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Student understanding of ionic bonding: molecular versus electrostatic thinking?

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Abstract:

Research interviews have produced evidence that individual school pupils and chemistry students have 'alternative conceptions' of one of the main categories of chemical bond - the ionic bond. The present paper reports the results of a small scale survey designed to investigate if these alternative conceptions are widespread. The data suggest that there are common aspects of student thinking about ionic bonding which have significant implications for teachers of school science and college chemistry. Collectively these alternative conceptions are described as the MOLECULAR FRAMEWORK*, and are contrasted with the orthodox view, labelled the* ELECTROSTATIC FRAMEWORK*. The survey was designed to show the extent to which learners' views matched these two perspectives. It was found that the statements derived from the alternative framework were judged as true by large proportions of the learners surveyed. It is concluded that the* MOLECULAR FRAMEWORK *is a useful model for representing common aspects of learners' alternative ideas in this area of the science curriculum. Teachers of science and chemistry should be aware of the need to contrast molecular and electrostatic ideas when teaching this topic.*

Introduction

This paper reports the results of a survey of 370 learners designed to investigate whether certain 'alternative conceptions', previously reported in the literature on the basis of a small number of learners, were widely held. The survey follows up an interview study undertaken in the U.K., which was found to reflect previous Australian research. Interviews reveal the unique nature of each learner's ideas about the world. In order to undertake the survey a model of the common aspects of the alternative conceptions, called the **MOLECULAR FRAMEWORK** for understanding ionic bonding, was constructed. This representation was then used to design a simple survey instrument - the **TRUTH ABOUT IONIC BONDING DIAGNOSTIC INSTRUMENT**. The instrument was given to pupils studying at Key Stage 4 (G.C.S.E. level) of the U.K. National Curriculum in science, and to A level Chemistry students. The responses suggest that many of these students hold alternative conceptions similar to those of the original interviewees.

Misunderstanding the ionic bond?

Although there is a widespread literature on learners' ideas in science (e.g. Carmichael *et al.*, 1990) there have been few studies focussing on chemical bonding, described by Peter Fensham as one of the "big concepts in chemistry" (Fensham, 1975, p.199.) The present paper reports results from a small scale research project (Understanding Chemical Bonding) which is inquiring into the development of learners' thinking in this topic area. An earlier stage of the work involved sequences of in-depth interviews with A level chemistry students in an F.E. College in England. These interviews were usually about an hour long, and were focussed on a 'deck' of diagrams representing various chemical species (atoms, molecules, lattices *etc.*) The study was designed to explore the learners' understanding of chemical bonding at the start of an A level course, and then to follow the development of their thinking (Taber, 1993c.) The interview study therefore concentrated on in-depth investigation of a small number of learners. This approach provides the data for preparing detailed case studies (Taber, 1993a; 1993b; 1995a.)

The fundamental assumptions behind this type of study are those of what may be called the 'constructivism in science education' movement. These assumptions have been expounded many times: recent discussions may be found in Driver *et al.*, 1994, and Watts, 1992. With respect to the present study the main points are:

1. each individual learner is assumed to have a unique cognitive structure (i.e. "the knowledge someone possesses and the manner in which it is arranged", White, 1985, p.51);
2. learners construct their own meanings from their experiences (both outside and within formal teaching contexts);
3. learners make sense of science teaching in terms of their existing cognitive structure;

4. many aspects of the ‘knowledge’ an individual holds in her cognitive structure may be at variance with, or even contradictory to, formal scientific ideas;
5. learners existing ideas may act as a block to effective learning of curricular knowledge.

Although it is argued that the knowledge structures of each individual are unique, it is found that the ‘alternative conceptions’ of different learners are often similar enough to make general abstractions. It has been suggested “that ‘force and movement’ is considered as a ‘paradigmatic case’ by research workers concerned with alternative conceptions and their implications for learning” (Gilbert & Zylbersztajn, 1985, p.110), and here it is commonly found that before (and often after) instruction learners hold an ‘impetus’ perspective that has been summarised “if a body is moving there is a force acting upon it in the direction of the movement. If a body is not moving there is no force acting upon it” (Watts, 1983, p.226.)

The interview data revealed similarities in the comments of some of the learners as they discussed ionic bonding (and particularly as they considered the diagram reproduced here as figure 1). Of a cohort of twelve learners, five students in particular demonstrated similar ‘alternative conceptions’ about ionic bonding at the start of their A level course. (It should be pointed out that these were not ‘weak’ students, and all five proceeded to obtain top grades at the end of the A level course.) Their comments have been discussed in more detail elsewhere (Taber, 1993d, 1994a). Each of the five students had a slightly different set of ideas about ionic bonding, and the extent to which their own conceptions differed from the structure of ‘curricular science’ (Gilbert & Zylbersztajn’s term, 1985, p.109) varied. However there was enough similarity between their comments to *suggest* that perhaps a considerable proportion of chemistry learners had alternative conceptions of this type. It was decided that the hypothesis that these were common notions should be tested. This required reification of my interpretations of the different students’ comments into an entity that could be readily communicated, and could be the basis for testing the hypothesis. In other words it was appropriate at that point to construct a model.

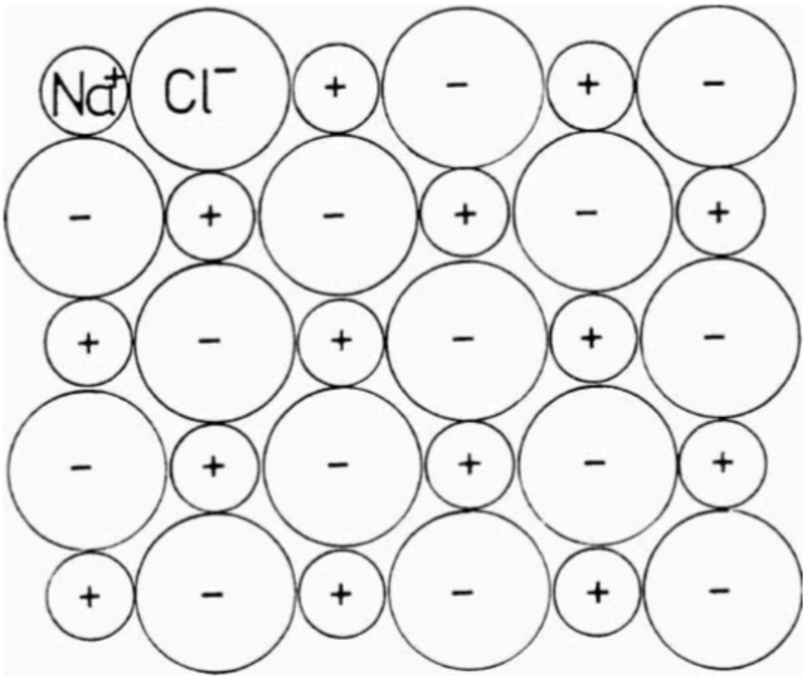

Figure 1.: **The representation of sodium chloride used in the TRUTH ABOUT IONIC BONDING DIAGNOSTIC INSTRUMENT.**

Two frameworks for understanding ionic bonding

This model, or representation, is called the **MOLECULAR FRAMEWORK**. A main theme of the **MOLECULAR FRAMEWORK** is that the ions in sodium chloride do not interact equally with all six of their nearest neighbour counter ions, but rather that the lattice is composed of ion pairs which are the 'molecules' of NaCl. That is, the interactions *within* an ion-pair are perceived differently than those *between* ion-pairs. The term molecule may or may not be used by the student, but the idea of 'ion-pairs as molecules' is implied by their comments. This alternative framework could be compared with the relevant aspects of the curricular science version, which is referred to as the **ELECTROSTATIC FRAMEWORK**.

The **MOLECULAR FRAMEWORK** consists of three related ideas (Taber 1994a.) These are alternative conceptions to the propositions of curricular science that compose the ELECTROSTATIC FRAMEWORK, and are referred to as the **VALENCY CONJECTURE**, the **HISTORY CONJECTURE**, and the **'JUST FORCES' CONJECTURE**. The two frameworks are compared in figure 2.

	MOLECULAR FRAMEWORK	**ELECTROSTATIC FRAMEWORK**
status	alternative framework	curricular science
role of molecules	ion-pairs are implied to act as molecules of an ionic substance	ionic structures do not contain molecules - there are no discrete ion-pairs in the lattice
focus	the electron transfer event through which ions may be formed	the force between adjacent oppositely charged ions in the lattice
valency conjecture	atomic electronic configuration determines the number of ionic bonds formed. (e.g.: a sodium atom can only donate one electron, so it can only form an ionic bond to one chlorine atom.)	the number of bonds formed depends on the coordination number, not the valency or ionic charge (e.g.: the coordination is 6:6 in NaCl)
history conjecture	bonds are only formed between atoms that donate / accept electrons. (e.g.: in sodium chloride a chloride ion is bonded to the specific sodium ion that donated an electron to that particular anion, and *vice versa*.)	electrostatic forces depend on charge magnitudes and separations, not prior configurations of the system (e.g.: in sodium chloride a chloride ion is bonded to six neighbouring sodium ions)
'just forces' conjecture	ions interact with the counter ions around them, but for those not ionically bonded these interactions are just forces. (e.g.: in sodium chloride, a chloride ion is bonded to one sodium ion, and attracted to a further five sodium ions, but just by forces - not bonds.)	a chemical bond is just the result of electrostatic forces - ionic bonds are nothing more than this (e.g. the forces between a chloride ion and each of the neighbouring sodium ions are equal.)

Figure 2: **a comparison of two frameworks for understanding ionic bonding.**

The reference to 'focus' in figure 2 relates to the close association that learners seem to make between the ionic bond and the process of ion formation. This does not seem an illogical connection for a student to make, but the association appears to be given more importance than is often justified. For example learners often assume that in an ionic structure the ions have been formed by electron transfer between the species present. This seems so deeply rooted that in a discussion of a precipitation (double decomposition) reaction one A level student actually suggested that when the two solutions were mixed the solvated ions transferred electrons back between their original partners before undertaking an new cycle of electron transfer to form the precipitate! Such a scheme is nonsensical from the curricular science viewpoint, but apparently made sense to this individual learner. (Once again it may be emphasised these ideas are not limited to the strugglers in the class - the individual concerned went on to obtain an A grade.)

One of the few previous studies was carried out in Australia by Butts and Smith (1987.) They had previously found that 29% of 266 year 12 chemistry students surveyed had rated 'the difference in properties between ionic compounds and molecular compounds' as either 'very difficult' or 'extremely difficult' (p.192.). They followed-up this finding by interviewing 28 year-12 chemistry students. Butts and Smith found that:

- most students associated sodium chloride with ionic bonding;
- students often volunteered information about the nature of the electron transfer process from sodium atom to chlorine atom which results in the formation of the bond;
- molecules of NaCl were referred to by 10 of the 28 students;

It was also suggested by various interviewees that:

- the molecules were held together in the solid by covalent bonds;
- there was a covalent bond holding sodium and chloride atoms together to form a sodium chloride molecule but that ionic bonds between these molecules produced the crystal structure;
- the wire 'sticks' of a 'ball and stick' model represented one ionic bond and five physical bonds;
- there should be seven wires around a chlorine atomic centre in the model, not six, because chlorine has seven electrons in its outer shell;
- sodium ions and chloride *ions* were released only when the solid dissolved in water ("solid sodium chloride doesn't conduct because it is in separate molecules" {p.196}); or when electric current was passed through the solid.

Although the specific points made by Butts and Smith's interviewees were not identical to those elicited in the U.K. interviews, it is clear that the model in figure 2 represents features of their alternative conceptions. Perhaps the main distinction is that for the Australian students non-ionic (covalent, 'physical') bonds appear to have a similar role to 'just forces' for the U.K. interviewees.

The Truth About Ionic Bonding Diagnostic Instrument

The instrument was designed to have the following characteristics:

1) It would be a pen-and-pencil type instrument that could be administered to whole groups of students.

2) The completion and analysis of the instrument would be relatively simple.

3) It would contain sufficient items to explore aspects of the VALENCY, HISTORY and JUST FORCES conjectures, and to compare support for the alternative MOLECULAR FRAMEWORK with the model from curriculum science (the ELECTROSTATIC FRAMEWORK.)

It was decided to present the original figure of ionic bonding used in the interview study (here reproduced as figure 1) showing a plane in NaCl, alongside a number of statements that might, or might not, be true. The respondent was asked to select 'true' or 'false' for each statement, although the option 'do not know' was available to avoid the need for a student to guess if they had no idea. A response sheet was provided and the learners were asked to ring one of 'TRUE' , 'DO NOT KNOW' and 'FALSE' for each item. The diagram:

1) represented an archetypical ionic substance (sodium chloride), that was likely to be strongly associated with the type of bonding being considered;

2) showed an obviously symmetrical arrangement of ions, where each ion in the body of the diagram could clearly be seen to have 4 equally nearest neighbours (in two dimensions);

3) represented a material where minimal covalent character would be expected to be introduced (through polarisation of ions that could effect the symmetrical relationship between an ion and its neighbours).

Thirty statements were written to explore these aspects of student understanding (see table 1.) Some were correct from the ELECTROSTATIC FRAMEWORK, and some were correct from the various aspects of the MOLECULAR FRAMEWORK. A few items were deliberately correct or incorrect from both these perspectives. From the 'electrostatic' viewpoint there were more false statements than true ones - but this was not considered problematic (for example it was expected that most respondents would be familiar with answering multiple choice questions where most statements offered are incorrect.) The first item was a 'filter' designed to remove from the analysis students who did not recognise the presence of ionic bonding. Some attempt was made to randomise the presentation of other items. Some items were complementary (in that they suggested a similar idea about the cation or the anion in terms of the frameworks considered) and others were logically contradictory so that selecting TRUE for one would seem to imply selecting FALSE for the other. It was recognised that the reading level required for some items was quite high, but it was felt this could not be avoided in presenting statements of this type.

The instrument was piloted with a class at the Further Education College where the original U.K. interview studies had previously been undertaken, to check that administration and analysis were straightforward. Consideration of the results led to a few minor alterations of wording, but no significant changes (The final wording is that given in table I).

The sample

It was not within the resources of the present project to undertake a large scale survey with a fully representative sample of chemistry learners. Instead the more modest aims were to increase the sample size to over a hundred A level students, to include KS4 pupils as well if possible, and to draw the sample from several different institutions. For this purpose a short note was placed in *Education in Science* asking interested teachers to contact the author (Taber, 1994b). It is likely that the teachers who responded are not a representative sample of those teaching chemistry nationally. Students were only included in the survey if their teachers (1) read professional journals, (2) were interested enough to write for more information, and (3) were motivated sufficiently to administer the instrument and return the responses for analysis. It is perhaps therefore not unlikely that the respondents were from classes taught by particularly committed and reflective teachers, compared to the wider population.

The final version of the instrument was used to collect data from 8 institutions in England, over the period to to October 1994. Responses were received from a total of 370 students: 157 pupils having studied bonding at KS4 (Key Stage 4 - intended for 14-16 year olds) of the National Curriculum, and 213 A level chemistry students (i.e. 16-19 year olds.) 84 of the latter had not yet studied bonding on their A level course, and 129 had. Data from these three groups were analysed separately. All analysis was carried out by the author.

item	statement
1	The diagram represents a substance with ionic bonding.
2	Each chloride ion in the diagram is bonded to only one sodium ion.
3	A sodium ion is only bonded to the chloride ion it donated its electron to.
4	A sodium atom can only form one ionic bond, because it only has one electron in its outer shell to donate.
5	The reason a bond is formed between chloride ions and sodium ions is because an electron has been transferred between them.
6	In the diagram a chloride ion is attracted to one sodium ion by a bond and is attracted to other sodium ions just by forces.
7	In the diagram each molecule of sodium chloride contains one sodium ion and one chloride ion.
8	An ionic bond is the attraction between a positive ion and a negative ion.
9	A positive ion will be bonded to any neighbouring negative ions.
10	Each sodium ion in the diagram is bonded to only one chloride ion.
11	A negative ion will be attracted to any positive ion.
12	It is not possible to point to where the ionic bonds are, unless you know which chloride ions accepted electrons from which sodium ions.
13	There are exactly fifteen molecules of sodium chloride in the diagram.
14	In the diagram each chloride ion is bonded to more than one sodium ion.
15	A chloride ion is only bonded to the sodium ion it accepted an electron from.
16	Each chloride ion in the diagram is attracted to only one sodium ion.
17	A chlorine atom can only form one ionic bond, because it can only accept one more electron into its outer shell.
18	There is a bond between the ions in each molecule, but no bonds between the molecules.
19	A negative ion can only be attracted to one positive ion.
20	The reason a bond is formed between chloride ions and sodium ions is because they have opposite charges.
21	In the diagram each sodium ion is bonded to more than one chloride ion.
22	In the diagram a sodium ion is attracted to one chloride ion by a bond and is attracted to other chloride ions just by forces.
23	A positive ion can only be attracted to one negative ion.
24	An ionic bond is when one atom donates an electron to another atom, so that they both have full outer shells.
25	A negative ion will be bonded to any neighbouring positive ions.
26	There are exactly fifteen ionic bonds in the diagram.
27	There is no bonding in the diagram.
28	Each sodium ion in the diagram is attracted to only one chloride ion.
29	There are no molecules shown in the diagram.
30	A positive ion will be attracted to any negative ion.

Table 1**: True or false? The thirty items presented in the TRUTH ABOUT IONIC BONDING DIAGNOSTIC INSTRUMENT**.

Results

A full report of the results was prepared and distributed to contributing institutions (Taber, 1995b.) Space limitations do not allow the full details to be reproduced here. 96% of respondents thought item 1, *The diagram represents a substance with ionic bonding*, was true. The other 4% were excluded from the analysis of subsequent items as it was not clear they would be judging the statements against their conceptions (if any) of ionic bonding. A summary of the responses for items 2-30 is given as table II. During analysis there were found to be occasional omissions where an item had been left (deliberately or otherwise), and there were a few ambiguous responses (as when both 'true' and 'false' might be selected for the same item.) As such ambiguous and null responses were in a small minority it was not felt they were significant, and they were excluded when calculating the percentages that appear in table II.

Item	statement	True (%)	False (%)
1	The diagram represents a substance with ionic bonding	96	2
2	Each chloride ion in the diagram is bonded to only one sodium ion	22	77
3	A sodium ion is only bonded to the chloride ion it donated its electron to	30	61
4	A sodium atom can only form one ionic bond, because it only has one electron in its outer shell to donate	58	33
5	The reason a bond is formed between chloride ions and sodium ions is because an electron has been transferred between them.	75	22
6	In the diagram a chloride ion is attracted to one sodium ion by a bond and is attracted to other sodium ions just by forces	39	49
7	In the diagram each molecule of sodium chloride contains one sodium ion and one chloride ion.	54	39
8	An ionic bond is the attraction between a positive and a negative ion	81	16
9	A positive ion will be bonded to any neighbouring negative ions	58	34
10	Each sodium ion in the diagram is bonded to only one chloride ion	33	63
11	A negative ion will be attracted to any positive ion	85	12
12	It is not possible to point to where the ionic bonds are, unless you know which chloride ions accepted electrons from which sodium ions	46	37
13	There are exactly fifteen molecules of sodium chloride in the diagram	60	34
14	In the diagram each chloride ion is bonded to more than one sodium ion	61	34
15	A chloride ion is only bonded to the sodium ion it accepted an electron from	46	46
16	Each chloride ion in the diagram is attracted to only one sodium ion	16	78
17	A chlorine atom can only form one ionic bond, because it can only accept one more electron into its outer shell	61	29
18	There is a bond between the ions in each molecule, but no bonds between the molecules	36	51
19	A negative ion can only be attracted to one positive ion	31	65
20	The reason a bond is formed between chloride ions and sodium ions is because they have opposite charges	85	14
21	In the diagram each sodium ion is bonded to more than one chloride ion	57	37
22	In the diagram a sodium ion is attracted to one chloride ion by a bond and is attracted to the other chloride ions just by force	50	37
23	A positive ion can only be attracted to one negative ion	26	70
24	An ionic bond is when one atom donates an electron to another atom, so that they have full outer shells	72	24
25	A negative ion will be bonded to any neighbouring positive ion	56	36
26	There are exactly fifteen ionic bonds in the diagram	43	45
27	There is no bonding in the diagram	8	89
28	Each sodium ion in the diagram is attracted to only one chloride ion	20	74
29	Thee are no molecules in the diagram	32	58
30	A positive ion will be attracted to any negative ion	83	12

Table II: **Percentages of learners responding 'true' and 'false' to items 2 to 30.[1]**

(This analysis for items 2-30 excludes respondents who answered 'false' to item 1, and any ambiguous responses.)

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[1] Statements considered correct form a canonical curriculum perspective are shaped green; incorrect statements are shaded blue. For some statements (red shading) more students made the incorrect response than the correct response. For a number of statements a quarter of unambiguous responses were incorrect (orange shading). For most of the other statements the number of wrong responses reached 10% (sometimes used as the level to identify 'common' alterntive conceptions - shaded yellow).

Tables III and IV are examples of how the results in table II were derived from the raw numbers.

group	no of 'true' responses	no of 'do not know' responses	no of 'false' responses	sub-total	ambiguous responses	item unanswered	total
A: KS4/GCSE (after bonding taught)	114	6	24	144	0	1	145
B: A level (before bonding taught)	63	0	17	80	0	1	81
C: A level (after bonding taught)	88	3	37	128	0	0	128

Table IIIa: Responses to item 5

group	%age of 'true' responses	%age of 'do not know' responses	%age of 'false' responses
A: KS4/GCSE (after bonding taught)	79	4	17
B: A level (before bonding taught)	79	0	21
C: A level (after bonding taught)	69	2	29
A+B: taught to GCSE level	79	3	18
B+C: A level students	73	1	26
A+B+C: all learners	75	3	22

Table IIIb: Percentages of (unambiguous) responses to item 5

Table III: **Responses to the statement: "The reason a bond is formed between chloride ions and sodium ions is because an electron has been transferred between them."**

group	no of 'true' responses	no of 'do not know' responses	no of 'false' responses	sub-total	ambiguous responses	item unanswered	total
A: KS4/GCSE (after bonding taught)	111	5	28	144	0	1	145
B: A level (before bonding taught)	39	5	34	78	1	2	81
C: A level (after bonding taught)	58	13	56	127	1	0	128

Table IVa: Responses to item 13

group	%age of 'true' responses	%age of 'do not know' responses	%age of 'false' responses
A: KS4/GCSE (after bonding taught)	77	3	19
B: A level (before bonding taught)	50	6	44
C: A level (after bonding taught)	46	10	44
A+B: taught to GCSE level	68	5	28
B+C: A level students	47	9	44
A+B+C: all learners	60	7	34

Table IVb: Percentages of (unambiguous) responses to item 13

Table IV: **Responses to the statement: "There are exactly fifteen molecules of sodium chloride in the diagram."**

THE VALENCY CONJECTURE

The valency conjecture would limit sodium and chlorine to forming one ionic bond each as their ions have charge of magnitude one. Items 2, 4, 10, 14, 17, and 21 related to this aspect of ionic bonding (see table II.) A majority of the respondents thought that the sodium and chloride ions could only form one ionic bond each (items 4, 17). Most thought that the ions were bonded to more than one counter ion (presumably not necessarily by *ionic* bonds), although about a third of respondents thought they could only be bonded to one (items 2, 10, 14, 21; the percentages vary according to item from 22% to 37%.)

THE HISTORY CONJECTURE

The history conjecture implies that in some way it matters how a particular ion came to be charged, i.e. where the parent atom donated its electron to, or accepted its electron from. An ionic bond is closely associated with the process of electron transfer and only occurs between the ions that have donated and accepted the electron. Items 3, 5, 8, 12, 15, 20 and 24 are of particular relevance (see table I.) Although most respondents agreed with the electrostatic definition of an ionic bond (item 8), most *also* agreed that the ionic bond was when electron transfer took place to give full outer shells (item 24.) Similarly the majority of respondents agreed that a bond was formed because of the opposite charges on the ions (item 20), but most *also* agreed the bond was formed because electron transfer had occurred (item 5). Respondents were equally divided over whether or not a chloride ion was only bonded to the sodium ion it had accepted an electron from (item 15), although most disagreed with the equivalent statement concerning the sodium ion (item 3.) More respondents agreed than disagreed that it was not possible to point to where the ionic bonds where unless one knew which chloride ions had accepted electrons from which sodium ions (item 12.)

THE 'JUST FORCES' CONJECTURE

This explains the attraction between ions that have not been involved in electron transfer as just due to forces, rather than ionic bonding. Items 6, 6, 22 ,25 and 26 are particularly relevant (See table I.) Just over a third of respondents did *not* think that "a positive ion will be bonded to any neighbouring negative ions" nor that "a negative ion will be bonded to any neighbouring positive ions" (items 9, 25.) Almost two fifths of the respondents agreed that "in the diagram a chloride ion is attracted to one sodium ion by a bond and is attracted to other sodium ions just by forces" (item 6), and half agreed that "in the diagram a sodium ion is attracted to one chloride ion by a bond and is attracted to other chloride ions just by forces" (item 22). Respondents were fairly evenly split over the truth of the statement that "there are exactly fifteen ionic bonds in the diagram" (26.)

THE PRESENCE OF MOLECULES

Items 7, 13, 18 and 29 made explicit reference to the presence of molecules in the figure (see table I.) Most students thought the statement that "there are no molecules shown in the diagram" (item 29) was false, and agreed that "there are exactly fifteen molecules of sodium chloride in the diagram" (item 13.) A little more than half the sample agreed that "in the diagram each molecule of sodium chloride contains one sodium ion and one chloride ion" (item 7.) A little over a third of the respondents agreed that "there is a bond between the ions in each molecule, but no bonds between the molecules" (item 18.)

Seven other items (11, 16, 19, 23, 27, 28 and 30) were included which would not distinguish between the ELECTROSTATIC and MOLECULAR FRAMEWORKS, but could provide useful comparisons with other possible views (see table I.) Although the number of students agreeing that "there is no bonding in the diagram" (item 27) was small, this still represents 26 students who had *agreed* the diagram represented *a substance with ionic bonding* (item 1.) Perhaps like one of the students in the interview study they thought the figure represented 'before' bonding (maybe viewing overlap or a symbolic line as necessary for representing bonding). The six items referring to 'attractions' all gave majority support for the view that attractions are not limited to specific ion-counter ion combinations, but it is of interest that for each of the six items at least an eighth of respondents actually believed that the number of inter-ion attractions was limited; and over a quarter agreed that "a negative ion can only be attracted to one positive ion" (item 19) and that "a positive ion can only be attracted to one negative ion" (item 23.)

DISCUSSION

Close examination of the results (table II) reveals some intriguing aspects of the response patterns (see Taber 1995b for a more detailed discussion.) Apparently contradictory statements may both be seen as true by some respondents. This may mean that these items are not contradictory when interpreted from the respondents perspective. However it could also mean that some of these learners hold 'multiple frameworks' (Pope and Denicolo, 1986) like the A level student 'Annie' who gradually learnt the ELECTROSTATIC FRAMEWORK for understanding ionic bonding, but would often revert to an alternative framework she exhibited at the start of her course (Taber, 1995a.) If a learner had access to ideas associated with both the electrostatic and molecular frameworks she might well respond to a statement as 'true' if it was valid according to either viewpoint.

Items that are identical except for the references to sodium and chlorine being swapped around are supported by different proportions of the respondents. This may be significant if learners see ionic bonding differently when focussing on cations or anions. However if the respondents do hold multiple frameworks, then it is possible to conjecture that the order of presentation of items has some effect here, each item being interpreted by the reader in the context of the last few response decisions made.

Statements that appear to have very similar meanings are supported to different extents. Perhaps respondents are sensitive to subtle nuances of the wording of the items that the author did not intend. Whereas the interview study provided the researcher with opportunities to explore such nuances, the diagnostic instrument is too crude to allow this.

Just as the earlier interview study led to questions that the TRUTH ABOUT IONIC BONDING DIAGNOSTIC INSTRUMENT was designed to explore, the results of the survey suggest further research questions. The apparent asymmetry between the response patterns when the cation was discussed compared to the anion could be investigated to see if this was more than an artifact of item sequencing. The 'JUST FORCES' conjecture may need to be refined as for some respondents the crucial distinction seems to be between *ionic bonds* and *bonds*, rather than between *bonds* and *forces*. (Perhaps Butts and Smith's finding that students expected covalent bonds as well as ionic bond to be present in sodium chloride is significant here.) Indeed the meanings that learners give to the terms 'attraction', 'interaction', 'force' and 'bond' seems to be a fruitful area for further enquiry. A significant minority of the respondents did not think that the opposite charge on counter ions was a sufficient reason for them to be attracted. This demonstrates an ignorance of basic electrostatic principles that reflects an earlier case study report (Taber, 1995a.)

It is interesting to examine the results (table II) to consider if there is evidence of progression within the sample proceeding from those who have studied bonding at GCSE/KS4 level, to those who have studied the topic at A level. Certainly the balance of the responses for some items moves towards the 'curricular science view', whilst for other items there seems virtually no shift. Due to the unrepresentative nature of the sample the extent to which valid comparisons may be drawn between the three classes of respondent is limited, and it is not intended to discuss these features further here. It has been suggested that appraising progression in chemistry is difficult because of the nature of conceptual development in the subject (Taber 1995c.) On-going work suggests that chemistry students hold a range of alternative conceptions loosely based on the 'octet rule' as all-embracing explanatory principle (Taber 1995d). Chemical processes are often understood in anthropomorphic terms: atoms actively striving for full outer shells (Taber & Watts, in press.) Progression in individual learners may be modelled on the extent to which they are able to explain chemistry in terms of the explanatory frameworks of curricular science (electrostatic principles, quantum theory) rather than relying on animistic applications of the octet heuristic. The MOLECULAR FRAMEWORK may be seen as one part of a broader model that will represent the common aspects of these conceptions. Within the specific topic of ionic bonding, figure 2 could be used with many students as a basis for following progression in individuals, in terms of the transition from thinking characterised by the MOLECULAR FRAMEWORK, to that characterised by the ELECTROSTATIC FRAMEWORK.

CONCLUSIONS

The data that is presented in this paper support the contention that 'alternative conceptions' about ionic bonding are widespread among learners who have been taught about chemical bonding at school or college. In particular the model constructed to represent common aspects of learners' ideas elicited in interviews - the MOLECULAR FRAMEWORK presented in figure 2 - seems to be widely supported in this sample of 370 chemistry learners. It seems that many chemistry students' understanding of ionic bonding

- over emphasises the process of electron transfer;
- explicitly or tacitly uses the notion of *ion-pairs as molecules*;

- is restrained by an inappropriate consideration of valency;
- pays heed to an irrelevant 'electron history';

and

- distinguishes between what are actually equivalent interactions between ions.

It has been provisionally suggested that although this alternative framework is focussed on one topic, the ionic bond, it reflects aspects of student explanations across the whole of chemistry, and further research is planned.

There were many permutations of response to the survey items, reflecting each learner's unique cognitive structure, but it is suggested that the MOLECULAR FRAMEWORK has proved to be a useful model for focussing this research into learners' alternative thinking. When the framework was first proposed it was emphasised that it is "only a model to highlight the similarities" in the interviewed students' alternative conceptions (Taber, 1994a, p.101). Such an model is a construction of the researcher (Taber and Watts, in preparation), intended to facilitate the discussion and exploration of a common area of student difficulty in chemistry. Providing that it is understood in those terms it is suggested that it should be brought to the attention of trainee and practising science teachers. The results presented suggest it is a model which is likely to represent aspects of the thinking of a significant proportion of learners in most chemistry classes.

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References:

Butts, B., and Smith, R., HSC Chemistry Students' Understanding of the Structure and Properties of Molecular and Ionic Compounds, **Research in Science Education**, **17**, 1987, pp.192-201.

Carmichael, Patrick, Rosalind Driver, Brian Holding, Isabel Phillips, Daryll Twigger and Mike Watts, **Research on students' conceptions in science: a bibliography**, Children's Learning in Science Research Group, Centre for Studies in Science and Mathematics Education, University of Leeds, 1990 (plus addenda, 1991, 1992).

Driver, Rosalind, Ann Squires, Peter Rushworth and Valerie Wood-Robinson, **Making Sense of Secondary Science: research into children's ideas**, London: Routledge, 1994.

Fensham, P., Concept formation, in Daniels, D.J. (Ed.), **New Movements in the Study and Teaching of Chemistry**, London: Temple Smith, 1975, pp.199-217.

Gilbert, John K., & Arden Zylbersztajn, A conceptual framework for science education: The case study of force and movement, **European Journal of Science Education**, **7** (2), 1985, pp.107-120.

Pope, Maureen & Pam Denicolo, Intuitive theories - a researcher's dilemma: some practical methodological implications, **British Educational Research Journal**, **12** (2), 1986, pp.153-166.

Taber, Keith S., Stability and lability in student conceptions: some evidence from a case study, paper to the symposium '**Science Education - Teacher Education**', British Educational Research Association Annual Conference, Liverpool, September 1993(a).

Taber, Keith S., Annie: Case study of an A level student's understanding of chemical bonding, paper to the symposium '**Science Education - Teacher Education**', British Educational Research Association Annual Conference, Liverpool, September 1993(b).

Taber, Keith S., Student conceptions of chemical bonding: using interviews to follow the development of A level students' thinking, paper presented to the Conference on On-going Research, '**Facets of Education - Dimensions of Research**', Institute of Educational Research and Development, 24.6.93 (1993c), University of Surrey.

Taber, Keith S., Understanding the ionic bond: student misconceptions and implications for further learning, paper to be presented to the symposium '**Research and Assessment in Chemical Education**' (22.09.93) at the Royal Society of Chemistry Autumn Meeting, Warwick, 21-23.09.93 (1993d).

Taber, Keith S., Misunderstanding the Ionic Bond, Education in Chemistry, **31** (4), July 1994(a), pp.100-103.

Taber, Keith S., Understanding Chemical Bonding, entry in 'Notes & News' section, **Education in Science**, April, 1994(b), p.30.

Taber, Keith S., Development of Student Understanding: A Case Study of Stability and Lability in Cognitive Structure, **Research in Science & Technological Education**, **13** (1), 1995(a), pp.87-97.

Taber, Keith S., The Truth about Ionic Bonding?, research report, January, 1995(b), available from the author.

Taber, Keith S., An analogy for discussing progression in learning chemistry, **School Science Review**, **76** (276), March 1995(c), pp.91-95.

Taber, Keith S., The octet rule: a pint in a quart pot?, **Education in Chemistry**, **32** (3), May 1995(d).

Taber, K. S. & Watts, M., The secret life of the chemical bond: students' anthropomorphic and animistic references to bonding, **International Journal of Science Education**, in press.

Taber, Keith S. and Mike Watts, The pupil as postmodern scientist: an actionable approach to alternative frameworks, in preparation.

Watts, M., A study of schoolchildren's alternative frameworks of the concept of force, **European Journal of Science Education**, **5** (2), 1983, pp.217-230.

Watts, Mike, Children's learning of difficult concepts in chemistry, Chapter 15 of Atlay, M., Bennett, S., Dutch, S., Levinson, R. & West, D. (Eds.), **Open Chemistry**, London: Hodder & Stoughton, 1992, pp.213-228.

White, Richard T, Interview protocols and dimensions of cognitive structure, Chapter 4 of West, Leo H.T., and A. Leon Pines (Eds.), **Cognitive Structure and Conceptual Change**, London: Academic Press Inc., 1985, pp.51.-59.