	
31	5	7	+2
32	10		
33	9		
34	6	11	+5
35	10		
36	5		
37	3	6	+3
38	12	13	+1
39	11	15	+4
40	6	8	+2
41	5		
42	6	5	-1
43	8		
44	12	14	+2
45	7	8	+1
46		13	
47	6		
48	4		
49	6	8	+2
50	6		
51			
52	7	11	+4
53	4		
54	9	11	+2
55	7	9	+2
56	12		
57	10	12	+2
58	10		
59			
60	9		
61	9		
62	9	9	0
63	7		
64	5	11	+6
65	8	11	+3
66	11		
67	6	7	+1
68	12	8	-4
69	7		
70	3		
71	1	5	+4
72	8	10	+2
73	7		
74	6	8	+2
75	11	13	+2
76	5		
77	6		
78	7		

Table 6-3

N = 74 (44)

Mean Score $\bar{X}$ = 7·47 (10·61)

Standard Deviation S = 2·80 (2·64)

Mean scores and standard deviations for each test were calculated and a statistical test of significance involving means[33] showed that the difference in means was significant at the 1% level, i.e. the 'average' performance in the post test was significantly better than in the pre test.

Previous research[46] has indicated that doing a pre test before instruction enhances learning. Hartley[46] has said that, "It seems in order for pre test effects to manifest themselves either the tests or the instruction (or both) must be difficult; if students successfully learn to criterion then it is impossible to detect pre test effects." In this case any difficulty in the pre test it was assumed had no measurable effect in the post test performance.

The reliability of the test was measured by calculating the correlation coefficient for pre and post test scores - this was r = 0·63.

6·14 Attitudes to Programmes 1, 2 and 3

The students were asked to indicate in the post test how useful, how easy and how interesting they found each program. Also how long they took to do each programme. Results were as follows:-

Programme	1	2	3
Extremely valuable	7	4	5
Very useful	17	19	20
Satisfactory	12	12	9
Not very useful	1		1
A complete waste of time			
Much too easy			
Too easy			
Reasonably easy	28	25	25
A little difficult	6	8	8
Very difficult	2		
Very interesting	3	3	4
Interesting	17	17	16
Satisfactory	13	12	12
Dull	2		
Tedious			1
Took 5-10 minutes to do	6	6	8
Took 10-15 minutes to do	10	14	14
Took 15-20 minutes to do	8	10	8
Took more than 20 mins. to do	11	4	4

6·15 Analysis of the Results of Programme 7 - An Assessment of Programmes 1 - 6

Model Number	Compound the model represents	Identified correctly by
17	LiF	92%
18	KBr	88%
19	CsBr	80%
20	CdF_2 or CaF_2	68%
21	CuCl	68%
22	NaBr	72%
23	ZnF_2	56%

Points worthy of note from cumulative results:-

1. Finding a coordination number from a space filled model is not easy.
2. There is confusion about which ion is cat- and which an-.
3. Having found the coordination numbers of the separate ~~ions~~, there is some doubt about the method of evaluating the ratio of coordination numbers - should it be cation : anion or anion : cation? - perhaps this point should be elucidated in the programme script.
4. Having found the ratio of coordination numbers correctly, how do we then evaluate the stoichiometry? All right if ratio 1:1, but when 2:1, then stoichiometry is 1:2. Students obviously guessed the response given when identifying model 20 since there was an almost even split between 1:2 and 2:1. This detail will have to be dealt with in the rewrite of Programme 5.

6·16 The Model Construction with some Practical Details

Foamed polystyrene spheres were used to build all space-filling models[51] since they were most suited for assemblages of positive and negative ions. 'Beever' drilled methyl methacrylate spheres of diameter 6·9 mm and steel rods 1 mm diameter were used to build 'ball and stick' models which when built were scaled to an interatomic distance of 1 cm to 1 Angstrom unit. The polystyrene spheres, supplied by Griffin and George, were obtained with diameters $\frac{1}{2}$", $\frac{3}{4}$", 1", $1\frac{1}{2}$", $1\frac{3}{4}$" and 2" and they represented an economic scale of $\frac{1}{2}$" to 1 Angstrom unit. The Cl^- ion represented a lot in the models made determined the scale.

Ions represented in space-filling models were approximate in size using the following conversions and the colour coding used was as shown:-

Ion	Ionic Radius (A°)	Sphere size used	Colour of ion in model
Li	0·60	$\frac{1}{2}$" diameter	silver
Na	0·95	1"	Silver
Cs	1·69	$1\frac{3}{4}$"	gold
Zn	0·74	$\frac{3}{4}$"	copper
K	1·33	$1\frac{1}{2}$"	silver
Ca	0·99	1"	gold
Ti	0·68	$\frac{3}{4}$"	silver
Cu	0·96	1"	copper
Cd	0·97	1"	gold
Pb	0·84	$\frac{3}{4}$"	silver
F	1·36	$1\frac{1}{2}$"	light green
Cl	1·81	$1\frac{3}{4}$"	grass green
Br	1·95	2"	red/brown
O	1·40	$1\frac{1}{2}$"	red
S	1·84	$1\frac{3}{4}$"	yellow

Copper, silver and gold were used to represent metal ions whose coordination was /

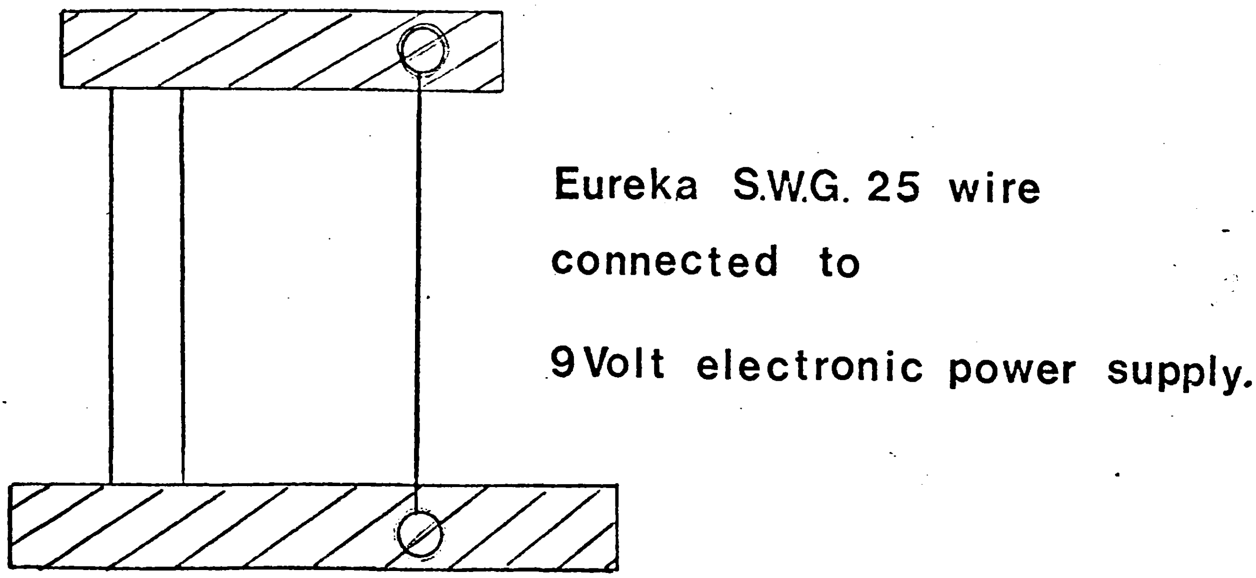
was 4, 6 and 8 respectively.

<u>Note</u> : It is more important to get the radius ratio nearly correct than to match exactly the ionic radius of each ion. Perhaps more sizes of spheres would give more facility in designing models. Styrofoam spheres $\frac{3}{4}$" - $2\frac{1}{2}$" diameter with $\frac{1}{8}$" intervals can be obtained[47] in the U.S.A.

Stages adopted in constructing Models

1. Determine or check the type of structure,[48] internuclear distances, ionic radii and angles between bonds.
2. Count out the correct number and sizes of spheres required.
3. Count out the correct number of connectors (1" lengths of pipe cleaner were used for space filling models, steel rods of appropriate lengths for ball and stick models); also have scissors, pliers, protractor template, pencil, ruler, hammer and glue to hand.
4. Mark the polystyrene spheres using the protractor template, tetrahedrally,[49] octahedrally or cubic for 4, 6 or 8 fold coordination, as appropriate.
5. Pierce holes in polystyrene spheres for connectors.
6. Paint polystyrene spheres with the colour already indicated, as appropriate, (spray paints suitable for polystyrene were used).
7. Assemble models

<u>Note</u>: For unit cell models, the spheres were marked then sectioned, using a hot wire connected to a rheostat. They were then painted and finally assembled.



For Beever models, the spheres made of polymer were drilled when supplied and a colour coding was also adopted:-

Na - ruby	Cl - green
Cs - ruby	S - yellow
Zn - clear	F - green
Ca - ruby	O - red
Ti - topaz	

Assembly was done using pliers and a leather hammer.

Finally, the models, after construction, were made permanent by encasing the space filling ones in perspex boxes and sandwiching the ball and stick ones between two sheets of perspex. Beevers' ball and stick models are sturdy, inexpensive and easy to store.

The scripts and slides from Programmes 1, 2, 3 and 7 can be found in the Appendix to Chapter 6 on p194-207.

CRYSTAL STRUCTURES PROGRAMMES

First, an introduction

Crystalline solids can be of three types:- 1. Metallic

2. Ionic

and 3. Covalent

Metallic solids consist of atoms which can be represented by spheres of equal size.

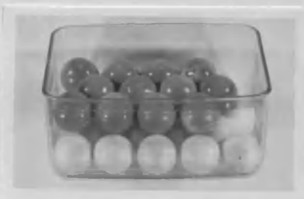
Ionic compounds consist of positive and negative ions and both of these can be represented by spheres of varying sizes. Generally the positive ions are smaller than negative ions. Ionic solids have ions which tend to pack as closely as possible so that their potential energy is a minimum.

We start by considering metals where the problem reduces to packing of spheres with the same diameters.

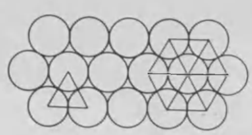
Close Packing of Spheres - Programme 1

Use Models 1, 2, 3, 4 and construction kit.

Slide 1 Spheres of equal size when shaken in a box tend to arrange themselves in such a way that they are as closely packed as possible.

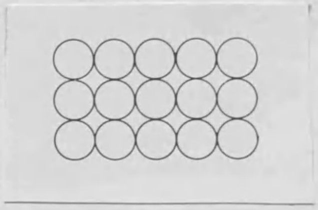


Slide 2 Let us look at one layer of these spheres which are close packed.
For every three spheres, each one touches the other two and their centres are at the corners of an equilateral triangle.
Centres of spheres lie at the corners of a 6-connected triangular net as you can see.



Slide 3 /

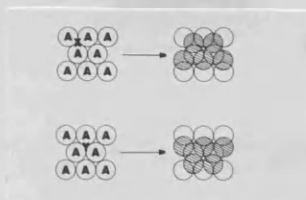
Slide 3 We observe that spheres can also be packed like this and that they are not as closely packed as before.



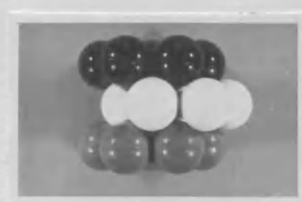
Slide 4 When we look at close packing of spheres in three dimensions, we find the most compact grouping of four spheres is when their centres are the corners of a regular tetrahedron. Close packing in 3D can best be attained by stacking close packed layers like those in slide 2.

Spheres of one layer fit into the hollows of adjacent layers.

Slide 5 If spheres of one layer are labelled A, those of adjacent layers can have centres above X or Y. In such sphere stackings, each sphere has twelve equidistant neighbours. Because of alternative positions available for each layer, there is an indefinite number of close packed layer sequences.



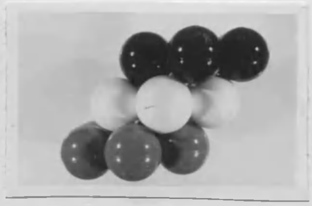
Slide 6 If we build ABAB layers of close packed spheres that is, the B layer of spheres in position X, and the A spheres in layer three directly above the A spheres in layer one, then we have hexagonal close packing.



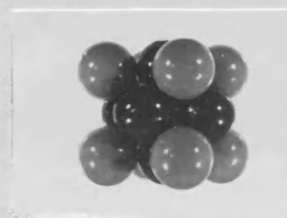
Now, using the construction kit and following the first set of instructions on the box, build a model for yourself. While doing this, switch off the tape.

Slide 7 /

<u>Slide 7</u> If we build ABC layers of close packed spheres i.e. the B layer of spheres in position X and the C layer in position Y, then we will have hexagonal close packing.
Using the construction kit, follow the second set of instructions on the box and build a model for yourself. This time, you should observe that the first and third layers of spheres are different, with regard to relative positions of corresponding spheres where in ABAB packing they were the same.
Switch off the tape.



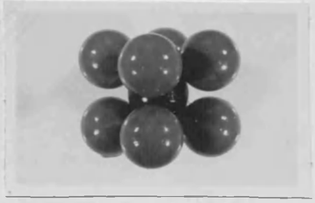
<u>Slide 8</u> When we have ABC layers of hexagonally close packed spheres, we can identify face centred cubic packing as shown.



<u>Slide 9</u> Can you see face centred cubic structure in ABC layers? The model you see has been designed to show how a face centred cubic structure fits into hexagonal close packing. Again use the kit, this time follow the third set of instructions and build a model for yourself. You should be able to equate ABC hexagonal close packing with face centred cubic packing.
Leave your model after construction so that it can be checked. Switch off the tape.

<u>Slide 10</u> Now compare your model with this slide which is what you should have.

<u>Slide 11/</u>



Slide 11 Another common way of packing spheres which is not close packed is body centred cubic with this stacking method, each sphere has only eight equidistant neighbours. Packing of spheres in hexagonal close packing face centred cubic arrangement fills approximately $\frac{3}{4}$ of the available space; with body centred cubic arrangement, the volume of space filled is appreciably less.

Thus, there are three ways of close packing spheres -

(i) hexagonal close packing ABAB type

(ii) face centred cubic packing ABC type, and

(iii) body centred cubic packing.

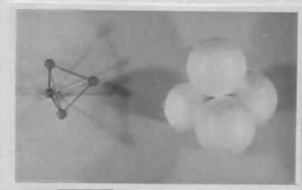
Most metals and alloys crystallise in either hexagonal close packing or face centred cubic arrangement of atoms. A few crystallise in body centred cubic arrangement. Examine models 1, 2, 3 and 4 to verify you can recognise the close packing arrangements.

Features of Close Packing

(i) <u>Interstitial sites</u> - <u>Programme 2</u>

Use models 1, 2, 3 and 7

<u>Slide 1</u> In a close packed arrangement of spheres we find <u>each</u> sphere rests on three spheres in an adjacent layer as shown.

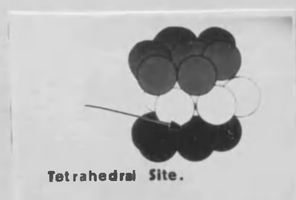


The centres of the four spheres are corners of a regular tetrahedron. The spheres touch each other at one point only and so there is a space at the centre of the tetrahedron - this can be called a tetrahedral site or hole.

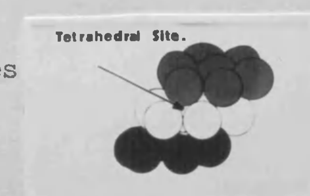
This does not mean the shape of the site is tetrahedral.

The actual size of the tetrahedral site is very much smaller than the size of the surrounding spheres although the larger the spheres, the larger the site will be.

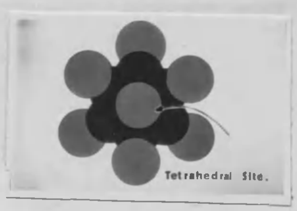
<u>Slide 2</u> Take model 1. Each white sphere will be in contact with three red spheres in the layer above and three blue spheres in the layer below, such that you should be able to see two tetrahedral sites associated with each of the white spheres, one immediately above and the other below it.



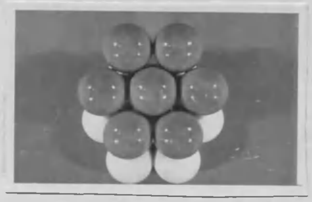
<u>Slide 3</u> Take model 2. Each white sphere will be in contact with three red spheres and three blue ones in the layers above and below as before. This time, look at the central white sphere in the model and you should see three red spheres above and three blue spheres below it, meaning there is a tetrahedral site above and below each white sphere.



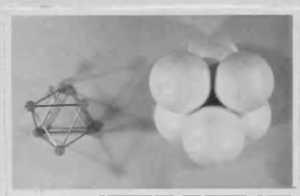
Slide 4 Take model 3. Each red corner sphere forms a tetrahedron with three blue face centre spheres and so there is a tetrahedral site under each corner ion.



Slide 5 Take model 1. Look down from the red to the blue layer. Are all the holes tetrahedral? You should see that some are bigger than the tetrahedral ones we have already mentioned. Can you see the bigger holes occur when three red spheres are above three white spheres, or when three blue spheres are below three white spheres?

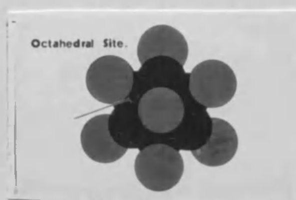


Slide 6 When we have such an arrangement of six spheres the centres of the spheres form a regular octahedron as shown.
This second type of interstitial site is an octahedral site or hole.

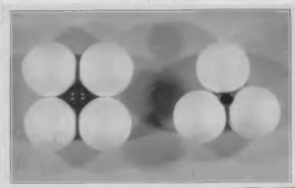


Slide 7 Take model 2. Two sets of three red spheres have a triangular arrangement and have three white spheres forming a triangular arrangement beneath.
At the centre of each of these arrangements with six spheres there is an octahedral site.

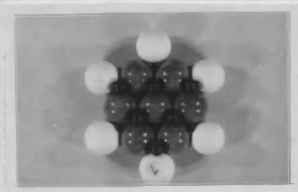
Slide 8 Take model 3. Can you see that the six blue spheres are octahedrally disposed and so must have an octahedral site at their centre?
If the structure was extended, four blue and two red spheres would form an octahedral arrangement at the centre of which there would be an octahedral site.



<u>Slide 9</u> When you look at an octahedral site and a tetrahedral site side by side you can see the octahedral site is the bigger one.



<u>Slide 10</u> Between any two layers of hexagonally close packed spheres each octahedral site is equidistant from three surrounding tetrahedral sites, and each tetrahedral site is equidistant from three surrounding octahedral sites.
Green spheres fill the octahedral sites and blue spheres fill the tetrahedral ones.



Features of Close Packing

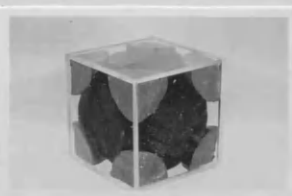
(ii) <u>Unit Cells</u> - <u>Programme 3</u>

Use models 1, 2, 3, 4, 8, 9, 10 and 11

<u>Slide 1</u> In crystal structures, it is conventional to describe a structure in terms of a unit cell. The unit cell of a structure is the unit which when repeated in the same orientation and joined to other identical units gives the whole structure.

When we define the unit cell for body centred cubic packing we clearly must cut each corner sphere of model 4 in three mutually perpendicular directions so that edges of the unit cell pass through centres of the red spheres.
The unit cell has one red sphere and one blue sphere.

<u>Slide 2</u> Now, look at model 3, the face centred cubic arrangement and imagine it cut to form a unit cell. Can you see that red corner spheres become $\frac{1}{8}$th spheres and blue face spheres become $\frac{1}{2}$ spheres so that edges of the unit cell pass through centres of the spheres?



Look at model 9 to see the complete unit cell.
How many red spheres are there?
How many blue spheres are there?
Yes, that is right, three blue and one red.
Note; the tetrahedral sites behind the red corners are still there.

<u>Slide 3</u> We now try to define unit cells for hexagonal close packing.

First ABAB hexagonal close packing - model 1.
Clearly /

Clearly the unit cell for each 'A' layer will be hexagonal so that edges pass through centres of the six corner red or blue spheres. How much of each red and of each blue sphere is there at the corners of the unit cell?

Yes, exactly $\frac{1}{6}$ th.

There is also, half of the centre red and centre blue in A layers of the unit cell - remember this sphere is cut in only one direction while others are cut in three directions, not mutually perpendicular in this case.

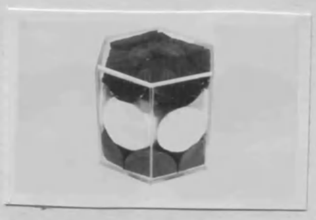
What is left in the unit cell of the B 'white' spheres packed into the hollows of the adjacent A layers?

As you can see, if you examine model 10 closely, edges of the unit cell do not pass through centres of the white spheres, but they are cut in such a way that segments which fit oppositely in the layer form a whole sphere - thus there are exactly three spheres in the B layer of the unit cell.

How many spheres are there in each 'A' layer of the unit cell?

Yes, $1\frac{1}{2}$ spheres in each 'A' layer, plus the three in the 'B' layer makes a total of six spheres in the unit cell for ABAB type.

Slide 4 We now construct the unit cell for ABC hexagonal close packing.



Again, the unit cell is hexagonal and the 'A' layer in the unit cell as before is six corner pieces which are $\frac{1}{6}$th sphere and $\frac{1}{2}$ a sphere in the middle.

The 'B' layer where white spheres fit into hollows in the 'A' layer is as before, three white /

white spheres each one segmented so that the segments fit adjacently on top of the 'A' layer. This time, however, the 'C' layer is different from the A and B ones. The blue spheres of the 'C' layer fit into hollows in the 'B' layer so that they are not directly above A red spheres and this means the spheres are segmented in the same way as the white 'B' layer ones and then sliced horizontally so that there are exactly $1\frac{1}{2}$ spheres in the C layer, that is, half the number in the B layer.

How many spheres are there in the unit cell for ABC hexagonal close packing?

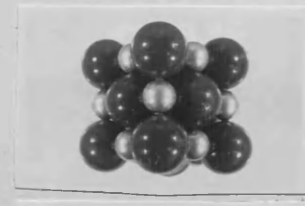
You should have found the answer is six, exactly the same as for ABAB but with a different arrangement in the 'C' layer.

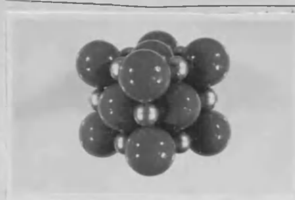
Examine models 8, 9, 10 and 11 and verify that you could construct unit cells for each of the packing arrangements we studied in Programme 1.

Identification of some MX and MX_2 type structures
Programme 7

In this programme you can look again at the models you have tried to identify and questions you were asked will be answered. We would, however, like to see where you have had difficulty, so please leave your answer scripts in the tray provided.

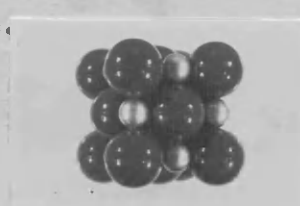
Slide 1 This model represents the structure of sodium chloride which you studied in Programme 4.





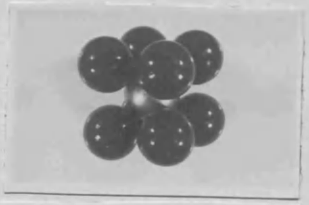
Slide 2 You should be able to see that this model must belong to the set of sodium chloride structures given on sheet 2. Check that the coordination number of each metal (silver) ion is 6 and the coordination number of each halide ion is also 6. Thus, the ratio of coordination numbers is 6 to 6 which is 1 to 1. This implies the stoichiometry is 1 to 1 which implies the formula is MX type. When the unit cell is defined there are a total of four metal (silver) ions and four halide ions which verifies an MX type structure.
Now using sheets 1 and 2, the cation which is smaller than the cation in model 12 can be identified as lithium and the anion which is smaller than the chloride anion in model 12 represents fluorine. Hence the model 17 represents lithium fluoride.

Slide 3 This model also shows the sodium chloride structure. Each metal (silver) ion has coordination number 6 and each halide number has coordination number 6. In the unit cell if defined, there must be /

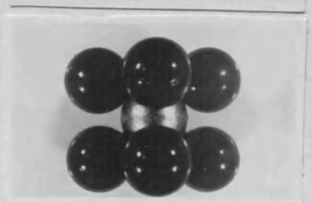


be four metal and four halide ions, thus the stoichiometry is 1 to 1 verifying the formula is MX type.
Using sheets 1 and 2, the cation which is bigger than the cation in model 12 must represent potassium and the anion which is bigger than the chloride ion must represent bromine. Model 18 is a bromide, in fact, potassium bromide.

Slide 4 This model has the caesium chloride structure which you studied in programme 5.

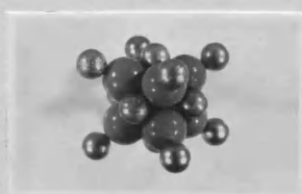


Slide 5 You should be able to see that this model must represent caesium chloride structure. Check this time, the coordination number of each metal (gold) ion is 8 and the coordination number of each halide ion is 8.



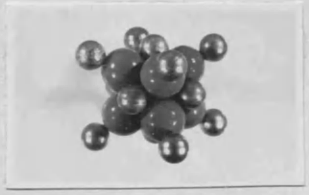
Thus the ratio of coordination numbers is 8 to 8 which is 1 to 1. This implies the stoichiometry is 1 to 1 which in turn implies the formula is MX type. When a unit cell is defined there is one metal (gold) ion and one halide ion. Remember corner ions become $\frac{1}{8}$th spheres for the unit cell. In this model the cation equals in size the caesium cation in model 13 and the anion is bigger than the chlorine anion.
Model 18 represents caesium bromide.

Slide 6 Here you can see the structure of calcium fluoride which you studied in programme 5.



Slide 7 /

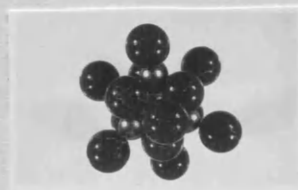
Slide 7 You should observe that this model has the fluorite structure. The coordination number of each metal (gold) ion is 8 and the coordination number of each halide ion is 4, thus the ratio of coordination numbers is 8 to 4 which is 2 to 1. Now, if we had eight halide ions round each metal ion and four metal ions round each halide ion, then there are twice as many halide ions as metal ions and so the stoichiometry is 1 to 2. Hence the formula must be MX_2.



If we were to define a unit cell, we would have four metal ions and eight halide ions verifying the MX_2 formula.

This is a model of a compound which has the fluorite structure but it is not calcium fluoride. From sheets 1 and 2, it is not difficult to deduce that it may be copper fluoride or cadmium fluoride where cation sizes are approximately equal and anion sizes are the same.

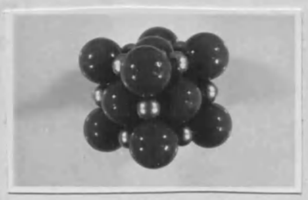
Slide 8 This model represents one you have already studied in programme 5, but let us go stepwise through the deductive process of identification. The coordination number of each metal (copper) ion is 4, that is, each has four nearest neighbours which are green. Similarly the coordination number of each halide (green) ion is 4. The ratio of coordination numbers is 4 to 4 which is 1 to 1; thus the stoichiometry is 1 to 1 implying the formula is MX type.



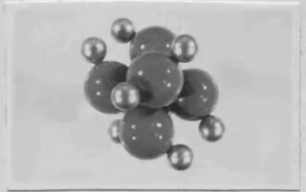
Remember this can be checked if you identify a unit cell where there would be four whole copper ions or cations and eight times $\frac{1}{8}$th corner green ions plus six times $\frac{1}{2}$ face centre green anions which makes a total of four cations and four anions. Thus the ratio of the number of cations/

cations to the number of anions is 4 to 4 which is 1 to 1. This model shows the structure of zinc blende where anions have a face centred arrangement and cations are at the centre of a tetrahedral arrangement of anions. If you compare the cation with zinc it is bigger and the anion equals in size sulphur. From sheets 1 and 2 where some zinc blende structures are shown, we can deduce that model 20 represents copper chloride.

<u>Slide 9</u> Clearly we have another compound with the sodium chloride structure. Coordination number of each cation equals the coordination number of each anion equals 6. The ratio of coordination numbers is 6 to 6 which is 1 to 1. The formula is MX type.
The model represents sodium bromide.



<u>Slide 10</u> Lastly, we look at the structure of this more complex model. The coordination number of each cation (silver) is 3, and the coordination number of each anion (light green) is 6. Thus, the ratio of coordination numbers is 6 to 3 which is 2 to 1, implying the stoichiometry is 1 to 2 implying the formula is MX_2 type.
In fact, this model shows the rutile structure which you met in programme 5. Here the cation size is smaller than lead in model 16 and the anion size is slightly smaller than oxygen.
This model represents zinc fluoride as listed in sheet 2.



A standard colour coding has been used when constructing the models which are approximately to scale. Just a reminder, please leave your answer sheet.

PROGRAMME 7

Identification of some MX and MX_2 type structures

Crystal structures of MX and MX_2 types tend to occur in sets. The radius of each ion is a significant factor in determining which type of structure will be formed.

TAKE MODELS 17 and 18

First we can deduce if each one is an MX or MX_2 type of structure in one of two ways.

Method A

1. What is the coordination number of each metal (silver) ion? (i.e. how many nearest neighbours of the other colour has each metal ion?) ________
2. What is the coordination number of each halide ion? (i.e. how many nearest metal (silver) neighbours has each halide ion?) ________

Ratio of Coordination numbers = :

⇒ stoichiometry is
⇒ formula is ________ type

Now check using Method B

When a unit cell is defined for each model -

1. How many metal (silver) ions are there? _____
2. How many halide ions are there? _____

Ratio of number of cations to number of anions = :

⇒ stoichiometry is
⇒ formula is ________ type

In programmes 4 and 5 we looked at three MX type structures and two MX_2 type structures.

Which structure is shown by Model 17 ? _____

Which structure is shown by Model 18 ? _____

Now use sheet 1 which has information on ionic radii and sheet 2 which has information on structures and try to identify which compounds the models represent.

Model 12 /

Model 12 which you have studied may be used for comparison -

1. Is the cation in 17 smaller or bigger than the cation in model 12? ________

   ∴ the cation might be ________

2. Is the anion in 17 smaller or bigger than the anion in model 12? ________

   ∴ the anion might be ________

MODEL 17 MUST REPRESENT ________

Repeat for model 18 which must represent ________

TAKE MODEL 19

1. What is the coordination number of the metal (gold) ion? ________
2. What is the coordination number of the halide ion? ________

   Ratio of Coordination numbers = :

   ⇒ stoichiometry is
   ⇒ formula is ________ type

Which structure is shown by model 19 ?

Now use sheet 1 and sheet 2 to try to identify which compound the model represents.

Model 13 which you have studied may be used for comparison.

MODEL 19 MUST REPRESENT ________

TAKE MODEL 20

1. What is the coordination number of each metal (gold) ion? ________
2. What is the coordination number of each halide ion? ________

   Ratio of Coordination numbers = :

   ⇒ stoichiometry is
   ⇒ formula is ________ type

Which structure is shown by model 20 ? ________

Now /

Now use sheets 1 and 2 to try to identify which compound the model represents.

Model 15 may be used for comparison -

The cation must be ______

The anion must be ______

MODEL 20 MUST REPRESENT ______

Now take models 21, 22 and 23 and using the method of identification indicated state which structure each model represents.

Ratio of Coordination numbers in model 21 is :

MODEL 21 REPRESENTS ______

Ratio of Coordination numbers in model 22 is :

MODEL 22 REPRESENTS ______

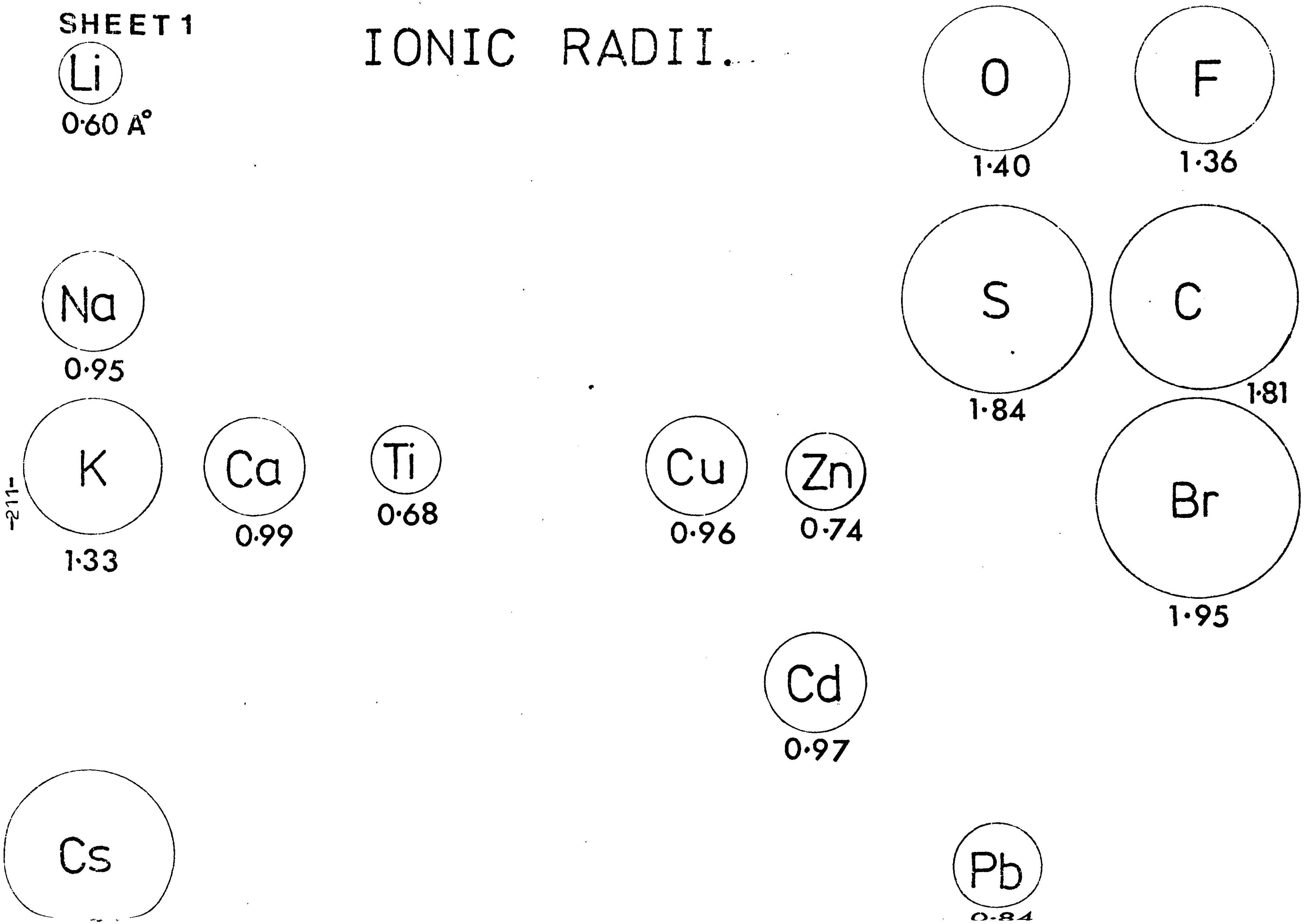
Ratio of Coordination numbers in model 23 is :

MODEL 23 REPRESENTS ______

Check your answers by listening to the tape provided. Please leave this in the answer tray so that we can see if and when difficulty occurs.

SHEET 1

IONIC RADII.



SHEET 2

STRUCTURES OF SOME MX TYPE COMPOUNDS

CsCl STRUCTURE	NaCl STRUCTURE	ZnS STRUCTURE
Coordination 8:8	Coordination 6:6	Coordination 4:4
	LiF LiCl LiBr	
	NaF NaCl NaBr	
	KF KCl KBr	
		Zinc Blende
CsCl CsBr		CuF CuCl CuBr
$1 \geq r^+/r^- \geq 0{\cdot}732$	$0{\cdot}732 > r^+/r^- \geq 0{\cdot}414$	$0{\cdot}414 > r^+/r^- \geq 0{\cdot}225$

STRUCTURES OF SOME MX_2 TYPE COMPOUNDS

Fluorite STRUCTURE	Rutile STRUCTURE
Coordination 8:4	Coordination 6:3
CaF_2	TiO_2
CuF_2	ZnF_2
CdF_2	
PbF_2	PbO_2

QUESTION SHEET 1

1. Which one of the following elements has a structure at room temperature made up of closely packed single atoms?

   A) C B) Cu C) S D) none of these E) don't know

2. When circles of the same diameter are drawn so that each circle just touches the other circles round it, what is the maximum number of circles each one can touch?

   A) 3 B) 4 C) 5 D) 6 E) don't know

3. When spheres of equal size are packed together as closely as possible, and in layers, how many other spheres will each one touch?

   A) 4 B) 6 C) 8 D) 12 E) don't know

4. If we build a layer of spheres of the same size so that they are as closely packed as possible and then stack an identical layer on top of this one, how many different ways are there of positioning the second layer ensuring that closest packing still remains?

   A) 2 B) 3 C) 12 D) infinity E) don't know

5. In the AB AB hexagonal arrangement of spheres of equal size each sphere is coordinated by a number of other spheres. This number will be -

   A) 3 B) 4 C) 6 D) 12 E) don't know

6. In the ABC,ABC face centred cubic packing arrangement of spheres of equal size, each sphere is coordinated by -

   A) 4 B) 5 C) 6 D) 12 E) don't know spheres

7. In the body-centred cubic arrangement of packing spheres of equal size each sphere is coordinated by -

   A) 4 B) 6 C) 8 D) 12 E) don't know spheres

8. When spheres of equal size are as closely packed as possible the volume of space occupied is approximately -

   A) 65% B) 75% C) 85% D) 95% E) don't know

9. When spheres of equal size are as closely packed as possible the largest space or 'interstitial site' can be found at the centre of an arrangement of -

   A) 3 B) 4 C) 6 D) 8 E) don't know close packed spheres

10. Given the model with 6 white spheres and 6 blue spheres, how many <u>complete</u> tetrahedral sites can you see between the blue and white layers?

    A) 6 B) 3 C) 4 D) 5 E) don't know

11. /

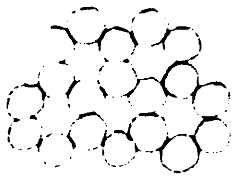
11. Using the same model, how many complete octahedral sites can you see?

A) 2 B) 3 C) 4 D) 6 E) don't know

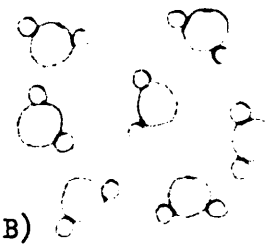
12. The structures of four elements and compounds are shown below.

Which structure most closely resembles that of Zn ?

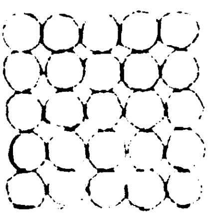
A)
B)
C)
D)
E) don't know



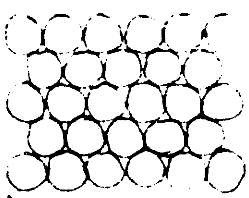
A)



B)



C)



D)

13. What is the smallest "repeat unit" in the following 2D pattern?

X • X • X • X
• X • X • X •
X • X • X • X
• X • X • X •
X • X • X • X

Is it

A) X •
• X

B) X •
• X
X •

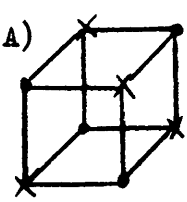
C) X • X
• X •

D) X • X
• X •
X • X

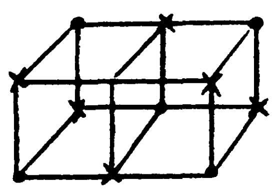
E) don't know

14. Take model 12 A), a ball and stick model of NaCl, what is the smallest "repeat unit" in 3D? Is it -

A)



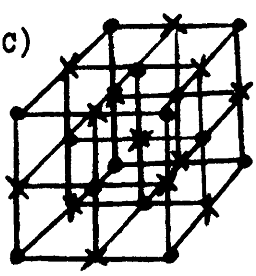
B)



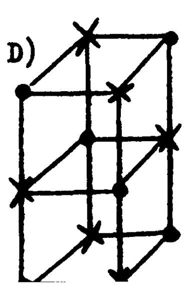
X represents the centre of a red sphere

• represents the centre of a green sphere

C)



D)



E) don't know

15. Suppose you were asked to build a unit cell for a close packed arrangement of equal spheres showing face centred cubic packing, what would you require?

A) 8 whole spheres for corners and

6 whole spheres for face centres.

B) 8 quarter spheres for corners and

6 half spheres for face centres.

C) 8 eighth spheres for corners and

6 half spheres for face centres.

D) 8 quarter spheres for corners and

6 whole spheres for face centres

E) don't know

1. Chemical Education Project Report to Scottish Education Department, A.H. Johnstone, 1969

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