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TURKISH UNDERGRADUATE STUDENTS' MISCONCEPTIONS ON ACIDS AND BASES

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Abstract. *This study is aimed at determining students' misconceptions about acids and bases. In order to fulfill this aim, open-ended diagnostic questions and semi-structured interviews were used. The diagnostic questions were administered to 91 undergraduates who enrolled in the Primary Science Teacher Training Department in a state university in Turkey. In addition 11 students were interviewed in order to clarify their written responses and to further probe students' conceptual understandings of the questions asked in the test. The findings revealed a number of misconceptions. The results have implications for tertiary level teaching, suggesting that a substantial review of teaching strategies is needed.*

Key words: *misconceptions, acids, bases, equilibrium, science education.*

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Introduction

A major thrust in science education research over the past three decades has been the documentation of students' misconceptions (also termed alternative conceptions) in a wide range of subject areas (Pfund and Duit, 2004). These beliefs have been shown to have the potential to impede future understanding, and have also been shown to be remarkably resistant to change. Research has shown that some students tend to reject explanations that are in conflict with their beliefs and prefer to retain an erroneous idea that makes sense to them (Stepans et al., 1986). It is critical to identify these misconceptions so that teaching can be carried out to help students build their knowledge upon foundations that are scientifically accurate (Uno, 1999). Since new knowledge is constructed on the base of existing cognitive structure, alternative conceptions have to be dealth with in order to address new ones developing.

Bodner (1986), in his discussion of the constructivist approach to chemical education, suggested that knowledge cannot simply be handed down from instructor to students—students must actively construct knowledge from new information and their existing experiences and knowledge. Students use their existing knowledge base to evaluate new information; if the new information is consistent with this existing knowledge base, it can be assimilated. However, if the

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new information contradicts it, the knowledge base must be changed to accommodate the new information. Because knowledge is constructed by the student (Resnick, 1983; Jonassen, 1991), any erroneous information that is part of the student's knowledge base may adversely affect subsequent learning.

Studies in science education show that teaching strategies based on a conceptual change approach have been effective in dispelling students' alternative conceptions (Treagust et al. 1996). A conceptual change approach based on Piaget's construct of disequilibrium and dealing with students' alternative conceptions has developed over the past 20 years, and has become a central organizing concept in both science education research and science teacher education (Thorley and Stofflett, 1996). Posner et al. (1982) have argued that in order for successful conceptual change to take place, learners need to become dissatisfied with their existing belief and the new concept has to be shown to be intelligible, plausible and fruitful. The design of teaching approaches based on this idea has proven to help students change their alternative conceptions (Chambers and Andre, 1997).

Several researchers have documented student misconceptions concerning acids and bases. Cros et al (1986) investigated first year university students' conceptions of the constituents of matter and conceptions of acids and bases. The students were found to have a good knowledge of formal descriptions, but inadequate conceptions of concrete phenomena, such as heat being released during an acid-base reaction. The students did not appear to connect their knowledge with everyday phenomena. In a follow-up study, Cros et al (1988) found that some of the students had modified their concepts so that, for example, a scientific definition for acids replaced the former descriptive definition. However other concepts, such as the descriptive definition used for pH, hardly changed. Furthermore, introduction of Lewis generalizations which combines acidity, basicity, electrophilicity and nucleophilicity within a broad integrated scheme opens a new set of difficulties (Zoller, 1990).

Schmidt (1991) has stressed the example of a common misconception about neutralization: that the neutralization of acid and base always gives a neutral product. He refers to the 'neutralization' label as 'a hidden persuader': after all pupils are usually introduced to neutralization reactions through examples where strong acids react with strong bases to give a neutral solution.

Hand and Treagust (1991) identified five key misconceptions about acids and bases among sixty 16-year-old students. Then, they developed and implemented a curriculum about acids and bases based on the conceptual change approach, which aimed to remedy the student misconceptions. These were: an acid is something which eats material away; an acid can burn you; testing of an acid can only be done by trying to eat something away; to neutralize is to break down an acid or to change from an acid; a base is something which makes up an acid; and a strong acid can eat material away faster than a weak acid.

Nakhleh and Krajcik (1994) established that some of students who participated in the study had the following misconceptions: the pH is inversely related to harm and bases are not harmful; bubbles or bubbling is a sign of chemical reaction or strength; acids and bases have their own particular color or color intensity; the molecules fight and combine, and phenolphthalein helps with neutralization; acids melt metals, acids are strong and bases are not strong; pH is a compound called phenolphthalein, a chemical reaction and a number related to intensity

Erduran (1996) analyzed eight physical science textbooks for coverage on acids, bases, and neutralization. She indicated that although textbooks are readable, they fail in making explicit connections to important, underlying themes such as chemical change and physical properties. Further she suggested that conceptual frameworks which the students are exposed to in textbooks might be deficient not only in terms of content but also in terms of how content is weaved into a broader framework.

In his study, Schmidt (1997) stated that the idea that in any reaction between an acid and a base a neutral solution is formed has been found to be quite common among students. He also determined that many students hold the misconception that conjugate acid–base pairs consist of positively and negatively charged ions, which can somehow neutralize each other.

Bradley and Mosimege (1998) investigated whether student teachers at a university and a college of education hold any misconceptions about acids and bases. The misconceptions were explored through the use of a questionnaire which focused on: theory of acids and bases; properties of acids and bases; acid and base strength; pH function; equations for acid-base reactions; molecular representations of acids and bases. The results of their study revealed that achievement was disappointing generally and student teachers at the university performed better.

In order to investigate twelfth-grade Greek students' understanding of acid-base equilibria, Demerouti et al. (2004) constructed and utilized a questionnaire consisting of ten multiple choice and eight open-ended questions. They found that the students had misconceptions and difficulties on the following topics: dissociation and ionization, definition of Brųnsted-Lowry acids and bases, ionic equilibria, neutralization, pH, buffer solutions, and degree of ionization. Some of the misconceptions are similar to those reported elsewhere in the literature. Also, in one of their current work (Kousathana et al. 2005), the development of students'ideas and models about acids and bases (with emphasis on the Arrhenius, the Brųnsted–Lowry, and the Lewis models) were presented. In addition, misconceptions (alternative and instructional ones) on acid-base (ionic) equilibria were examined from the history and philosophy of science perspective. The relation between the development of the models and students' misconceptions were investigated.

The domain of acids, bases and neutralization offers a unique area for studying. This domain constitutes a rich and complex conceptual framework which encompasses various key aspects of chemistry: acids and bases possess sets of physical and chemical properties which need to be weaved together carefully for a meaningful investigation of these chemicals; neutralization involves chemical change, a central concern in chemistry that needs to be emphasized; an explanation of neutralization makes reference to the atomic theory which is vital for understanding of all topics in chemistry; at advanced levels, neutralization is considered in relation to other important chemistry concepts such as reaction rate and chemical equilibrium. An understanding of acids, bases and neutralization is crucial for understanding these related topics.

The purpose of this study is to explore the conceptions of undergraduate students regarding concepts of acids and bases and to determine the difficulties that students may have in understanding these concepts. The findings and educational implications obtained from this research are expected to provide useful references for science teacher trainers as well for curriculum designers.

Methodology of Research

A diagnostic test composed of five open-ended questions was specifically developed for this study (see Appendix). Question 1 required students to predict the pH of pure water at two different temperatures. Students' understanding of neutral solution was questioned by the second question. Question 3 was used to find out whether students predict the pH of excessively diluted solution of a strong acid. Question 4 tested students' understanding of neutralization of a strong base and a weak acid. Finally, question 5 aimed to explore students' understanding of the hydrolysis concept.

All questions were piloted and required modifications were made prior to the administration of the test. The content validity of the test questions was assessed by three chemistry lecturers. The questions were administered to 91 second year undergraduates enrolled in the Primary Science Teacher Training Department in a state university in Turkey. In Turkish educational system, primary school covers grades 1-8. The first part of the primary school (grades 1-5) is taught by a class teacher, while the following years (grades 6-8) are taught by the subject teachers such as science, mathematics, social science, computer, foreign language etc. Primary Science Teacher

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Training Department in Turkey trains science teachers who teach science between grades 6-8 (approximately 12-14 years old). The subjects took General Chemistry-I and II in the first year, and the second year they were attending an Analytical Chemistry course at the time of conducting the research. A traditional lecturing approach was followed in the courses. The test was conducted under normal class conditions without previous warning. The students were confirmed that the results of the test would be used for research purposes and would be kept confidential.

Students' responses to the diagnostic questions were analyzed. Misconceptions were determined and percentages were calculated. The misconceptions identified over the 20% of the subjects are reported here. In addition, 11 students were interviewed in order to clarify their written responses and to further probe students' conceptual understandings of the ideas tested in the questions asked in the test. Interviewees were selected on the basis of their responses given to the test. If a student presented a misconception and did not provide detailed or clear explanation to his/her response was requested to interview. Interview time was varied between 20 minutes and half an hour. All interviews were tape recorded after taking the interviewees' consent and transcribed for analysis. The interviews were not submitted to detailed analysis, instead they were used in order to exemplify the misconceptions throughout the results section during discussion. As the interviews were conducted in Turkish, the quotations reported in the paper were translated into English by the author. In order to assure the quality of English, all translations were checked by an English language expert from the English Language Department.

Results of Research

Table 1. Students' misconceptions identified through students' written responses.

Misconceptions	%
pH of pure water (distilled or de-ionised) is always equal to 7	65
pH of a neutral solution is always 7	63
A solution of 10^{-8} M HCl has a pH of 8	70
Neutralization of acid and base always gives a neutral product	35
In a neutralization reaction, when one of the reactants (acid or base) is weak, the neutralization does not completely take place	41
Hydrolysis is to being separated of a matter into its ions by water	73

The results of the students' written responses to question 1 (see Table 1) revealed that 65% of the students considered that pure water always has a pH of 7. In other words, they believed that the pH of pure water is the same (7) at different temperatures, although the pH of pure water is 7 only at 25^{o}C. This kind of reasoning of the students suggests that they did not consider the temperature effect on ionic product of water and of course, on its pH. The following excerpt from a student's interview exemplifies this notion (*R* and *S* stand for researcher and student, respectively):

R: What can you say about the value of the pH of pure water?
S: It is 7.
R: Could you please explain, why?
S: I know that pure water is neither basic nor acidic, it is neutral. To be neutral, the pH should be 7… Yeah I said, if water has a pH of 7, it is neutral.
R: OK. What would you say about the pH of pure water at different temperatures?
S: …must be same. It is 7.

...

R: ... should water have different degree of dissociation at different temperatures?

S: I don't think so. At any temperature, water would dissociate so that the concentrations of H^+ and OH^- will be same, 10^{-7} M.

R: Why do you think so?

S: Because, in order for water to be neutral, its pH must be 7.

As can be clearly seen from the above dialogue, without considering the temperature effect on ionization constant of water, the respondent stated that at every temperature, the degree of dissociation of water would be the same. One possible reason for holding this misconception could be attributed to the fact that during instruction, when the related topics were being presented, no or insufficient emphasis of the temperature effect was placed on the pH value of water. Also, in solutions of related exercises and problems, only saying that a pH of 7 means neutrality could cause the above misconception for the students, as can be seen in the following excerpt from a student's interview:

"...from all exercises and problems I have experienced, I know that pure water has a pH of 7"

The above situation is not different also for chemistry textbooks. The following statement from a chemistry textbook (Fine and Beall, 1990, p.422) reflects this:

"pure (neutral) water has a pH of 7; pH values lower than 7 represent acidic solutions; and pH values
higher than 7 represent basic solutions"

without referring to the temperature effect on pH values.

In addition, one possible reason for omitting temperature effect on equilibrium constant of water can be attributed to the use of different terms, in different examples, for naming the same concept. In other words, the students could probably be unaware that "ionic product of water" stands for the "equilibrium constant for dissociation of water". As indicated by Selvaratnam (1993), terms such as ionic product, solubility product, dissociation constant…etc should be used in terms of the equilibrium constant. This would help simplify learning, emphasizing that the same principles are involved in all types of equilibria, otherwise it complicates the learning of chemistry. Anecdotal evidence also supports this notion.

Question 2 revealed a misconception that the pH of a neutral solution is always 7. This view held by 63% of the students supports the findings above mentioned, because it can be clearly said that also for this case, the students did not consider temperature effect on pH. A typical dialogue from an interview is representative of this notion:

R: Could you please define neutral solution?

S: It is a solution which has a pH of 7... like pure water.

R: Is it possible for the pH of a neutral solution to be higher or lower than 7?

S: No, then the solution would not be neutral. To be neutral, its pH should be 7... whatever done, it is
impossible to change the value of neutral pH.

From the above dialogue, it is suggested that the students' reasoning behind this misconception is the same as that in previous misconception. The findings about the misconceptions mentioned above is consistent with those in the work of Demerouti et al (2004) with twelfth-grade students in which it was reported that the neutrality concept seemed to confuse the students so that the majority of them defined this concept in terms of the pH= 7 value.

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Question 3 required students to predict the pH of a solution of 10^{-8} M HCl. The majority of the students (70%) reasoned that the pH of the solution would be 8. The students' written responses about this question showed that they simply used the equation of *pH = -Log [H⁺]* to find out the pH of the solution, as indicated in the following excerpt from one of the written responses:

"$HCl \rightarrow \underset{10^{-8}}{\underline{H^+}} + Cl^-$ pH=-Log [H^+] => pH=-Log [10^{-8}] and so, pH= 8"

The analysis of the students' written responses showed that many students tended to leave the explanation section of this question blank rather than giving reasoning for their answers. This is similar in the interviews in which they repeated some of the statements from their written responses. The following excerpt from one interview confirms this rationale:

S: …according to pH=-Log [H^+], pH will be 8.
R: but, this is an acid solution, isn't it?
S: yeah…but the equation says that its pH is 8.
R: then, in this case, how can you explain that an acid solution has a pH of 8?
S: I don't know…

However, the results of interviews and written responses revealed that few students reasoned that the pH of the solution is 8, because it is too dilute. In addition, the students stated that if an acid solution was getting dilute, the pH of the solution would be over 7. The following excerption taken from one of the students' responses best exemplifies this approach:

S: …its pH would be 8.
R: but, this is an acid solution, isn't it?
S: Yeah.
R: then, in this case, how can you explain that an acid solution has a pH of 8?
S: for example…let's… consider a solution of 10^{-5}M HCl. If we diluted it ten times, the pH would be 6;
again diluted ten times, the pH would be 7; again diluted ten times, the pH would be 8.

A quotation from another student's interview is similar:

"…If we added a large amount of water into this solution, we can make the pH of 8"

This misconception had been also revealed in a previous work in which it was reported that the students holding the misconception assume that the strong acid determines the pH and some took into account only the acid ionization (Demerouti et al. 2004). As they said, in the case of low acid concentration, the ionization equilibrium of water is important and should be taken into account.

Two common misconceptions relating to the neutralization concept were determined from students' responses to Question 4. The one held by 35% of the students was that the neutralization of acid and base always gives a neutral product. This misconception suggests that the students thought that all salts are neutral. The following excerpt from a student's interview best exemplifies this notion:

S: all neutralization reactions result in neutral solution.
R: Please explain why.
S: the products are water and salt…and we know water is neutral… also salt is neutral because its structure contains no H^+ or OH^- which can ionize and so, the resulting solution would be neutral.

R: for a salt, is it possible to be acidic or basic?
S: No, because it is only a salt. If it was acidic or basic, then we should call acid or base, not salt.

The above finding was similar to that of Schmidt (1991), and Ross and Munby (1991), in which it was stressed that most of the students misunderstood the concepts of neutralization and neutrality, and they suggested that the reason of this misconception was that students failed to realize the central role of water in neutralization reactions.

The results also indicated that some of the students of this study showed semantic understanding in their explanation of neutralization concept; in a neutralization process, a neutral product will occur. Schmidt (1997) also pointed out the negative influence of the term "neutralization" which described reactions that leave neither acid nor base and indicated that students have difficulties in understanding neutralization of a strong acid by a weak base. The following quotation from an interview dialogue supports this notion.

"…this is neutralization, and it is clear that this causes neutral products."

The misconception indicated that the students had the idea that acid and base consumes each other completely in all neutralizations namely every neutralization yields a neutral solution. As reported by Schmidt (1991), the reason for this can probably be attributed to introducing students to neutralization reactions through examples where strong acids react with strong bases to give a neutral solution.

The other misconception revealed by question 4 is that in a neutralization reaction, when one of the reactants (acid or base) was weak, the neutralization does not completely take place and the strong one (acid or base) determines the pH of the resulting medium. Relating to the question 4. 41% of the students stated that the pH would be over 7, indicating that after sodium hydroxide neutralized the initially ionized part of the weak acid, there will be excess hydroxide ions in medium and this causes basic pH. This view clearly suggests that the students consider that after the initially ionized part was neutralized, the weak acid will not ionize any more. The following quotation from an interview dialogue emphasis this kind of view:

S: ... here acid and base cannot completely consume each-other. Because, we know that the acid partly ionizes and the ionized part will be neutralized. After this, there still will be acid and base.
R: OK. Will neutralization stop after the initially ionized part of the acid was consumed?
S: Yeah… because, there is no H^+ any more.
R: What you think, will the rest of the acid dissociate to give more H^+?
S: No... I don't think so.
...
R: Could you please explain why the pH will be over 7?
S: There will be plenty of OH^- ions from sodium hydroxide. This causes the basic pH of the solution.

The above dialogue demonstrates leads us to suggest that the student had possibly failed to extend the application of the principles of chemical equilibrium to the ionization equilibrium of a weak acid. However, some of the students did not provide logical explanations, but only said that the pH will be determined by the stronger between the acid and the base. The following written response of a student indicates this notion:

"...acid is weak, base is strong. So, the solution will have basic pH"

With regard to the above misconception, Demerouti et al. (2004) reported similar findings. They found out that the respondents believed that for its neutralization, a strong base requires more moles of a weak acid than that of a strong acid.

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The results of the final question revealed a common misconception about the hydrolysis concept. 73% of the students considered that in hydrolysis, water causes the separation of substance ions. This suggests that these students regard hydrolysis as the ionic dissolution of substances in water. The following excerpt shows this view:

S: …hydrolysis is a compound to be separated of into its ions by water.
R: Could you please give an example?
S: like, NaCl + Water ? Na^+ + Cl^-
R: This is dissolution, isn't it?
S: Yeah...but please pay attention that in that case, the solvent is water.
R: What do you mean? Please, explain more.
S: Yeah…I mean that it is a specific situation of dissolution… I think dissolution in water is specifically called hydrolysis.

In the above dialogue it can be seen that the student consider hydrolysis as a sub-concept of dissolution concept. Because, the students holding this view used the term hydrolysis only in the case of dissolution of an ionic matter in water, excluding molecular dissolution, as clearly indicated in the following quotation:

S: … if ionization takes place in water, this is called hydrolysis.
R: What about dissolving of sugar in water? Is that also a hydrolysis?
S: No, there is no ionization in dissolving of sugar, so no hydrolysis.

Conclusions and Implications

The results of this study showed that Turkish undergraduate students have a number of common misconceptions in the topic of acids and bases. These can be summarized as:

- pure water (or a neutral solution) has always a pH of 7;
- the pH of an acid solution that is excessively diluted can be over 7;
- all salts are neutral in terms of acidity-basicity;
- the neutralization of a strong base by a weak acid (and vice versa) does not proceed to completion (even if the reactants are in stoichiometric amounts), hence the resulting solution is basic (or acidic);
- hydrolysis is considered as being the separation of a substance into ions by water.

The written responses given by the students revealed several misconceptions that probably affect the quality of their learning in typical chemistry classes. In addition, the data from the students' interviews showed that in many cases their understanding of basic concepts is limited, distorted, wrong, or missing entirely. In the light of this evidence, chemistry instructors may sometimes overestimate their students' understanding of basic acid-base concepts. It is clear that instructors should consider supplementing the lecture format with a variety of active-learning teaching strategies that would encourage the students to become aware of their misconceptions. Instructors also would benefit from knowing their students' misconceptions and by making efforts at remediating them.

Garnett et al. (1990) and Garnett and Treagust, (1992a, b) have discussed some probable origins of student misconceptions, based on interview studies The origins of these misconceptions include: compartmentalization of physical science subjects; inadequate prerequisite knowledge; misuse of everyday language in chemical situations; use of multiple definitions and models; and rote application of algorithms. Misconceptions arise not only from students' contacts with the physical and social world and from textbooks (Cho et al. 1985), but also as a result of interaction with teachers (Gilbert and Zylberstajn, 1985).

The prevalence of alternative conceptions amongst students suggests that undergraduate education in chemistry should be modified so that the major conceptual problems are addressed throughout the curriculum. Misconceptions showing lack of understanding of basic chemistry principles suggest that the underlying principle may often be lost. The students often fail to recognize when arguments are valid, and thus either over- or under-extend them. Using of everyday language and examples presents both negative and positive opportunities. Students who attempt to connect their studies with their prior experiences may not realize words may have different meanings in everyday speech and in scientific discourse (Renstrom et al., 1990; Gilbert et al., 1982).

The presence of the misconceptions challenges instructors to consider how best to instruct students at this level. First, the instructor must determine which of these conceptions are present in their classroom. To maximize the likelihood of new learning occurring in our classrooms, it is vital that teachers take existing student knowledge into account. We have often treated student minds as 'blank slate' onto which we can load concepts. If this were so, education would be simple. The amount of learning that occurs in the science classroom and indeed in any classroom is largely determined by the pre-knowledge that students bring with them to the lesson. It is the students' prior knowledge that influences what new or modified knowledge they will construct as a result of their learning experiences in the classroom. The students' motivation level and attentiveness have a part to play, certainly, but what they already know about a topic is by far the most important factor to consider (Ausubel, 1968) – it will either be a bridge to new learning or a barrier.

As we have seen, many student misconceptions are highly resistant to eradication. Researches indicate that many will never be overcome (Wandersee et al. 1994). Instructors must then create the disequilibrium necessary for students to rearrange their conception in the direction of the expert's conception. If instructors acknowledge the possibility of misconceptions concerning fundamental concepts even in an advanced undergraduate course, they will be better able to develop scientifically accepted concepts by addressing and attempting to remediate student misconceptions. Only then will the student's ideas become congruent with correct conceptions.

One of the most fruitful outcomes of the studies on children's misconceptions is to alert teachers to students' difficulties in conceptualizing science knowledge and hence, as said, suggest more effective strategies for improving classroom instruction. Before teaching a concept, such as acids and bases, chemical bonding, redox, chemical equilibrium, teachers should be able to check the literature to find out what is known about misconceptions that students may bring to class and which teaching methods are the best in correcting these misconceptions. Many research studies have identified common student misconceptions in a wide variety of areas, including Science and these are contained in numerous journals.

Among many instructional materials, textbooks are most important information sources for students. Many research studies have found that the textbooks used in schools have inadequate or sometimes incorrect information (Soyibo, 1995). Therefore, textbook authors should help teachers become aware of the common misconceptions students bring to the chemistry classroom. In parallel to textbooks, guide materials and new teaching materials that may help to remedy students' misconceptions should be devised and presented to teachers' usage.

Assisting students to overcome misconceptions can be a difficult and time consuming task, one which takes time away from other science activities. It is this that often deters teachers from making the effort. They complain that they have not the time because there is too much content to cover. The answer is simple. If our lessons do not attempt to built on the students' correct understanding of concepts, then other, more important, science activities may be a total waste of time. The misconceptions found here, and the additional alternative conceptions reported elsewhere, provide a starting point for chemistry instructors who wish to familiarize themselves with alternative conceptions and misconceptions their students

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might possess. The results of this paper which summarize the prevalent misconceptions identified in this study offer clues to instructors as to where other misconceptions might lie.

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Appendix

Question 1 - Compare the pH values of pure water at 25^{o}C and 70^{o}C. Explain your answer as carefully as you can.

Question 2 - What is a neutral solution? Explain your answer as carefully as you can.

Question 3 - Predict the pH value of a solution of 10^{-8} M HCl. Explain your answer as carefully as you can.

Question 4 - At 25^{o}C, when equal amounts of 0, 1 M NaOH (aq) and 0, 1 M CH_3COOH (aq) are mixed, what about the pH of medium?

a) pH > b) pH = 7 c) pH < 7

Explain your answer as carefully as you can.

Question 5 - What is hydrolysis? Explain your answer as carefully as you can.

Резюме

ОШИБОЧНЫЕ ПРЕДСТАВЛЕНИЯ ТУРЕЦКИХ СТУДЕНТОВ О КИСЛОТАХ И ОСНОВАНИЯХ

Тацеттин Пинарбаши

Целью настоящего исследования было определение ошибочных представлений студентов о кислотах и основаниях. Для ее достижения использовались тесты с открытыми диагностическими вопросами и полуструктурированные интервью. Был опрошен 91 студент младших курсов факультета подготовки учителей-естественников начальной школы одного из государственных университетов Турции. Кроме того, 11 студентов были проинтервьюированы с целью объяснения их письменных ответов и для дальнейшего зондирования концептуального понимания вопросов теста студентами. Исследование вскрыло множество неправильных представлений. Его результаты могут быть полезны для преподавания третичного уровня. Необходим основательный пересмотр стратегий преподавания.

Ключевые слова: ошибочные представления, кислоты, основания, равновесие, естественнонаучное образование.

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