"HIGH SCHOOL STUDENTS' IDEAS ABOUT ENERGY OF CHEMICAL REACTIONS"

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1 - INTRODUCTION

This study describes an investigation of misconceptions held by Portuguese secondary students about the processes of energy changes associated with a chemical reaction.

In Portugal, the topic of chemical reactions is formally introduced in grade 8 (age 14). At this level the idea of chemical change is simply equated in terms of the separation/reorganization of atoms with no mention of the nature of the chemical bonds involved as this is only elaborated in grade 10; notions of exothermic/endothermic processes are introduced in the usual manner (heat given out/heat taken in). In grade 11 (age 17) the above aspects are refined and energy changes are now explained in terms of a formal model involving the ideas of bond breaking/bond forming and associated enthalpy changes. At this stage students become familiar with the notion of internal energy.

An important type of changes which are studied in the chemistry course are spontanecus endothermic reactions. These have been recognized to be conceptually difficult for secondary students (Johnstone et al. 1977). Part of the trouble probably derives from an inadequate analogy with mechanical systems (e.g. fall of bodies) where spontaneity is usually related with energy being evolved. However, little is known about students'misconceptions in this domain.

Until grade 11, Portuguese students are not formally taught the relationship between the processes of energy changes (energetic component) and the way the reaction takes place (structural component). Also, the topic of energy, namelly the principle of energy conservation, is only introduced in grade 9 in the physics course and with no links with the chemistry course, although the teacher in both courses is the same. Thus for beginning chemistry students (grades 8 and 9) one may reasonably predict the two above aspects interfering with proper learning. Further, inadequate representations elaborated in this domain in the earlier years may later become barriers to conceptual change as suggested by research on students' misconceptions in other content areas (see Driver and Erickson, 1983; Gilbert and Watts, 1983, for reviews). It follows that this is an important domain of enquiry.

2 - RESEARCH QUESTIONS

The study aims to investigate the following questions:

a) What conceptions are used by Portuguese secondary students to explain the energy changes associated with a spontaneous endothermic reaction, in particular: (i) whether structural and energetic aspects are articulated; (ii) how the principle of conservation of energy is used.

b) How different these conceptions differ between students from different grades?

c) Which possible reasons lie behind existing misconceptions?

3 - METHOD

A) The sample (N = 30) was formed by two instructional groups: 15 subjects from grade 9 (average age 15; 10 males) and 15 subjects from grade 11 (average age 17; 15 males). Subjects were randomly selected from an initial group of volunteers drawn from mix ability classes of a high school located in an urban area of Portugal. In each sub-group students had been exposed to the same chemistry course and also had the same teacher. All had already been taught the principle of conservation of energy.

B) The experimental task consisted in dissolving NH_4Cl (10g) in H_2O (50 cm^3)*. The average temperature fall was -12.9°C. All NH_4Cl was dissolved. The reaction took place in a 100 cm^3 insulated container (with thermometer and stirrer) so that thermal energy transfer with the environment was minimized. This design was intended to promote cognitive conflict involving the idea of energy conservation.

C) Students were interviewed individua , during the summer of 1984. No time limit was set and the average time spent with each student was 40 min. Tipically the experiment was first demonstrated by the researcher. Subjects were then requested first to describe and then to explain what they had observed using a semi-structured interview format. Typical questions were: "What happens to the NH_4Cl?" or "How do you explain the temperature fall?". The interviews were tape recorded and later transcribed in written protocols. These were subsequently analysed to extract students' ideas following closely the method proposed by Erickson (1979). Ideas were organized under two content oriented categories: structural component category and energetic component category.

* As it involves deep structural changes with separation of ionic entities and not simply intermolecular changes (state of aggregation), this transformation is better acknowlegded as a chemical change (Gil, 1974).

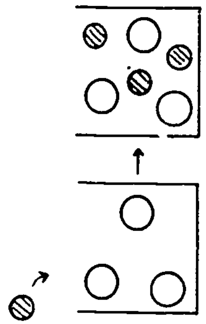
4 - RESULTS

Results obtained for each content category are presented first. Tentative relationships between the two content categories are then analysed.

4.1 - Structural component

Five basic ideas were used by students to explain the way the reaction took place (Table 1). The overall results may be rationalized in terms of a model of chemical change involving the attibute of the permanent nature of substance (Méheut et al. 1983). As the three last ideas closely correspond to misconceptions already referred to in the litterature though in other contexts (see Andersson, 1986 for a review) only details concerning the first two will be dealt with in the following sections.

Table 1 - Ideas used to explain the chemical change

Ideas	Main features: Process of chemical change	Main features: Conservation of reactant(s)	N(grades 9 + 11)%
Serial interaction	sequence model	no conservation	0 + 3 = 3 10%
Principal reactant	different status between the two reactants; only one has an active role	H_2O is conserved	1 + 2 = 3 10%
Conglomerate *	reactants simply connected fi: 	H_2O and NH_4Cl conserved	2 + 1 = 3 10%
Diffusion **	no interactions salt  H_2O	"	2 + 4 = 6 20%
Mixing ***	H_2O and NH_4Cl simply mixed; only macroscopic aspects; descriptive view.	"	6 + 3 = 9 30%
Uncodeable+Other	-	-	4 + 2 = 6 20%

For references see: (*) Shollum, 1982; (**) Cosgrove and Osborne (1981); (***) Andersson (1986).

Serial interaction

The processes of bond breaking/bond forming are not simultaneous, rather they take place one after the other. Firstly, the reactants are broken down into smaller structural units so that the initial substances ceasses to exist; secondly, new chemical species are formed:

Manuel (grade 11): "When water reacts with ammonium chloride both reactants are broken down into particles... then they combine to form new species."

There is no distinction between the nature of the structural units of the two reactants (NH_4Cl "molecules"). H_2O molecules would also suffer intramolecular ruptures:

Rui (grade 11): "Maybe the molecules of ammonium chloride all split apart... the bonds of both (the reactants) are broken down and then maybe the atoms coming from the water are gathered together with those coming from the ammonium chloride."

In spite of the erroneous character of these explanations, serial interaction is the concept which is closest to the acceptable answer according to the teachers point of view.

Principal reactant

There is an interaction between the two reactants but structural changes only take place in NH_4Cl; the water remains unchanged and only plays a passive role:

José (grade 11): "The bonds in the ammonium chloride are broken down and the water doesn't experience any change."

It is not clear whether the fragments formed are NH_4^+ / Cl^- ions or other entities: "... it's (the salt) breaking into smaller particles..." The notion of a principal reactant may presuppose that changes at microscopic level would only occur where changes are observed at macroscopic level, a view reflecting a perceptually guided model of chemical change. Thus it is highly predictable for heterogeneous systems in which one of the reactants is not directly perceived (combustions) or remains apparently unchanged (this study). Such a misconception is probably reinforced by language habits: textbooks often mention "the reaction of... with...", instead of "the reaction between... and...". Also relative order of the reactants represented in the reaction equation may be influential (the "principal reactant" would be the one written in the first place).

To sum up, the configuration of the results doesn't reveal any major differences between the two instructional groups thus suggesting the persistence of earlier misconceptions despite formal instruction. Ideas of chemical change involving some sort of interaction between the reactants seem to be difficult (30% of subjects) and over 70% of the students are probably guided by perceptual features or their

understanding of the chemical change. No one conception is acceptable according to academic standards.

4.2 - ENERGETIC COMPONENT

For the students, four conceptions were used to explain the processes of energy changes (Table 2). These conceptions may be organized under two categories according to whether students did equate energy changes as the result of a process involving both reactants and products (bilateral process) or simply the reactants or the products (unilateral process).

Table 2: Ideas used to explain energy changes

Ideas	Main features	N(grades 9+11) %
Sequential transfer	sequence model	0 + 2 = 2 6.7%
Absorption	temperature and energy not differentiated, hence energy was used; no energy conservation.	3 + 1 = 4 13.3%
Dissipation	temperature and energy not differentiated, hence energy was transferred to somewhere; energy conservation.	3 + 5 = 8 26.6%
I can't explain it	temperature and energy not differentiated; the energy is conserved, hence T should remain constant.	7 + 4 = 11 36.7%
Uncodeable + Other	-	2 + 3 = 5 16.7%

4.2.1 - Energy of the reaction is the result of a bilateral process

Sequential transfer

The energy associated with the chemical change results from a two step process: firstly, there is energy absorption (bond breaking of reactants); secondly, energy is evolved (bond forming of products). The net effect is endothermic.

Miguel (grade 11): "... the bonds (of reactants) break apart and there is absorption of energy. Then, the atoms which come from the water are linked with those coming from the ammonium chloride and energy is evolved... this (energy evolved) is smaller than the energy absorved... during the reaction there is energy consumption."

Consistently, the two students who used this idea also used a sequence model in 4.1 (Serial interaction). They do not seem to appreciate energy transformations (kinetic to potential) at the molecular level; the process would simply involve a transfer of the energy existing between the water molecules, "non-bonding" energy, to the bonds. The temperature of the water would depend on the amount of "non-bonding" energy and that would explain the temperature fall:

Miguel (grade 11): "There is energy scattered between the water molecules and it was absorbed by the new bonds formed... I think that's it. The temperature is... how can I put it? Let us say, it results from the energy not used in the bonds. But the total energy inside (the container) is always the same".

For these students conservation of energy involves the balance of two terms, each corresponding to the same form of energy though functionally different. "Non-bonding" energy seems to have the status of a material substance and it's not excluded that the concepts of temperature and energy were not fully differentiated.

4.2.2 - Energy of the reaction is the result of a unilateral process

In this case the idea of a net effect was absent. A common trait to all answers was to identify temperature with energy (heat energy) a common misconception for junior and secondary students (Erickson, 1979; Tiberghien, 1984). Such a misconception facilitated cognitive conflict between ideas of energy conservation and the observation of the temperature fall. Each of the three conceptions belonging to this category corresponds to a different way used by the students of solving such a conflict. An important influence of perceptual aspects of the task on the students' views should not be excluded. They should, therefore, be regarded as tentative explanations.

Absorption

The energy decreases inside the container because of the temperature fall. Thus it was used during the process, probably absorved by one or both the reactants:

Isabel (grade 9):

(student, S) ".. some energy was used.

(interviewer, I): Why?

S : The temperature decreases!

I : How was the energy used?

S : Well, the container is insulated and energy can't get through it, thus maybe the substance, that substance (ammonium chloride), kept the energy."

These students achieved cognitive reconciliation assuming that energy which is "absorved" doesn't matter when considering energy conservation. With a non-insulated system they would probably use the conception which is presented below.

Dissipation

As the temperature decreases the energy decreases hence energy is transferred to somewhere outside the solution. Two basic ways were suggested for such an energy transfer:

(i) energy occupies the small space existing between the cover of the container and the solution:

Neto (grade 9): "... The energy comes out (of the solution) to that small space... to that area (under the cover)... energy must have been released because the temperature is like that (decreases)".

(ii) The system is not insulated. Hence energy may be transferred to the environment, which becomes hotter:

Carlos (grade 11): "... The temperature (of the water) decreases because energy was released... the container isn't completely insulated. It (energy) comes out through these little holes in the cover (where the thermometer and the stirrer enter)".

The logic of this answer implies that endothermic reactions may be equated with a temperature increase of the surroundings It also reveals an inadequate understanding of thermal balance.

I can't explain it

Subjects consider that energy must be conserved but don't know how to equate it with the observation of the temperature fall (which is related with an overall energy decrease). Thus, in this case, the conceptual conflict was not solved.

Filipe (grade 11): "The energy remains the same inside the container. It can't come out because it's a thermal insulator... the temperature should also be the same! I am confused, the temperature decreases and the energy is constant... I don't see how it works!"

These students would probably use a "Dissipation" explanation in the case of a non-insulated system.

To sum up, similar ideas were generally used by students of different grades to explain energy changes associated with the reaction. As for the structural component (4.1) this result suggests that previous knowledge was probably an important factor as misconceptions seem to have persisted despite formal instruction.

The results also suggest that the principle of conservation of energy might have been accepted but not properly understood. Students in grade 11 weren't able to appreciate the conversion of kinetic to potential energy at molecular level and to equate temperature in terms of average kinetic energy of particles. Rather, they have used conceptually less demanding transfer models. As referred to in the Introduction, the conservation of energy was introduced in the physics course. It is not because students are able to properly conceptualize the conversion of kinetic to potential energy in a physics context (where it can be directly observed with the help of mechanical systems) that ideas about energy conversion will be properly used in a chemistry context where the conversion of one form of energy into another essentially lies beyond personal experiences and have to be equated in terms of internal energy. Teachers should be aware of such a crucial difference.

Over 90% of the students did not articulate energy changes with the way the reaction took place. Students appear to have conceptualizad these two related aspects as two independent bits of information. In particular: (i) the relation of a net effect of energy with structural aspects was absent; (ii) only part of the system, reactants or products, was considered. Except for students using a sequence model no coherent pattern emerged for ideas used by individual subjects to explain both the structural and the energetic component. Sequence models were also used by secondary students to explain how electric current flows in a circuit (Shipstone, 1982) and, in our view, their use is consistent with a limited capacity memory model (Johnstone, 1980). In fact, understanding of energy changes associated with a chemical reaction implies a hollistic perception of the reacting system involving the coordination within and between two sub-systems, hence a high level of information. Use of a sequence model may be a way to lower memory overload.

5. CONCLUSIONS

The main goal of science education is to promote concept learning, for concepts are what we think with. Teachers and curriculum developers, although generally competent in their subjects may not be familiar with students' common misconceptions. Improvements in student learning can be brought about if they are more knowledgeable about the nature of students' misconceptions and how to plan instruction so as to promote conceptual change.

The results of this investigation suggest that the topic of chemical reactions in secondary chemistry curriculum in Portugal should be carefully redesigned. First, the timing of introduction of certain key ideas (e.g. energy conservation) and its coordination between different subject areas should be under close scrutiny. The process of transferring new information from one context to another is not automatic. Such a transfer, if not properly achieved, may lead to inadequate conceptualizations which may persist despite formal instruction. Secondly, one has to question the role of some standard experiments used to introduce essential ideas of thermodynamics in schools. For example, widely used non-insulated systems don't seem to be of great help to promote conceptual change in the misconception "temperature = energy (heat energy)". Thirdly, the language used to introduce chemical concepts may be responsible for the development/reinforcement of inadequate ideas as the meanings students ascribe to science facts and principles may not coincide with those intended by the teacher. Moreover, both teacher and student may be unaware of this (possibly the case of the notion of "principal reactant").

Of course the above proposals are not intended to solve all the problems faced by students in the understanding of spontaneous endothermic processes. This will remain a difficult concept to master until they can appreciate the direction in which energy changes take place. It should be noted that recent proposals have been made to teach a simplified version of the second principle of thermodynamics even to 14/15 year old students (Solomon, 1982). We hope that all these proposals will contribute to a more successfull science teaching effectiveness in such an important area of chemistry.

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