Pre-Instructional Conceptions about Transformations of Substances[+)]

by

Helga Pfundt[++)]

Abstract

The findings gleaned in the past from classroom observation and individual interviews indicate that certain framework conceptions can be identified by means of which pupils explain special transformations of substances and which are activated in view of new experiences made in the course of chemistry instruction. The aim of the investigations to be described here is to uncover such framework conceptions of transformations of substances. Approximately 30 interviews were conducted involving 8-13 year-old pupils. The interviews dealt with the burning of alcohol, occurences during the heating of copper vitriol (aqua copper sulfate) and its recovery and the extraction of lead from a lead ore (lead(IV)-oxide).

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++) Address: Institute for Science Education (IPN), Olshausenstraße 40 bis 60, 2300 Kiel, Germany.

1. The Problem of everyday Conceptions in Chemistry Teaching

In recent years growing interest has been paid in physics teaching everywhere to the learners' conceptions and, thus, to problems which arise during instruction as a result of conceptions carried over from everyday life.+) Quite often findings of psychological studies on cognitive development, particularly those of J. PIAGET and his colleagues, could be adapted. More recently findings from the psychology of memory gained in the context of physical subject matter have become available. In chemistry teaching the problem of everyday conceptions was hitherto hardly considered. Nor are there any findings from other sciences to rely on: psychologists practically never used chemical subject matter on which to base their studies.

One reason for the different degree of interest might be that the chemical phenomena in the surroundings are not as favorable towards disclosing regularities and thus to the formation of general conceptions as physical phenomena. The attempt to register the innumerable special conceptions of innumerable chemical phenomena must needs seem hardly to make sense to the educator. This is particularly so because in chemistry instruction mostly chemical phenomena are used with which the pupils are not familiar from their surroundings and of which the pupils therefore have not yet developed specific conceptions which could be put to use in chemistry instruction. Physics instruction is in quite a different situation: it deals with a great many phenomena with which the youths have been confronted early-on and of which they therefore have certain conceptions.

+) Representatives of several research groups met in September 1981 at an international Symposium in Ludwigsburg. A book containing the papers read there is available from the IPN in Kiel (Proceedings of the International Workshop on Problems Concerning Students' Representation of Physics and Chemistry knowledge). A bibliography concerning the topic "conceptions" is also available from the IPN.

It must be noted here, however: even though the pupils are not yet familiar with and therefore do not yet have a certain conception of most of the phenomena dealt with in chemistry instruction, existing framework conceptions could still play an important role. The findings from classroom observation and individual interviews (see F. STÜCKRATH, 1953; H. KRAUSE, 1962, 1964, 1965; J. WENINGER, 1972; H. PFUNDT, 1975, 1981) indicate that young people develop some encompassing conceptions besides very specific ones. It must be assumed that the general assumption of D.P. AUSUBEL (1974) is also true for chemistry instruction: all new experiences which the pupils make during instruction are ordered with the aid of pre-existing conceptions. (For the treatment of conceptions in science instruction, see particularly W. JUNG, 1981.)

2. Aims of the Investigations

The investigations described here deal with framework conceptions of transformation of matter. It is not the main aim of the investigations to determine what specific conceptions exist of the one or the other transformation of a substance. Instead, an attempt is made to determine how qualitative change as such is conceived of, what possibilities of explanation are considered. Such possibilities of explanation would have to be brought up to date in view of special transformations of substances during instruction as well as in the course of studies and they would have to determine specific interpretations.

I consider it important to ascertain:

(1) what general conceptions the pupils bring with them to class
(2) what changes these conceptions undergo in the course of instruction and
(3) what general conceptions adult laymen have at their disposal a short or long time after they have left school.

Such investigations can help to bring the presence of such conceptions and their influence on the acquisition of scientific conceptions into the open. A long-term aim should be to seek ways - on the basis of the findings - of dealing properly with the conceptions found and to equip the pupils more effectively than before with lasting scientific conceptions.

The investigations which I have carried through so far dealt with the conceptions which children developed prior to instruction in chemistry.

3. Framework Conceptions in Chemistry

If one, from the point of view of a chemistry educator, wants to find out pre-instructional framework conceptions of transformations of substances, one will have to keep in mind the conceptions to which chemistry instruction wants to lead the pupils. The direction of the questions in the investigations is dependent to no small extent on such goal orientations.

In this connection it must be asked: in what frame does modern chemistry place transformations of substances? From what fundamental problems has this frame arisen? And what other solutions have been attempted for this problem?

These questions will be discussed in detail elsewhere (H. PFUNDT, 1982). For now, let me summarize:

For every attempt to solve the problem, how transformation of matter might be conceived of, a difficult conflict arises: when new unified substances are formed from two initial substances the properties of the initial substances disappear, i.e. the initial substances can no longer be perceived in the end product. Despite this, they can be recovered from the end

product with all their original properties. For instance, red shiny copper and colorless oxygen can be "extracted" from black copper oxide although they are not perceptible in it. In view of the disappearance and origination of substance properties, how can the reversibility of substantial processes be explained?

The reversibility of substantial processes seems to demand something which outlasts all changes. Chemistry, from the time of its beginnings, has been on a search for something lasting in the face of continual change. On a search for elements, atoms, elementary particles (see, e.g. A.G.M. VAN MELSEN, 1957; E. STRÖKER, 1967). Thus, the question is: what is conserved during the formation of new unified substances from the initial substances so that the recovery of the initial substances becomes understandable? What changes so that it becomes understandable why the properties of the initial substances can not be perceived in the end product?

Modern chemistry when solving the conflict between change and invariance presumes that each substance is defined by a very specific combination of properties. The disappearance of these properties and the appearance of new properties indicate the destruction of the initial substances and the birth of new substances. Substances, therefore, do not change their properties: copper, for example, does not turn black upon heating. They cease to exist and new substances come into existence. For example, when copper oxide is formed, copper and oxygen cease to exist and copper oxide comes into existence. Copper oxide does not contain copper and oxygen in "altered form", i.e. with other properties. Copper and oxygen have not realized new properties in copper oxide which before were latent in them. Instead, copper and oxygen no longer exist in copper oxide.

With such a concept of substance as a basis the conflict between change and invariance can not be solved via an assumption such as is made in various versions of the different element hypotheses: when new unified substances are formed the initial substances are conserved, i.e. they can be recovered from the end products. The initial substances do, however, change their properties, i.e. their original properties are not perceptible in the end products.

A possible solution might be found with the aid of a discontinuum conception: with the aid of the conception of substance as particle systems: when one considers substances as systems of non-changeable particles, it is the particles which outlast all change, and the configuration which can be destroyed and created anew. Just as one can rearrange the pieces of a mosaic to create a totally new picture in which the old picture is no longer apparent, from which however the old picture can be reconstructed, one can rearrange the particles of a substance to create a totally new substance in which the old substance is not apparent, from which, however, it can be reconstructed.

Both the element hypotheses and the modern hypothesis of the atom offer a solution for a further problem: humans find in their surroundings an incalculable multitude of substances and they observe transformations of substances everywhere. How can this multitude be made surveyable?

The element hypotheses reduce the multitude of substances to comparatively few basic substances of which all substances are composed. According to these hypotheses, all transformations of substances are the result of a combination or decomposition of the elements. The hypothesis of atom reduces the multitude of substances to comparatively few kinds of atoms. The differ-

ent substances are then diverse systems of different atoms. In the course of the transformation of substances the atoms re-combine to form new systems.

Considering transformations of substances within the framework of the atom hypothesis is a conception to which chemistry instruction would like to lead. For this, the concept of substance, on which the hypothesis of atom is based, is at least implicitly presumed.

The question after the pre-instructional concept of substance is therefore central in the described investigations of conceptions.

4. Carrying out the Investigations

Investigations concerning conceptions about transformations of substances always provide information about conceptions of substances. It is therefore sufficient only to study the conceptions of transformations of substances. For my investigations on pre-instructional conceptions, I used the following four experiments:

(1) Burning alcohol

(2.1.) Heating blue vitriol (aqua copper sulfate)

(2.2.) Adding water to the white substance (copper sulfate) which is formed when heating blue vitriol.

(3) Heating a brown ore (lead(IV)-oxide) on a piece of charcoal in front of a blowpipe: production of lead

In other words, I dealt with transformations with which the pupils were not familiar from everyday life. The pupils did not even have any experience with burning alcohol. Accordingly, the pupils could not have any special conceptions of these

processes. But rather they developed them while they were being questioned. My aim was to find out *whether* the special conceptions were developed within certain pre-existing general conceptions. And if so, within *which* general conceptions.

I have hitherto interviewed in individual sessions some 50 pupils from second to seventh grade between the ages of 8 and 13. Other individual interviews were carried through by students during a seminar about pupils' conceptions. The pupils attended the "Gymnasium" or were potential or future pupils at "Gymnasium" if they were attending the "Gesamtschule" or still elementary school. I wanted to interview children with good verbal skills. I consider this restriction not only as legitimate, but necessary at the present. It is still difficult enough to capture conceptions reliably and differentiated enough. To what extent the conceptions found in these pupils can be generalized to pupils attending other types of schools is a question which must be considered later. I assume that the general conceptions are similar but that there are considerable differences within these general conceptions.

The separate investigations were structured as follows:

(1) Performance of the experiment and observation by the pupil

(2) Free verbal statements by the pupil: description of observations, comparison with familiar processes, interpretations, questions

(3) Questions by the interviewer concerning familiar processes which the pupil thinks are similar

(4) Questions by the interviewer concerning interpretation

(5) Provision of interpretations and reactions of the pupil.

The interviews thus began quite freely and became increasingly restricted. In the most restricted section (5) I tried to ascertain which of the provided conceptions were accepted by the pupils and for what reasons other conceptions offered were rejected.

This type of methodical procedure is justified by the existing didactic interest: in the investigations it is not a question of finding out ready-made conceptions waiting to be recalled at any time but the readiness with which the pupils - in the face of new phenomena - go in one or the other direction of their own accord or as a result of prompting from the interviewer. This readiness is the crux of instruction: for the teacher it is important to know which conceptions the pupils are willing to develop or accept when faced with certain factual and communication phenomena.

W. JUNG (1978) referred to this distinction between "latency" and "virulence" with respect to conceptions: "A very important point is the difference between "latency" and "virulence". In the field of linguistics an analogous problem was discussed under the headings "competence" and "performance". Not every child can, for instance, arrive at atomistic conceptions (= distribution of smallest, invisible pieces of sugar) on his own when explaining, e.g., the dissolution of sugar. One can, of course, try to ascertain what percent of the children have these conceptions at what age. But it is at least equally interesting to find out what percent and what children are *ready* for this explanation; i.e. those who do not discover the explanation on their own but who have awaited it, so to speak" (W. JUNG, 1978, p. 131).

In this context JUNG also says that it would practically be an impossible task to check whether the conceptions expressed were pre-existent or were developed ad hoc. Conceptions are developed, enriched, differentiated, specified and changed as a result of various occurences - occurences which happen unplanned outside of school or planned in instruction, but also in investigations on the registration of conceptions. It would hardly be possible to determine whether an interview was the cause of the registered conception.

Because of the didactic interest an attempt was also made to involve the pupils in very intensive confrontation with the matter. The explanations provided in the last section of the interviews stimulated such a confrontation. In that section I also asked when something was not clear to me and when something seemed - within my own conceptual framework - contradictory. I also pointed out other thought possibilities from the ones provided by the pupils. Whenever possible, one and the same pupil was questioned about several transformations of substances. (The sequence of interviews on the four different transformations of substances differed from pupil to pupil.) Such a procedure was meant to bring loose ends in relation to one another and to create greater consistence. Those conceptions were to be registered which would be important for instruction: conceptions which are developed as a result of intensive reflection on the matter and not conceptions spontaneously expressed and then swiftly retracted. The interest of the children and their delight in the different, almost philosophical, questions was very stimulating for me.

Such a procedure always involves the difficult task of testing whether the developed conceptions were possibly adopted more superficially under the influence of the interview or whether they were actively incorporated into the overall conceptual network (cf. the interesting considerations of F. KUBLI (1981) and R. ÖRTER (1971, p. 73 ff.).

When it is important to study conceptions which pupils develop or accept after intensive reflection, i.e. conceptions which are related to the rest of the conceptual network of the pupils, the question arises, how useful *written* interviews can be - quite apart from the difficulties of their interpretation. Maybe it is possible to develop methods of investigation in which written interviews follow a group discussion. By this means, greater populations could be studied.

5. Preliminary Findings of the Investigations

5.1. Conceptions about the Burning of Alcohol

In the course of my own teaching and later on while testing the IPN course "Substances and its Transformations" (J. WENINGER, H. PFUNDT, et al., 1979), I found that pupils at the beginning of chemistry instruction consider the burning of metals, coal, wood and other solid substances as the irreversible destruction of these substances in the sense that the substances can by no means be recovered. They are irrevocably destroyed (cf. H. PFUNDT, 1975). The word "burn" was used precisely in this sense. One of my pupils, for example, commented on the recovery of zinc from the ash of zinc - a process completely unexpected to her - "zinc has not been burned by burning".

When using our modern concept of substance we must describe burning - just as all transformations of substances - as the destruction of the burning substance but not as an irreversible destruction. Like all transformations of substances, burning, too is reversible in the sense that the initial substances can be recovered from the end substances even though the method may be complicated. The burning of zinc, for example, can very generally be described on the substance level as follows: a new, homogeneous substance originates from zinc and oxygen whereby zinc and oxygen cease to exist. They can, however, be recovered from this substance.

For further investigations on the burning process I used alcohol since it is not a solid substance and since it burns without forming ash. The children poured some alcohol into a porcelain saucer and lighted it. It burns with a large flame, and forms invisible gases.

Of the 10 pupils interviewed, most brought the burning of alcohol not only in connection with familiar burning processes but with the evaporation of water. This came as a suprise to me, because the children knew that water can be formed again from the water vapor by cooling it. But it is understandable: the evaporation of water is as familiar to the pupils from

everyday life as burning processes and - with the exception of the very striking formation of flames - the phenomena involved in the evaporation of water and the burning of alcohol are very similar: a colorless fluid substance disappears without residue.

As previous investigations have shown, children between the ages of 10 and 13 mostly explain the evaporation of water in two ways: either as division of a portion of water (thought of as being continuously structured) into small drops and their dispersion into space or as the "thinning" of a portion of water (also thought of as being continuously structured) (F. GRÜTZMANN, 1980; H. PFUNDT, 1981).

Although most pupils mentioned the evaporation of water in connection with the burning of alcohol, only one pupil saw no fundamental difference between burning and evaporation: in both processes the fluid substance is distributed. The only difference is that during burning, this distribution goes faster "due to the heat" than during evaporation. Accordingly, the original substance, i.e. alcohol, can be recovered from the gases which form during burning, provided it is possible to collect what has been distributed.

In the opinion of 7 of the 10 pupils, the burning of alcohol was not so much a process such as the evaporation of water but more like the burning of wood, paper and other solid substances: alcohol ceases to exist and gases come into existence. Alcohol cannot be recovered from these gases "since the alcohol has been burned". The alcohol has been irreversibly destroyed.

The remaining 2 out of the 10 interviewed pupils combined both conceptions: alcohol consists of two components. One component burns, i.e. is irreversibly destroyed, while gases are formed. The other component meanwhile evaporates, i.e. "is distributed". What is distributed can be put together again but not to form

alcohol, but a noncombustible fluid substance. In order to regain alcohol, a "new" combustible substance would have to be added to this fluid substance.

On the basis of the 10 investigations carried out, thus two very different conceptions for the burning of alcohol show up, which may arise separately or in combination with one another: the conception of an irreversible destruction, the conception of a distribution without substantial transformation and a combination of both conceptions.

5.2. Conceptions about Occurrences During the Heating of Blue Vitriol (Aqua Copper Sulfate) and During the Addition of Water to the Resulting White Substance (Copper Sulfate)

5.2.1. For another series of investigations I chose a process which, in contrast to the burning of alcohol, can very easily be reversed: the decomposition through heat of aqua copper sulfate - a blue solid substance (blue vitriol). When aqua copper sulfate is gently heated, copper sulfate (a white solid substance) and water vapor are formed. When water is added to the resulting copper sulfate, aqua copper sulfate is recovered:

aqua copper sulfate ⇄ copper sulfate o water

In the modern concept of substance these processes can be described very generally like this: aqua copper sulfate transforms into two new substances, copper sulfate and water (which are not already contained in it) and itself ceases to exist. The original homogeneous substance, aqua copper sulfate, is recovered from copper sulfate and water, whereby copper sulfate and water cease to exist.

The investigations on both processes were sometimes carried through one right after the other and sometimes on two separate days. All children were questioned about the change of aqua copper sulfate *before* they performed the experiment to recover the substance, i.e. before they experienced the reversibility of the process.

5.2.2. In the investigations on the transformation of aqua copper sulfate the children heated glittering blue crystals of the substance in an open porcelain crucible. A lustreless white substance is formed. The form of the crystals remains the same, at least in part, so that except for the change of color and shine, hardly any change is apparent. During transformation, a crackling is audible. Sometimes tiny particles shoot up: some crystals crack as a result of the formation of (gaseous) water vapor. The water vapor is invisible and escapes unnoticed in the selected experimental setup.

A surprising amount of experience is brought into the pupils' explanations. The numerous very interesting details cannot be described here.

Two of the ten pupils interviewed explained the process as drying, 2 spoke of bleaching, the remaining 6 assumed - this came as a surprise to me - the formation of ash. Some of the children who had the conception of ash formation also assumed drying.

I would like to report two interviews in more detail because they show the important role of existing preconceptions.

One of the interviews was carried out by a student-teacher during the previously mentioned seminar and involved a 12 year-old girl: the student asked the girl to heat blue vitriol in a test tube and not in a crucible so that the attention of the girl was drawn from the start to the formation of water. In this experimental setup the steam condenses (to an astounding degree) at the cool top of the test tube and thus cannot be overlooked. The pupil, Julia, immediately called the resulting solid substance "ash" because it was white and crumbly like wood ash. She spoke, as other children did, of a "burning without a flame". Despite considerable effort on the part of

the student-teacher (who slipped increasingly from an open interview to an instructional conversation), Julia was not willing to pay any attention to the water: the vitriol was simply a bit damp and while it was being burned, it dried. The idea that by adding water to the "ash", blue vitriol could be recovered, was considered farfetched by her: "When you pour water on wood ash, wood is not re-formed". After - at the request of the student - she dripped water on the white substance, she recognized that something blue was formed but that perhaps the blue was somewhat lighter and the form of the pieces was not exactly the same as that of the original vitriol.

11 year-old Stephanie took quite a different approach. In contrast to Julia, she heated blue vitriol in an open crucible so that she was not able to note the escaping water. In spite of this, she immediately called the resulting solid substance "dried vitriol" and explained that drying was the result of heating - as in wood. It crackled exactly the same way. And besides, something crumbly was formed. Stephanie saw the resulting solid substance not as white, but very light blue. She explained that something similar had happened as when earth dries. The earth also becomes very light then. And when water is poured on it, it becomes dark again. Accordingly, Stephanie wanted to add water immediately to the white substance in order to recover blue vitriol. After she had done this, she was pleased to ascertain that precisely the original appearance was restored. The fact that the blue substance felt dry, did not surprise her: the water was completely absorbed in the vitriol.

These two studies show very clearly how new experiences were incorporated into an already existing framework. For Julia, it was the framework "ash formation". For Stephanie, "drying".

These frameworks determined the expectations: is it feasible that when water is added to the white substance, the original blue vitriol is recovered? These frameworks also determined perception: is the substance which forms during heating very light blue or white? Does the solid substance which forms when water is added look the same as the original vitriol? Due to the different frameworks, perception is awarded different importance. Julia paid no attention to the water she saw. Stephanie assumed there was water without having been able to see any.

Of special importance to me was the children's handling of several sentences which were provided in the last section of the interviews. They dealt with the conception of substance: is substance considered as something which can change its properties but is itself conserved? Or, as in modern chemistry, is a change of property considered as a sign that the substance has ceased to exist? Sentences such as the following were meant to stimulate a conscious confrontation with various conceptions of substance:

The blue vitriol changes its properties.

The blue vitriol itself changes.

The blue vitriol ceases to exist and the white substance comes into existence.

The white substance is the same vitriol as the original vitriol.

The white substance is changed vitriol.

The white substance is no longer vitriol.

I would not have dared to confront the children with such differentiated descriptions if the first child interviewed had not touched upon these questions herself: can a substance change its properties without itself changing? When a substance itself changes, is it still the same substance or does it cease to exist?

The two children with the "drying" conception were quite sure of their answers: "When the color changes, not the whole substance need change". "The substance becomes white but it itself does not change. It does not cease to exist." "Only *its appearance* changes". "It is still the same vitriol".

The children with the "bleaching" conception were somewhat uncertain.

All 6 children with the "ashing" conception assumed that the substance itself changes. Susanne, 12,10 years old even rejected (in contrast to the other 5) the sentences: "The vitriol turns white" and the "vitriol changes its properteis" since they implied that the vitriol is conserved. Not all 6 children, however, were certain whether they should agree with the sentence "The vitriol ceases to exist and the white substance comes into existence". Two children wanted to make their position dependent on whether or not the white substance was still "usable" or was "spoiled". They considered whether the observed processes were reversible. The process of heating vitriol apparently is, in the conceptions of the children, not as radical as a "real" burning - even when it was explained as the formation of ash.

5.2.3. It was amazing how suddenly the "ashing" conception changed after the children - in a subsequent interview - dripped water on the white substance and then really did accept that the same vitriol was recovered: "Then the vitriol must have stayed the same if it only changed color". "Then it wasn't ash after all". It became very clear: the reversibility of the process implied for all children that the vitriol had remained the same: it had only changed its properties, above all, its color. Reversibility implied conservation of the substance during a change of properties.

Not all children with the "bleaching" and "ashing" conception saw the water added to the white substance as a *component* of blue vitriol - at least not as a *necessary* component. 9,7 year-old Jochen for instance did not make the water itself responsible for the recovery of blue vitriol, but its coldness[+]. He thought the original vitriol did not contain any water, only the one which formed from the white substance and water.

Other children thought all of the water had evaporated after its addition and, in doing so, contracted the cracked particles to form the original not cracked vitriol. The water, or rather its coldness (Jochen) or its properties (Christina)

[+] When I asked Jochen to get water for the experiment, he asked: "hot or cold?". I answered: "Just cold water". The "coldness" of the water then became the key to Jochen's explanation in the entire interview. He became angry that in the interview guide, talk was only of "water" and I meekly added the word "cold" everywhere.

Such unforeseen occurences in the course of the interviews which one first considered as troublesome interruptions can provide valuable indications of conceptions: Certainly it was not entirely accidental that Jochen insisted on the "coldness" and stuck with it so persistently. Another child considered, without my having hinted at it, whether one could perhaps recover the blue vitriol by cooling the white substance. If a white substance could be gained from a blue one by heating, it is certainly feasible that a blue substance could be recovered from a white one by cooling.

has the effect "that the vitriol changes its color from white to blue" but once the water has brought this change about, it is no longer necessary.

It became increasingly clear to me from the investigations on the recovery of blue vitriol that all children were working with the conception of a substance which can realise several properties: vitriol can be blue or white, Which of these possibilities is realized depends on certain conditions such as the presence or at least the influence of water. In subsequent interview guides, I included a sentence with this content. It is one of the few sentences which all children interviewed agreed wholeheartedly to.

5.3. Conceptions about the Extraction of Lead from a Brown Ore (Lead(IV)-oxide)

In the interviews on alcohol and blue vitriol I had the impression that burning usually was considered onesidedly as a process in which the original substances cease to exist, but not as a process in which new substances come into existence, The resulting gas or the resulting white substance are destroyed products, something which has become useless. Andreas compared "burning" of blue vitriol to taking apart a Lego crane: at the end, the crane is destroyed and there remains only a pile of pieces. Andreas did not in his mind reassemble the pieces to build, for instance, a Lego car. (I will come back to this interesting comparison later in connection with the atomic conception.)

I chose extracting lead from brown lead oxide in the assumption that I would find an "opposite" conception here: a new substance begins to exist. From something which looks useless, an "intact", usable substance is formed.

At present I have only carried out four interviews. I did not find the conception I had presumed in any of the four children. To my surprise, the pupils again developed the conception of changeable substances - in one case, combined with the conception of destruction. In addition, all children had a conception of a mixing and decomposing: both lead and lead oxide were considered as composite substances whose components face very different fates during the observed process.

The previously executed investigations do not yet suffice to set up more dependable hypotheses about the conceptions of the formation of lead.

6. On The Suspected General Conceptions

In the previous investigations some general conceptions of changes of substances have allready become recognizable:

- the conception of an irreversible destruction of substances,
- the conception of an irreversible changing of properties of lasting substances,
- the conception of a reversible changing of properties of lasting substances,
- the conception that substances with all their properties continue to exist, that they are merely distributed or mixed or seperated.

The conception of substances which change their properties was developed wherever reversibility was experienced. If the initial substance can be recovered from the end substance, the conception can not be far off that during transformation something is conserved, that the transformation involves a substance which remains itself but realises various properties.

In individual cases it happened that a child assumed - without ever having experienced or assumed reversibility - a change of properties of substances and not a complete destroying of the substances in question.

This might indicate that the difference between the conception of an irreversible destruction, whereby a substance ceases for all time to exist, and the conception of the change of the properties of substances, whereby a substance continues to exist, does not seem so great. The perishableness can perhaps be seen as a border case where the change of properties becomes so great that it "gnaws at the substance". Substantial changes are then, so to speak, far-reaching accidental changes which can only be reversed with difficulty - if at all, i.e. changes of properties.

When children without experience or assumption of reversibility assume some transformations of substances to be merely a change of properties under conservation of the substance but not a destruction of substances, the question must be asked: what are the properties which can change without the substance itself undergoing change? What are the identity criteria?

A fairly *un*important property for the children seems to be the *color*. Children learn at an early age that things can be colored or dyed with different colors without changing the thing's essence. This experience with things is apparently carried over to substances.

An important attribute seems to be the size of a portion of substance, the *volume*. One girl thought there was a decrease of volume during heating of blue vitriol. This played an important role in her assumption that an ash had formed, i.e. that the blue vitriol did not retain its identity.

On the basis of experience with reversibility, the conception of a substantial change apparently can quite easily be converted generally into the conception of accidental change. 2 of the girls questioned, at the end of the interview, considered whether - in contrast to their earlier convictions - all change is only a more or less far-reaching change of properties of substances which have basically remained the same.

One must realize that reversibility does not necessarily - as logical consequence-require the conception of conservation. Reversibility can also be explained using the conception of perishability and formation of new substances. An important indication of why the conception of conservation is so much more satisfying was provided by Susanne, one of the pupils interviewed. At the end of all interviews in which the concept of substance had repeatedly played an important role, I gave Susanne the modern definition of substances: substances are defined by certain properties. According to this, they don't change their properties, but cease to exist and come into existence. Susanne was very dissatisfied with this definition: then there would have to be an endless amount of substances and a constant perishing and origination of substances - a completely chaotic world!

In this reaction there is indication that the conception of substances which can alter their properties but themselves are conserved provides an answer to the previously mentioned basic question (see section 3): how can the multitude of substances and transformations of substances be made surveyable? Considerations such as those of the girls mentioned above point in the direction of an element hypothesis: there is a limited number of substances which remain the same during all changes but which realize various properties which are potentially present in them.

I assume that this still is a prevalent everyday conception today (see: J. WENINGER, 1972). Our everyday language includes a multitude of expressions which express such a conception. But even in chemistry we can still find the remains of this conception. What does a chemist mean when he says:

> Diamond and graphite are two different *forms* or *modifications* of *carbon*. Water can be solid, fluid or gaseous.

Whoever means a substance when he says "carbon" or "water", and not an abstract, expresses at the same time that this *substance* can exist in various forms, i.e. "with different properties".

I think that Andreas' conceptions which I mentioned earlier show a pedagogical way to the atomic hypothesis and to a new concept of substance. Andreas - in response to my question, whether the change of vitriol would result in something lasting - said: yes and no. Then he gave the example of the Lego crane: the crane ceases to exist, the Lego pieces are conserved. From here it is not far to the conception of the change of particle systems: the structure of the systems perishes and originates and, with them, the substances. The particles, however, outlast all change.

The conception of atoms is seldom offered in instruction as the solution to the problem of the multitude of substances and transformation of substances, and to the conflict between change and conservation. It can, therefore, hardly be expected that the daily conceptions which represent a solution to these problems, will be given up in favor of an atomic conception whose potential is not recognized.

7. References

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