13 Artikel Periodico

by Nadi Suprapto

PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

USANDO O ENSAIO DIAGNÓSTICO EM TRÊS NÍVEIS PARA AVALIAR CONCEPÇÕES DE ENERGIA DE IONIZAÇÃO

USING ONLINE THREE-TIER DIAGNOSTIC TEST TO ASSESS CONCEPTIONS OF IONIZATION ENERGY

PENGGUNAAN TES DIAGNOSTIK *ONLINE* TIGA TINGKAT UNTUK MENGASES KONSEPSI TERKAIT ENERGI IONISASI

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Received 20 June 2020; received in revised fom 20 October 2020; accepted 23 October 2020

RESUMO

O termo que descreve as noções dos alunos de conceitos científicos diferentes dos cientificamente aceitáveis pelo cientista ainda é debatido. Este estudo explora como conceitos científicos realizados por alunos do ensino médio (HSSs), professores em formação (PSTs) e professores em serviço (ISTs) simultaneamente para tornar claro entre sua concepção vs. concepção dos cientistas, principalmente no conceito de energia de ionização. Portanto, é fundamental levantar a posição da concepção científica e do equívoco. Para diagnosticar os equívocos, alguns métodos podem ser usados: mapas conceituais, entrevistas, testes de múltipla escolha (uma camada), testes de várias camadas (duas camadas, três camadas, quatro camadas), testes abertos e outras. Este estudo usou testes de várias camadas com três camadas. No total, 326 participantes da Indonésia, incluindo 118 HSSs, 165 PSTs e 43 ISTs com especialização em química, foram convidados a concluir um teste on-line de Diagnóstico-Modificação de Energia de Ionização (IEDI * M). O teste consistiu em 12 itens de diagnóstico de três níveis. O estudo indicou que quatro conceitos alternativos substanciais foram reconhecidos: conservação de energia, sub-camadas preenchidas pela metade ou totalmente preenchidas estáveis, estrutura de regras do octeto e raciocínio baseado em relações. Os ISTs tiveram um desempenho melhor do que os HSSs e PSTs no entendimento da energia de ionização. O estudo também especificou a distribuição das concepções de energia de ionização do Grupo 1 e 2, e Período 2 e 3 no sistema periódico. Ao utilizar o IEDI * M, as porcentagens de conceitos alternativos diminuíram de um nível para dois níveis e de dois para três níveis. Este estudo oferece algumas implicações para o governo, formuladores de políticas, professores de química, professores em formação e membros do corpo docente universitário.

Palavras-chave: teste de diagnóstico, energia de ionização, teste de três níveis.

ABSTRACT

The term describing the students' notions of scientific concepts dissimilar from scientifically acceptable by the scientist is still debated. This study explores of how scientific concepts performed by high school students (HSSs), pre-service teachers (PSTs), and in-service teachers (ISTs) simultaneously to make clear between their conception vs. scientists' conception, especially in the ionization energy concept. Therefore, it is crucial to raise the position of scientific conception and misconception. For diagnosing the misconceptions, some methods can be used: concept maps, interviews, multiple-choice tests (one-tier), multiple-tier tests (two-tier, three-tier, four-tiers), open-ended tests, and others. This study utilized multiple-tier tests with three-tier. Totally, 326 participants from Indonesia, including 118 HSSs, 165 PSTs, and 43 ISTs majoring in chemistry, were invited to complete an online -Ionization Energy Diagnostic-Modification (IEDI*M) test. The test consisted of 12 three-tier diagnostic items. The study indicated four substantial alternative conceptions were acknowledged: conservation of energy, half-filled sub-shells or stable fully-filled, octet rule framework, and relation-based reasoning. ISTs performed better than HSSs and PSTs on the understanding of ionization energy. The study has also specified the distribution of ionization energy conceptions of Group 1 and 2, and Period 2 and 3 on the periodic system. By utilizing the IEDI*M, the percentages of alternative concepts decreased from one-tier to two-tier and from two-tier to three-tier. This study gives some implications for the government, policy-makers, chemistry teachers, pre-service teachers, and university faculty members.

Keywords: diagnostic test, ionization energy, three-tier test.

ABSTRAK

Istilah mendeskripsikan pemahaman siswa tentang konsep-konsep ilmiah yang berbeda dengan yang diterima secara ilmiah oleh ilmuwan masih menjadi perdebatan. Penelitian ini mengeksplor bagaimana konsep ilmiah yang ditunjukkan oleh siswa sekolah menengah atas (HSS), guru pra-jabatan (PST), dan guru dalam jabatan (IST) secara bersamaan untuk memperjelas antara konsepsi mereka vs konsepsi ilmuwan terutama atas konsep energi ionisasi. Oleh karena itu, penting untuk mengangkat posisi konsepsi ilmiah dan miskonsepsi. Untuk mendiagnosis kesalahpahaman, beberapa metode dapat digunakan: peta konsep, wawancara, tes pilihan ganda (satu tingkat), tes beberapa tingkat (dua tingkat, tiga tingkat, empat tingkat), tes terbuka, dan lainnya. Penelitian ini menggunakan tes tiga tingkat. Penelitian ini mengeksplorasi pemahaman konsep energi ionisasi antara siswa sekolah menengah (HSS), guru pra-jabatan (PST), dan guru dalam jabatan (IST) secara bersamaan. Sebanyak 326 peserta dari Indonesia, termasuk 118 HSS, 165 PST, dan 43 IST bidang kimia diundang untuk mengikuti tes online -Ionization Energy Diagnostic-Modification (IEDI * M). Tes terdiri dari 12 butir tes diagnostik tiga tingkat. Riset ini menunjukkan empat konsepsi alternatif substansial: konservasi energi, subkulit terisi setengah atau terisi penuh stabil, kerangka aturan oktet, dan penalaran berbasis hubungan. IST berkinerja lebih baik daripada HSS dan PST dalam pemahaman energi ionisasi. Riset ini juga telah menentukan distribusi konsepsi energi ionisasi dari Golongan 1 dan 2, dan Periode 2 dan 3 pada sistem periodik. Dengan memanfaatkan IEDI * M, persentase konsepsi alternatif menurun dari satu tingkat ke dua tingkat serta dari dua tingkat ke tiga tingkat. Penelitian ini memberikan beberapa implikasi bagi pemerintah, pembuat kebijakan, guru kimia, guru pra-jabatan, dan staf pengajar di universitas.

Kata-kata kunci: tes diagnostik, energi ionisasi, tes tiga tingkat.

1. INTRODUCTION:

There are some terms in describing the students' notions of scientific concepts. Previous scholars have used different words to represent the students' conception, such as "children's science ideas" (Osborne, Black, Meadows, and Smith, 1993), "alternative framework" (Klammer, 1998), "mental models" (Greca and Moreire, 2002), "misconceptions" (Suprapto, Abidah, Dwiningsih, Jauhariyah, and Saputra, 2018), and so forth. However, the terms of "alternative conception" and "misconceptions" more popular than others. Therefore these terms are frequently used in previous studies. However, both of them are used in this study.

For diagnosing the misconceptions, some methods can be used: concept maps, interviews, multiple-choice tests (one-tier), multiple-tier tests (two-tier, three-tier, four-tiers), open-ended tests, and others. Each method has pros and cons. Interviews and open-ended tests require a large amount of time to attain and analyze the data (Gurel, Eryilmas, and McDermott, 2015; Suprapto *et al.*, 2018). In contrast, standard multiple-choice tests (MCT) don't afford an in-depth investigation into the students' ideas. Two-tier multiple-choice tests can solve MCT's problem; however, they can't determine the proportion of the misconceptions since their lack of knowledge. Then, three-tier MCT will hold the strengths provided by two-tier and select the answers given to the first two-tier is due to false-negative (FN), false positive (FP), misconception (MSC), or a lack of knowledge (LK).

The major problem for using conventional MCT is to reduce FP and FN. "Students could provide correct answers with wrong reasoning as FP and wrong answers with correct reasoning as FN" (Suprapto *et al.*, 2018). Minimizing FP and FN offers a more valid test. Even though a two-tier test eliminates those drawbacks of a conventional MCT, it has a limitation: It cannot distinguish misconceptions (MSC) from a lack of knowledge (LK). The assumption that if more than 10% of the respondents picked a wrong combination of options across the two-tiers, that combination could be regarded as reflecting an MSC's presence. Three-tier tests enable researchers to address the drawback mentioned earlier by "adding tier that entails students to state whether or not they are sure about their answers to the first two-tiers" (Caleon and Subramaniam, 2010; Pesman and Eryilmaz, 2010; Suprapto *et al.*, 2018).

There were a few studies in science education on the development and application of three-tier tests, such as atmosphere-related environmental problems diagnostic test-AREPDit (Arslan, Cigdemoglu and Moseley, 2016), heat and temperature test (Eryilmaz, 2010), three-tier circular motion test (Kizilcik and Gunes, 2011), the wave diagnostic instrument-WADI (Pesman and Eryilmaz, 2010). Specifically, there are two popular three-tier conceptual tests in chemistry: a diagnostic test of states of matter (Kirbulut and Geban, 2014) and acids and bases three-tier test (Cetin-Dindar and Geban, 2011). Additionally, there are two-tier tests in chemistry: chemical concept tests (Chiu, 2007), ionization energy diagnostic instrument-IEDI (Tan, Taber, Goh, and Chia, 2005), etc. This study endeavors the IEDI with a three-tier conceptual test. The test is based on the work of Tan *et al.* (2005).

Four years ago, Chiu, Lin, and Chou (2016) found that chemistry in the third rank among the four science disciplines is studied by researchers after physics and biology in international journals. Therefore, study about chemistry content has also become the main attraction among researchers. Ionization energy is one of the essential topics in the ten-grade Indonesian curriculum. It discusses the basic concept of physical atomic properties and relates to electron affinity, atomic radius, and electronegativity, which are conceptually helpful in understanding each atom's characteristics. Research on this concept has concerned many researchers in the last 20 years (e.g., Taber, 2003; Lang and Smith, 2003; Tan *et al.*, 2005; Tan, Taber, Liu, Coll, Lorenzo, Li, Goh, and Chia (2008); Tan and Taber, 2011). Taber (2003) investigated college-level chemistry students in the UK. In Tan *et al.* (2005)' study, the investigation focused on A-level students (Grade 11 and 12) in Singapore and explored their understanding of the trend of ionization energies across Period 3.

However, no study investigated the understanding of ionization energy among high school students (HSSs), pre-service teachers (PSTs), and in-service teachers (ISTs) simultaneously. Therefore, this study describes the implementation of a three-tier diagnostic test to assess those participants' understanding of ionization energy either after their first time were taught (high school students) or appertained that subject (pre-service and in-service teachers).

Investigating the conception of ionization energy among HSSs, PSTs, and ISTs simultaneously explains the primary sources of misconception because the three levels are highly correlated. PSTs will become ISTs and then transfer their knowledge to HSSs. Thus, this study assesses the conception of ionization energy and the main misconception which happens in this concept. The research questions (RQs) that directed this study were:

1. To what extent do the HSSs', PSTs', and ISTs' understanding and confidences in answering questions of ionization energy?

2. To what extent do HSSs, PSTs, and ISTs performing misconceptions of ionization energy?

Therefore, this study aimed to explore the HSSs', PSTs', and ISTs' understanding and confidences in answering ionization energy questions. It was also aimed at analyzing the HSSs', PSTs', and ISTs' misconceptions of ionization energy.

2. MATERIALS AND METHODS:

2.1. The modification of Ionization Energy Diagnostic -IEDI instrument

The development of the modification of the Ionization Energy Diagnostic -IEDI*M diagnostic instrument of ionization energy tangled a modified version from Suprapto *et al.* (2018); Tan *et al.* (2005); Taber and Tan (2011). Initially, the instrument consisted of 10 two-tier items with each tier (see Table 1 and Appendix) and explored participants' understanding of the trend of ionization energies across Period 3. After getting permission for research purposes, the authors modified and translated into the Indonesian language. The modification and addition were executed due to forgetting the whole picture of the conception of ionization energy across Period 2, Period 3, Group 1, and Group 2. Finally, 12 three-tier items were used in the study (see Appendix).

2.2. Participants

The study presented the responses of 326 participants: 118 HSSs, 165 PSTs, and 43 ISTs to the IEDI*M from East Java in Indonesia. The participants comprised 134 (41%) males and 192 (59%) females (Table 2). The researchers distributed a letter of permission in researching all participants as a form of ethical academic consent. Besides, the researchers have also got approval from the university committee in conducting data collection. IEDI*M was administered to the participants after experiencing at least three months (spread over 3 to 4 weeks) of formal instruction on the ionization energy. HSSs have already got subject matter knowledge in grade 10, and PSTs have reviewed this content from the general chemistry course.

2.3 Procedure

Through an online survey (see Appendix) with an online-test facility in Google Form, participants could express themselves with more originality and enthusiasm, and it considers a real-time feature (Lina, Chang, Hou, and Wu, 2015).

2.4 Data Analysis

The IEDI*M responses of participants were input into an MS Excel datasheet. Variables were written in the columns, and participants' codes were written in the Excel datasheet rows. Six categories were produced (Table 3): i) Scientific Conception (SC), ii) False Positive (FP), iii) False Negative (FN), iv) Misconception (MSC), v) Lack of Knowledge because of Guessing (LKg), vi) Lack of Knowledge because of Deficiency (LKd). Among the six categories were simplified into four general categories: truly understanding (t), alternative conception (a), guessing (g), and deficient knowledge (d). This study follows the rule by Peterson, Treagust, and Gannett (1989): "the percentage of student responses >20% for the non-scientific options be defined as typical alternative responses".

3. RESULTS AND DISCUSSIONS:

3.1. The distribution of understanding about ionization energy among HSSs, PSTs, and ISTs

Table 4 demonstrates the percentages of SC, FP, FN, MSC, LKg, and LKd among HSSs, PSTs, and ISTs. When the items were checked for SC, it was found that the majority percentages above 20%, except for item 6 (all levels), item 7 and 12 (PSTs), and item 9 and 11 (HSSs and PSTs). Item 6 is related to the comparison of the first ionization energy between magnesium (Group 2) and aluminum (Group 3). While the items were cross-checked for FP, it was found that all participants performed the percentages above 20% for items 4, 6, 7, 8, and 11. Meanwhile, HSSs also indicated FP for items 2, 5, and 9, as well as for item 5 and item 12. Hereinafter, for FN, it was found that all the items, except for item 6 (HSSs and ISTs), were below 20%.

Turning to the MSC, it was found that the performance of participants to all items above 20%, except for items 2, 4, and 5. When items 9 and 12 were examined, it was seen that all levels performed MSC. Item 9 assessed the comparison of the first ionization energy between phosphorus and sulfur (period 3). The true answer of the first-tier is "the first ionization energy of phosphorus is greater than that of sulfur" since "the effect of an increase in nuclear charge in sulfur is less than the repulsion between its 3p electrons" (2nd tier). Considering for item 9, it was seen that the most participants chose one of the wrong alternatives – "the first ionization energy of P is less than that of S" for the 1st-tier and "the effect of an increase in nuclear charge in sulfur is greater than the repulsion between its 3p electrons" for the 2nd tier. In addition, some participants chose either "more energy is required to overcome the attraction between the paired 3p electrons in sulfur" or "3p electrons of sulfur are further away from the nucleus compared to that of phosphorus" for their reasoning in the 2nd tier.

Item 12 assessed the comparison of the first ionization energy between beryllium and boron (Period 2). The true answer of the 1st-tier is "the first ionization energy of beryllium is greater than that of boron" since "the 2p electron of boron has a lower penetrating power than the 2s electrons. Therefore, it outweighing the increase in nuclear charge" (2nd-tier). Turning to item 12, it was seen that most of the participants chose one alternative conception – "the first ionization energy of beryllium is less than that of boron" since "the 2s electron of beryllium has lower penetrating power than the 1s electrons; therefore it was outweighing the increase in nuclear charge". Additionally, some participants chose either "the 2p electrons of boron are further away from the nucleus compared to that of beryllium" or "the effect of an increase in nuclear charge in boron is less than the repulsion between its 2p electrons" for their reasoning. Meanwhile, items 1, 3, 6, 7, and 10 indicated a partial misconception (HSSs and ISTs). At the same time, for items 8 and 11, only HSSs denoted misconceptions.

In terms of lack of knowledge (LK), it was indicated that all percentages were below 20%, except item numbers 2 and 10 for PSTs that achieved 30.30% LKg for item 2 and 24.24% for item 10. This result reinforced the pros of using three-tier tests rather than conventional MCT. Kirbulut and Geban (2014) corroborated that three-tier tests provide more accurate results for students' misconceptions by differentiating MSC from LKg and LKd.

The HSSs', PSTs', and ISTs' responses and their confidence in completing IEDI*M are concise in Table 5. Both the phenomena and reason tiers were illustrated to distinguish among truly understanding (t), guessing (g), alternative conceptions (a), or deficient knowledge (d) (Lin, 2016).

3.2 The ionization process of the Sodium atom to form Sodium ion (item 1-4)

The MCT requires the participants to infer which reason of the sodium ion will combine with an electron to reform the sodium atom (Na) for item 1; the attraction of the nucleus for the 'lost' electron when an electron is removed from Na for item 2; the comparison of stability among Na(g) atom, Na^+ (g) ion, and a free electron for item 3; and the comparison between the second and the first ionization energy when Na is ionized for item 4.

For the category *truly understanding* in the context of phenomena 1 (P1) (Table 5), the participants performed that "the sodium ion will combine with an electron to reform the sodium atom since the Na^+ can appeal a negatively-charged electron" with the confidence level (40.68%, 31.52%, 72.09%) for HSSs, PSTs, and ISTs, respectively. However, some HSSs and PSTs have two *alternative conceptions* that "Sodium is strongly electropositive, so it only loses electrons," and "the sodium ion has a stable octet configuration, so it will not gain an electron to lose its stability".

In Phenomena 2, the participants performed that "the pull of the nucleus for the 'lost' electron will be redistributed among the remaining electrons in the Na^+ when an electron is removed from the Na atom", with the confidence level (61.02%, 42.42%, 69.77%) for HSSs, PSTs, and ISTs, respectively.

In the case of phenomena 3 (P3) for the category truly understanding, the participants performed that "the Na atom is more stable than the Na ion and a free electron" since "the sodium atom is neutral, and energy is required to ionize the sodium atom to form the sodium ion", with the confidence level (58.48%, 33.33%, 69.77%) for HSSs, PSTs, and ISTs, respectively. However, about 21.19% of HSSs and 24.24% of PSTs have an alternative conception that the outermost shell of sodium ion has achieved a stable octet configuration.

For the category *truly understanding* in the phenomena 4 (P4), HSSs and ISTs felt confidence that since "the second electron is removed from a paired 2p orbital and it experiences repulsion from the other electron in the same orbital," then "more energy is required to remove a second electron when the Na is ionized", with the confidence level 26.27% and 62.79%, respectively. However, PSTs have some alternative conceptions in their reasoning: "the same number of protons in Na^+ attracts one less electron." In-lined with Tan *et al.* (2005), some alternative conceptions, as indicated from item 1-4 are related to two headings as *octet rule framework*, such as (P1R2, P3R4, and P4A1) and *conservation of energy (force thinking)*, such as (P2R3 and P4R2). (Note: P1R2 indicated phenomena number 1 - reasoning number 2; P3R4 was phenomena number 3 - reasoning number 4, and so on.

3.3 The comparison of the first ionization energy between Sodium and Magnesium (item 5)

For the category *truly understanding* of the phenomena 5 (P5), the participants performed that "the first ionization energy of Na is less than that of Mg" since "the paired electrons in the 3s orbital of Mg experience repulsion from each other, and this effect is greater than the increase in the nuclear charge in Mg", with the confidence level (42.37%, 25.46%, and 62.79%) for HSSs, PSTs, and ISTs, respectively. However, there were about 26.68% of PSTs argued that magnesium has a fully-filled 3s sub-shell, which gives it stability in their reasoning. This situation in-lined with an *et al.* (2005). This alternative conception relates to the problem of *stable fully-filled or half-filled sub-shells* (P5R1).

3.4 The comparison of the first ionization energy among sodium, magnesium, and aluminum (item 6 and item 7)

All participants' levels performed below 20% of the correct understanding of phenomena 6 (P6). The most alternative conception among them is the combination of phenomena: "The first ionization energy of Mg is greater than that of Al" with the reasoning "the 3p electron of Al is further from the nucleus compared to the 3s electrons of Mg" (22.03% for HSSs and 38.79% for PSTs). Also, there was a combination of alternative conceptions of HSSs (34.75%) and ISTs (32.56%): "the first ionization energy of Mg is less than that of Al".

For item 7 (P7), HSSs and ISTs showed above 20% of truly understanding. The correct answer for the first tier is "the first ionization energy of sodium is less than that of aluminum." The second-tier reasoning is "the effect of an increase in nuclear charge in aluminum is greater than the shielding of the 3p electron by the 3s electrons". The most alternative conception among them is "the first ionization energy of sodium is less than that of aluminum" due to "the 3p electron of aluminum is further away from the nucleus compared to the 3s electron of sodium" (28.81% for HSSs, 43.63% for PSTs, and 23.25% for ISTs). However, HSSs have also varied in their reasoning, such as "aluminum will attain a fully-filled 3s sub-shell if an electron is removed" (20.34%), and "sodium will achieve a stable octet configuration if an electron is removed" (22.03%). Some alternative conceptions aforementioned were called relation-based reasoning (P6R2 and P7R3). This result corroborated the studies conducted by Tan *et al*. (2011).

3.5 The comparison of the first ionization energy among silicon, phosphorus, and sulfur (item 8, 9, and 10)

In P8, all participants expressed that "the first ionization energy of silicon is less than that of phosphorus" due to "the effect of an increase in nuclear charge in phosphorus is greater than the repulsion between its 3p electrons", with the percentage of *truly understanding*: 24.58%, 20.61%, and 44.19%, respectively. However, some PSTs have *alternative conceptions*: either "the first ionization energy of silicon is greater than that of phosphorus" or "the first ionization energy of silicon is less than that of phosphorus". Their reasoning varied either due to the problem of "*stable fully-filled or half-filled sub-shells"* (P8R2). The participant indicated that "the 3p sub-shell of P is half-filled. Hence it is stable" (21.21%) or due to "the 3p electrons of P are further away from the nucleus compared to that of Si" (23.03%).

For the category truly understanding in the context of P9, only ISTs performed that "the first ionization energy of phosphorus is greater than that of sulfur" due to "the effect of an increase in nuclear charge in sulfur is less than the repulsion between its 3p electrons", with the confidence level 7.91%. Even though PSTs showed less understanding in P9, however, their alternative conceptions are below 20% among four options. Meanwhile, HSSs indicated some alternative concepts: "more energy is required to overcome the attraction between the paired 3p electrons in sulfur" and "the effect of an increase in nuclear charge in sulfur is greater than the repulsion between its 3p electrons".

In P10, all participants performed above 20% of *truly understanding*: 27.97%, 23.64%, and 74.42, respectively. The scientific answer for the first-tier is "the first ionization energy of silicon is less than that of sulfur". The reasoning for the second-tier is, "The effect of an increase in nuclear charge in sulfur is greater than the repulsion between its 3p electrons". Nevertheless, some HSSs also have *alternative reasoning*: "sulfur will have its 3p sub-shell half-filled if an electron is removed", about 22.58%.

3.6 The comparison of the first ionization energy between lithium and sodium (item 11)

Phenomena 11 presented only ISTs with a proper understanding of comparing the first ionization energy between lithium and sodium (37.21%). There were some alternative conceptions among levels either "the first ionization energy of lithium is greater than that of sodium" due to "more energy is required to overcome the attraction between the paired 2s electrons in lithium" or "the 3s electrons of sodium are further away from the nucleus compared to that 2s of lithium". Additionally, some participants understood that "the first ionization energy of lithium is less than that of sodium" due to "more energy is required to overcome the attraction between the paired 2s electrons in lithium".

3.7 The comparison of the first ionization energy between beryllium and boron (item 12)

This phenomenon is similar to the phenomenon 6. It is noted that beryllium and boron in period 2, meanwhile magnesium and aluminum in period 3. However, both of the phenomena represent the comparison of the first ionization energy of Group 2 and 3. The best explanation in this context is "the first ionization energy of beryllium is greater than that of boron" due to "the 2p electron of boron has lower penetrating power than the 2s electrons. Therefore, it outweighing the increase in nuclear charge". HSSs and ISTs performed truly understanding about 22% and 23.26%, respectively. In addition, each level has a different of the most alternative conception, such as: "the 2s electron of beryllium has lower penetrating power than the 1s electrons. Therefore, it outweighing the increase in the nuclear charge for HSSs", "the 2p electrons of boron are further away from the nucleus compared to that of beryllium" for PSTs, and "the effect of an increase in nuclear charge in boron is less than the repulsion between its 2p electrons" for ISTs.

3.8 The misconceptions probed by the IEDI among HSSs, PSTs, and ISTs

Table 6 lists the misconceptions probed by the IEDI*M. Meanwhile, Table 7 depicts the percentages of misconceptions for all-tiers. Accordingly, three-tier calculates participants' MSC more precisely compared to two-tier and traditional MCT since they include two-tier and confidence tier together. The trend of MSC decline from one-tier to three-tier. This result confirmed the study of Kirbulut and Geban (2014) and Pesman and Eryilmaz (2010). Most MSC has been experienced by HSSs, except item 2. PSTs performed a moderate MSC, except item 4 and 8. In contrast, ISTs indicated less misconception than others, except items 9 and 12. However, these two items become a serious problem for all participant levels because they have misconceptions of all tiers.

Figure 1 also indicates the part of misconceptions about ionization energy, especially for Group 1, 2, period 2, and period 3. For instance, many participants have a problem with the ionization energy of beryllium versus boron and magnesium versus aluminum and silicon versus phosphorus and phosphorus versus sulfur. It is noted that beryllium and boron in period 2, meanwhile magnesium and aluminum in period 3. Generally, a significant number of HSSs and PSTs and some of ISTs did not adequately comprehend the trend of ionization energy across periods 2 and 3 and the factors influencing ionization energy. Then, if we compare between the three-tier test and two-tier test of ionization energy, the trend of misconceptions declines from one-tier to three-tier.

4. CONCLUSIONS:

The study sees the sights of HSSs', PSTs', and ISTs' understanding and confidence in answering questions about ionization energy. There were four significant common alternative conceptions were identified: 'conservation of force thinking', 'octet rule framework', half-filled sub-shells' or 'stable fully-filled, and 'relation-based reasoning'.

There are some implications derived from this study. First, ISTs should be aware of their alternative conceptions. Second, chemistry teachers should be mindful of their students, especially in this expression: 'even though we get success on conventional MCT, it does not necessarily reflect our conceptual understanding of chemistry'. Therefore, teachers should consider using assessment tools that provide opportunities to probe students' reasoning and perform confidently. Third, the government should be aware of the chemistry textbook since the most alternative conception and misconception either from books or the cycle of PSTs→ISTs→HSSs. Fourth, the government and university professors need to review the content knowledge and not assume that a university degree (PSTs) assures adequate teaching topics.

5. ACKNOWLEDGMENTS:

Thanks to the HSSs, PSTs, and ISTs who participated in the completion of the online survey.

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Appendix

Table 1. *The key stages in the development of the instrument*

Original study with two-tier items (Tan *et al.*, 2005; Taber and Tan, 2011)		This study	
Two-tier		**Three-tier**	
1st-tier	MCT (3 options): item 1-3; item 5-10 MCT (4 options): item 4	*1st-tier*	MCT (2 options): item 1-12
2nd-tier	MCT (3 options): item 1 and 2 MCT (4 options): item 3, 4, 8, and 10 MCT (5 options): item 5, 6, 7, and 9	*2nd-tier*	MCT (3 options): item 1 and 2 MCT (4 options): item 3 - 12
	-	*3rd-tier*	Level of confidence (sure or unsure): all items

Table 2. *Participants' background and demographic data*

Demographics		% Senior High School Students (n=118)	% Pre-service teachers (n=165)	% In-service teachers (n=43)
Gender	Male	69.49	19.39	46.51
	Female	30.51	80.61	53.49
Grade	10	33.90	-	-
	11	31.36	-	-
	12	34.74	-	-
Level	1	-	29.09	-
	2	-	18.18	-
	3	-	36.36	-
	4	-	16.36	-
Experience in teaching	<5 years	-	-	18.60
	5-10 years	-	-	20.93
	10-15 years	-	-	20.93
	15-20 years	-	-	18.60
	> 20 years	-	-	20.93

Table 3. *Categories of Conception*

Phenomena (P) 1st-tier	Reasoning (R) 2nd-tier	Confidence 3rd-tier	Category	
T	T	S	SC	t
T	F	S	FP	a
F	T	S	FN	
F	F	S	FN	
T	T	US	LKg	g
T	F	US		
F	T	US		
F	F	US	LKd	d

Note: T=True; F=False; S=Sure; US= Unsure; SC=Scientific Conception; FP=False Positive; FN=False Negative; LKg=Lack of Knowledge–Guessing; LKd= Lack of Knowledge–Deficiency of knowledge; t=truly understanding; a=alternative conception; g=guessing; and d=deficient knowledge

Table 4. *The percentages of the conception of ionization energy among HSSs, PSTs, and ISTs*

Conception level	Item 1			Item 2			Item 3			Item 4		
	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs
SC	***40.68***	***31.52***	***72.09***	***61.02***	***42.42***	***69.77***	***58.47***	***33.33***	***69.77***	***26.27***	16.97	***62.79***
FP	17.80	11.52	13.95	***23.73***	10.91	6.98	9.32	12.73	18.60	***41.52***	***58.18***	***23.26***
FN	7.63	6.67	2.32)	5.08	5.45	9.30	3.39	1.82	0	1.69	0.61	4.65
MSC	***29.66***	***40.61***	6.98	3.39	7.27	4.65	***23.73***	***34.54***	4.65	18.64	4.24	2.32
LK–g	3.39	7.88	0	5.3	***30.30***	9.30	3.39	9.70	4.65	7.63	16.97	6.98
LK–d	0.85	1.82	4.65	0.85	3.64	0	1.69	7.88	2.32	4.24	3.03	0
	Item 5			Item 6			Item 7			Item 8		
	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs
SC	***42.37***	***25.45***	***62.79***	3.39	2.42	16.28	***21.19***	16.36	***53.49***	***24.58***	***20.61***	***44.19***
FP	***23.73***	***44.24***	13.95	***18.64***	***30.91***	***25.58***	***41.52***	***34.54***	***27.91***	***28.81***	***46.06***	***32.56***
FN	6.78	2.42	2.32	***34.74***	19.39	**32.56**	0	0.61	0	1.69	0.61	2.32
MSC	16.10	12.73	4.65	***27.12***	***24.24***	6.98	***29.66***	***23.03***	9.30	***27.12***	10.91	9.30
LK–g	8.47	10.30	11.63	11.86	15.15	13.95	4.24	17.58	4.65	12.71	16.36	0
LK–d	2.54	4.85	4.65	4.24	7.88	4.65	3.29	7.88	4.65	5.08	5.45	11.63
	Item 9			Item 10			Item 11			Item 12		
	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs	HSSs	PSTs	ISTs
SC	11.86	15.76	***27.91***	***27.97***	***23.64***	***74.42***	8.47	2.42	***37.21***	***22.03***	12.12	***23.26***
FP	***22.88***	16.97	4.65	20.34	22.42	4.65	***45.76***	***58.18***	***46.51***	16.95	***28.48***	***23.26***
FN	1.69	1.82	4.65	4.24	1.21	2.32	5.08	1.21	0	4.24	4.85	6.98
MSC	***44.07***	***36.36***	***44.19***	***25.42***	***20.61***	11.63	***27.12***	15.15	11.63	***38.47***	***27.27***	***34.88***
LK–g	8.47	18.79	13.95	16.95	***24.24***	2.32	9.32	12.73	4.65	10.17	10.91	4.65
LK–d	11.02	10.30	4.65	5.08	7.88	4.65	4.24	10.30	0	8.47	16.36	6.98

Note: The ***bold- italics*** means the percentage of this response > 20%, (typical response)'; SC=Scientific Conception; FP=False Positive; FN=False Negative; LKg=Lack of Knowledge–Guessing; LKd= Lack of Knowledge–Deficiency of knowledge; HSSs= high school students; PSTs= pre-service teachers; ISTs= pre-service teachers

Table 5. *The HSSs', PSTs', and ISTs' performance and confidence in answering IEDI*M*

	HSSs			PSTs			ISTs		
P1	***60.17***^{t}	-	-	***50.91***^{t}	-	-	***86.05***^{t}	-	-
R1	***25.42***^{a}	0.85^{g}	0	***27.87***^{a}	1.21^{g}	1.82^{d}	0	11.64^{a}	2.32^{d}
R2	***22.03***^{a}	0.85^{g}	0.85^{d}	***24.24***^{a}	1.21^{g}	0	0	9.30^{a}	2.32^{d}
R3	***40.68***^{t}	1.69^{g}	7.63^{a}	***31.52***^{t}	5.45^{g}	6.67^{a}	***72.09***^{t}	2.32^{a}	0
P2	***89.98***^{t}	-	-	***79.18***^{t}	-	-	***86.05***^{t}	-	-
R1	***61.02***^{t}	4.23^{g}	5.08^{a}	***42.42***^{t}	18.19^{g}	5.46^{a}	***69.77***^{t}	6.98^{g}	9.30^{a}
R2	***21.18***^{a}	0.85^{g}	0.85^{d}	3.64^{a}	4.85^{g}	1.82^{d}	0	0	0
R3	5.93^{a}	0.85^{g}	0	14.54^{a}	7.27^{g}	1.82^{d}	11.63^{a}	2.32^{g}	0
P3	***71.18***^{t}	-	-	***53.94***^{t}	-	-	***93.07***^{t}	-	-
R1	***58.48***^{t}	2.54^{g}	3.39^{a}	***33.33***^{t}	4.85^{g}	1.82^{a}	***69.77***^{t}	0	0
R2	4.23^{a}	0	0.85^{d}	8.48^{a}	1.21^{g}	1.82^{d}	9.30^{a}	2.33^{g}	0
R3	7.63^{a}	0.85^{g}	0.85^{d}	14.54^{a}	3.64^{g}	1.21^{d}	2.33^{a}	2.33^{g}	0
R4	***21.19***^{a}	0	0	***24.24***^{a}	0	4.85^{d}	11.63^{a}	0	2.32^{d}
P4	***75.42***^{t}	-	-	***89.09***^{t}	-	-	***93.07***^{t}	-	-
R1	***30.51***^{a}	2.54^{g}	4.23^{d}	16.36^{a}	4.85^{g}	0	6.98^{a}	0	0
R2	19.49^{a}	2.54^{g}	0	***22.42***^{a}	4.85^{g}	1.21^{d}	0	0	0
R3	10.16^{a}	0	0	***23.63***^{a}	1.82^{g}	1.82^{d}	18.60^{a}	0	0
R4	***26.27***^{t}	2.54^{g}	1.69^{a}	16.97^{t}	5.45^{g}	0.61^{a}	***62.79***^{t}	6.98^{g}	4.65^{a}
P5	***73.73***^{t}	-	-	***79.39***^{t}	-	-	***89.37***^{t}	-	-
R1	12.71^{a}	3.39^{g}	1.69^{d}	***26.68***^{a}	3.64^{g}	1.21^{d}	6.98^{a}	4.65^{g}	4.65^{d}
R2	16.95^{a}	0.85^{g}	0	11.52^{a}	1.82^{g}	3.64^{d}	4.64^{a}	4.65^{g}	0
R3	***42.37***^{t}	3.39^{g}	6.78^{a}	***25.46***^{t}	4.25^{g}	2.42^{a}	***62.79***^{t}	2.32^{g}	2.32^{g}
R4	10.17^{a}	0.85^{g}	0.85^{d}	18.79^{a}	0.61^{g}	0	6.97^{a}	0	0

	HSSs			PSTs			ISTs		
P6	***28.81[t]***	-	-	***44.85[t]***	-	-	***48.84[t]***	-	-
R1	13.56[a]	2.54[g]	0.85[d]	9.69[a]	3.64[g]	1.21[d]	13.96[a]	0	0
R2	***22.03[a]***	1.70[g]	2.54[d]	***38.79[a]***	4.85[g]	4.85[d]	9.30[a]	0	2.32[d]
R3	3.39[t]	6.77[g]	***34.75[a]***	2.42[t]	4.85[g]	19.39[a]	16.28[t]	6.98[g]	***32.56[a]***
R4	9.87[a]	0.85[g]	2.54[a]	6.66[a]	1.82[g]	1.82[d]	9.30[a]	6.98[g]	2.33[d]
P7	***66.95[t]***	-	-	***66.67[t]***	-	-	***86.05[t]***	-	-
R1	***20.34[a]***	1.69[g]	1.69[d]	6.06[a]	2.42[g]	1.21[d]	6.97[a]	0	2.32[d]
R2	***22.03[a]***	0	0	7.88[a]	1.21[g]	3.03[d]	6.97[a]	0	2.32[d]
R3	***28.81[a]***	2.54[g]	1.69[d]	***43.63[a]***	7.27[g]	3.64[d]	***23.25[a]***	4.65[g]	0
R4	***21.19[t]***	0	0	16.36[t]	6.67[g]	0.61[a]	***53.49[t]***	0	0
P8	***64.41[t]***	-	-	***80.61[t]***	-	-	***76.74[t]***	-	-
R1	***27.96[a]***	5.93[g]	2.54[d]	12.72[a]	2.42[g]	1.82[d]	16.28[a]	0	4.65[d]
R2	10.17[a]	1.69[g]	0.85[d]	***21.21[a]***	3.64[g]	1.21[d]	6.98[a]	0	4.65[d]
R3	17.79[a]	1.69[g]	1.69[d]	***23.03[a]***	2.42[g]	2.42[d]	18.60[a]	0	2.32[d]
R4	***24.58[t]***	3.38[g]	1.69[a]	***20.61[t]***	7.87[g]	0.61[a]	***44.19[t]***	0	2.32[a]
P9	***43.22[t]***	-	-	***47.88[t]***	-	-	***44.19[t]***	-	-
R1	***22.88[a]***	4.24[g]	1.69[d]	19.40[a]	3.64[g]	4.85[d]	9.30[a]	0	2.32[d]
R2	12.71[a]	1.69[g]	5.08[d]	19.39[a]	4.85[g]	2.42[d]	0	0	0
R3	***31.36[a]***	1.69[g]	4.24[d]	14.54[a]	2.42[g]	3.03[d]	***39.53[a]***	4.65[g]	2.32[d]
R4	11.86[t]	0.85[g]	1.69[a]	15.76[t]	7.88[g]	1.82[a]	***27.91[t]***	9.30[g]	4.65[a]
P10	***64.41[t]***	-	-	***67.88[t]***	-	-	***81.40[t]***	-	-
R1	***22.58[a]***	4.24[g]	1.69[d]	11.52[a]	3.03[g]	3.64[d]	9.30[a]	0	0
R2	8.47[a]	5.93[g]	0.85[d]	18.79[a]	6.67[g]	3.03[d]	2.32[a]	0	4.65[d]
R3	***27.97[t]***	6.61[g]	4.24[a]	***23.64[t]***	11.51[g]	1.21[a]	***74.42[t]***	0	2.32[a]
R4	14.40[a]	0.85[g]	2.54[d]	12.73[a]	3.03[g]	1.21[d]	4.65[a]	2.32[g]	0
P11	***61.02[t]***	-	-	***72.73[t]***	-	-	***89.37[t]***	-	-
R1	***32.20[a]***	0.85[g]	0.85[d]	18.79[a]	3.64[g]	2.42[d]	***20.93[a]***	2.32[g]	0
R2	***21.19[a]***	2.54[g]	2.54[d]	***36.97[a]***	5.45[g]	4.85[d]	***23.25[a]***	0	0
R3	19.49[a]	2.54[g]	0.85[d]	17.58[a]	1.21[g]	3.03[d]	13.95[a]	0	0
R4	8.47[t]	3.39[g]	5.08[a]	2.42[t]	2.42[g]	1.21[a]	***37.21[t]***	2.32[g]	0
P12	***49.15[t]***	-	-	***51.52[t]***	-	-	***48.86[t]***	-	-
R1	***22.03[t]***	3.39[g]	4.24[a]	12.12[t]	5.45[g]	4.85[a]	***23.26[t]***	4.64[g]	6.98[a]
R2	***29.66[a]***	2.54[g]	3.39[d]	13.94[a]	3.03[g]	9.09[d]	16.27[a]	0	4.65[d]
R3	8.48[a]	0.85[g]	4.24[d]	***29.70[a]***	2.42[g]	3.64[d]	18.60[a]	0	2.32[d]
R4	16.95[a]	3.39[g]	0.85[d]	12.12[a]	0	3.64[d]	***23.25[a]***	0	0

Note

1: "P" = phenomena (1st tier); "R" =reasoning (2nd tier), i.e P1R1 = phenomena 1 reasoning 1; P12R4 = phenomena 12 reasoning 4, and so on.

2: * = correct answer

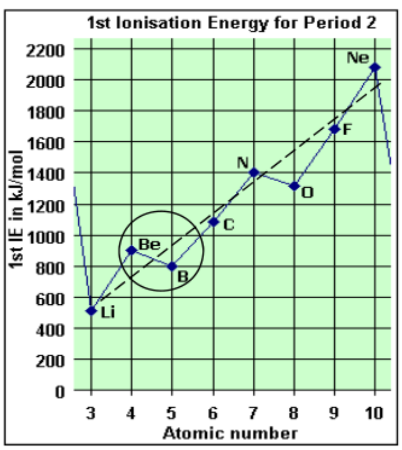
3: The ***bold-italics*** means the percentage of this response > 20%, (typical response)

4: "t"=truly understanding; "g"=guessing; "a"=alternative response; "d"= deficient

Table 6. *The misconceptions probed by the IEDI*M*

No	Item Choices	Subjects
1	1A1,1A2	PSTs, HSSs
2	2B2, 2B3	-
3	3B2, 3B3, 3B4	PSTs, HSSs
4	4B1, 4B2, 4B3	HSSs
5	5A1, 5A2, 5A4	HSSs
6	6B1, 6B2, 6B4	PSTs, HSSs
7	7A1, 7A2, 7A3	PSTs, HSSs
8	8A1, 8A2, 8A3	HSSs
9	9B1, 9B2, 9B3	ISTs, PSTs, HSSs
10	10A1, 10A2, 10A4	PSTs, HSSs
11	11B1, 11B2, 11B3	HSSs
12	12B2, 12B3, 12B4	ISTs, PSTs, HSSs

Alternative conceptions	vs	*Truly understanding*
Na < Mg < Al	vs	Na < Mg, Mg > Al, and Na < Al
Be < B	vs	Be > B
Si < P < S	vs	Si < P, P > S, and Si < S



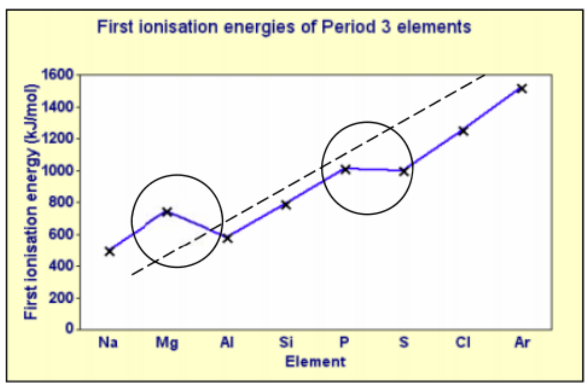


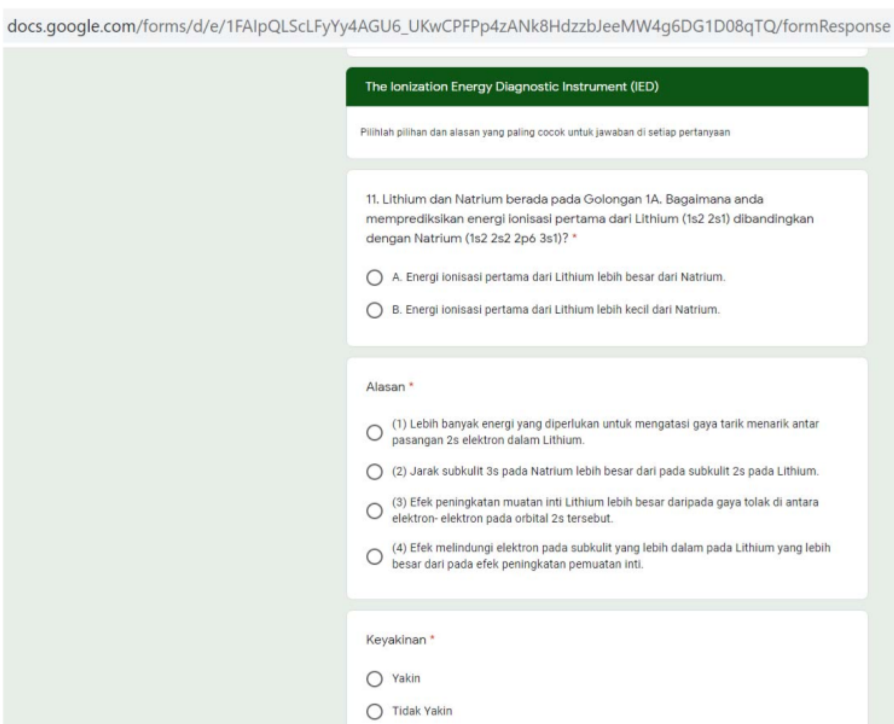
Figure 1. The first ionization energy of period 2 and 3 and the common parts of misconceptions.

Table 7. *The trends of misconceptions for all-tiers*

Misconception (MSC)	Percentages of Misconceptions								
	HSSs			PSTs			ISTs		
	one-tier	two-tier	three-tier	one-tier	two-tier	three-tier	one-tier	two-tier	three-tier
MSC 1	**39.83***	**30.51***	**29.66***	**49.09***	**42.42***	**40.61***	13.95	11.63	6.98
MSC 2	11.02	4.24	3.39	**21.82***	10.91	7.27	13.95	4.65	4.65
MSC 3	**28.82***	**25.42***	**23.73***	**46.06***	**42.42***	**34.54***	6.98	6.98	4.65
MSC 4	**24.58***	**22.88***	18.64	10.91	7.27	4.24	6.98	2.32	2.32
MSC 5	**26.27***	18.64	16.10	**20.61***	17.58	12.73	11.63	9.30	4.65
MSC 6	**71.19***	**31.36***	**27.12***	**55.15***	**32.12***	**24.24***	**51.16***	11.63	6.98
MSC 7	**33.05***	**33.05***	**29.66***	**33.33***	**30.91***	**23.03***	13.95	13.95	9.30
MSC 8	**35.59***	**32.20***	**27.12***	19.39	16.36	10.91	**23.26***	**20.93***	9.30
MSC 9 **)	**56.78***	**55.08***	**44.07***	**52.12***	**46.67***	**36.36***	**55.81***	**48.84***	**44.19***
MSC 10	**35.59***	**30.51***	**25.42***	**32.12***	**28.48***	**20.61***	18.60	16.28	11.63
MSC 11	**38.98***	**31.36***	**27.12***	**27.27***	**25.45***	15.15	11.63	11.63	11.63
MSC 12 **)	**50.85***	**46.61***	**38.14***	**48.48***	**43.64***	**27.27***	**51.16***	**41.86***	**34.88***

Note: * = the percentages of misconceptions > 20%
** = ISTs, PSTs, and HSSs have misconceptions of all-tiers

Sample of online test survey (Google forms with Indonesian version)



The Ionization Energy Diagnostic * Modification (IEDI*M) Instrument

Instructions
Choose the most suitable option and the reason for your choice in each question by filling the appropriate circles in the answer sheet. ***If you feel that all options given are inappropriate****, indicate the question number and write down what you think the correct answer should be behind the answer sheet.*

For Questions 1 to 4, please refer to the statement below.
Sodium atoms are ionised to form sodium ions as follows:

$Na(g) \rightarrow Na^{+}(g) + e$

1. Once the outermost electron is removed from the sodium atom forming the sodium ion (Na^{+}), the sodium ion will not combine with an electron to reform the sodium atom.
   A True.
   B False.
   Reason:
   (1) Sodium is strongly electropositive, so it only loses electrons.
   (2) The Na^{+} ion has a stable/noble gas configuration, so it will not gain an electron to lose its stability.
   (3) The positively-charged Na^{+} ion can attract a negatively-charged electron.
   Confidence: (a) Sure (b) Unsure

2. When an electron is removed from the sodium atom, the attraction of the nucleus for the 'lost' electron will be redistributed among the remaining electrons in the sodium ion (Na^{+}).
   A True.
   B False.
   Reason:
   (1) The amount of attraction between an electron and the nucleus depends on the number of protons present in the nucleus and the distance of the electron from the nucleus. It does not depend on how many other electrons are present, although electrons do repel each other (and can shield one another from the nucleus)
   (2) The electron which is removed will take away the attraction of the nucleus with it when it leaves the atom.
   (3) The number of protons in the nucleus is the same but there is one less electron to attract, so the remaining 10 electrons will experience greater attraction by the nucleus.
   Confidence: (a) Sure (b) Unsure

3. The Na(g) atom is a more stable system than the $Na^{+}(g)$ ion and a free electron.
   A True.
   B False.
   Reason:
   (1) The Na(g) atom is neutral and energy is required to ionise the Na(g) atom to form the $Na^{+}(g)$ ion.
   (2) Average force of attraction by the nucleus on each electron of $Na^{+}(g)$ ion is greater than that of Na(g) atom.
   (3) The $Na^{+}(g)$ ion has a vacant shell which can be filled by electrons from other atoms to form a compound.
   (4) The outermost shell of $Na^{+}(g)$ ion has achieved a stable octet/noble gas configuration.
   Confidence: (a) Sure (b) Unsure

4. After the sodium atom is ionised (i.e. forms Na^+ ion), more energy is required to remove a second electron (i.e. the second ionisation energy is greater than the first ionisation energy) from the Na^+ ion.
A True.
B False.
Reason:
(1) Removal of the second electron disrupts the stable octet structure of Na^+ ion.
(2) The same number of protons in Na^+ attracts one less electron, so the attraction
(3) The second electron is located in a shell which is closer to the nucleus.
(4) The second electron is removed from a paired 2p orbital and it experiences repulsion from the other electron in the same orbital.
Confidence: (a) Sure (b) Unsure

5. Sodium, magnesium and aluminium are in Period 3. How would you expect the first ionisation energy of sodium ($1s^2 2s^2 2p^6 3s^1$) to compare to that of magnesium ($1s^2 2s^2 2p^6 3s^2$)?
A. The first ionisation energy of sodium is greater than that of magnesium.
B. The first ionisation energy of sodium is less than that of magnesium.

Reason:
(1) Magnesium has a fully-filled 3s sub-shell which gives it stability.
(2) Sodium will achieve a stable octet configuration if an electron is removed.
(3) The paired electrons in the 3s orbital of magnesium experience repulsion from each other, and this effect is greater than the increase in the nuclear charge in magnesium.
(4) The 3s electrons of magnesium are further from the nucleus compared to those of sodium.
Confidence: (a) Sure (b) Unsure

6. How do you expect the first ionisation energy of magnesium ($1s^2 2s^2 2p^6 3s^2$) to compare to that of aluminium ($1s^2 2s^2 2p^6 3s^2 3p^1$)?
A. The first ionisation energy of magnesium is greater than that of aluminium.
B. The first ionisation energy of magnesium is less than that of aluminium.
Reason
(1) Removal of an electron will disrupt the stable completely-filled 3s sub-shell of magnesium.
(2) The 3p electron of aluminium is further from the nucleus compared to the 3s electrons of magnesium.
(3) The effect of an increase in nuclear charge in aluminium is greater than the repulsion between the electrons in its outermost shell.
(4) The effect of an increase in nuclear charge in aluminium is less than the repulsion between the electrons in its outermost shell.
Confidence: (a) Sure (b) Unsure

7. How do you expect the first ionisation energy of sodium ($1s^2 2s^2 2p^6 3s^1$) to compare to that of aluminium ($1s^2 2s^2 2p^6 3s^2 3p^1$)?

A. The first ionisation energy of sodium is greater than that of aluminium.
B. The first ionisation energy of sodium is less than that of aluminium.

Reason

(1) Aluminium will attain a fully-filled 3s sub-shell if an electron is removed.
(2) Sodium will achieve a stable octet configuration if an electron is removed.
(3) The 3p electron of aluminium is further away from the nucleus compared to the 3s electron of sodium.
(4) The effect of an increase in nuclear charge in aluminium is greater than the shielding of the 3p electron by the 3s electrons.

Confidence: (a) Sure (b) Unsure

8. Silicon, phosphorus and sulphur are in Period 3. How would you expect the first ionisation energy of silicon ($1s^2 2s^2 2p^6 3s^2 3p^2$) to compare to that of phosphorus ($1s^2 2s^2 2p^6 3s^2 3p^3$)?

A The first ionisation energy of silicon is greater than that of phosphorus.
B The first ionisation energy of silicon is less than that of phosphorus.

Reason:

(1) Silicon has less electrons than phosphorus, thus its 3p electrons face less shielding.
(2) The 3p sub-shell of phosphorus is half-filled, hence it is stable.
(3) The 3p electrons of phosphorus are further away from the nucleus compared to that of silicon.
(4) The effect of an increase in nuclear charge in phosphorus is greater than the repulsion between its 3p electrons.

Confidence: (a) Sure (b) Unsure

9. How would you expect the first ionisation energy of phosphorus ($1s^2 2s^2 2p^6 3s^2 3p^3$) to compare to that of sulphur ($1s^2 2s^2 2p^6 3s^2 3p^4$)?

A The first ionisation energy of phosphorus is greater than that of sulphur.
B The first ionisation energy of phosphorus is less than that of sulphur.

Reason

(1) More energy is required to overcome the attraction between the paired 3p electrons in sulphur.
(2) 3p electrons of sulphur are further away from the nucleus compared to that of phosphorus.
(3) The effect of an increase in nuclear charge in sulphur is greater than the repulsion between its 3p electrons.
(4) The effect of an increase in nuclear charge in sulphur is less than the repulsion between its 3p electrons.

Confidence: (a) Sure (b) Unsure

10. How would you expect the first ionisation energy of silicon ($1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$) to compare to that of sulphur ($1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$)?
A The first ionisation energy of silicon is greater than that of sulphur.
B The first ionisation energy of silicon is less than that of sulphur.

Reason
(1) Sulphur will have its 3p sub-shell half-filled if an electron is removed.
(2) The 3p electrons of sulphur are further away from the nucleus compared to that of silicon.
(3) The effect of an increase in nuclear charge in sulphur is greater than the repulsion between its 3p electrons.
(4) The effect of an increase in nuclear charge in sulphur is less than the repulsion between its 3p electrons.
Confidence: (a) Sure (b) Unsure

11. Lithium and Sodium are in the group IA. How would you expect the first ionisation energy of Lithium ($1s^2\ 2s^1$) to compare to that of Sodium ($1s^2\ 2s^2\ 2p^6\ 3s^1$)?
A The first ionisation energy of Lithium is greater than that of Sodium.
B The first ionisation energy of Lithium is less than that of Sodium.
Reason :
(1) More energy is required to overcome the attraction between the paired 2s electrons in Lithium.
(2) The 3s electrons of Sodium are further away from the nucleus compared to that 2s of Lithium.
(3) The effect of an increase in nuclear charge in Lithium is greater than the repulsion between its 2s electrons.
(4) The shielding effect of the inner shells of electrons are greater than the effect of increasing nuclear charge.
Confidence: (a) Sure (b) Unsure

12. How would you expect the first ionisation energy of Beryllium ($1s^2\ 2s^2$) to compare to that of Boron ($1s^2\ 2s^2\ 2p^1$)?
A The first ionisation energy of Beryllium is greater than that of Boron.
B The first ionisation energy of Beryllium is less than that of Boron.
Reason :
(1) The 2p electron of Boron has a lower penetrating power than the 2s electrons therefore it outweighing the increase in nuclear charge.
(2) The 2s electron of Beryllium has a lower penetrating power than the 1s electrons therefore it outweighing the increase in nuclear charge.
(3) The 2p electrons of Boron are further away from the nucleus compared to that of Beryllium.
(4) The effect of an increase in nuclear charge in Boron is less than the repulsion between its 2p electrons.
Confidence: (a) Sure (b) Unsure

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