

The ionisation energy diagnostic instrument: a two-tier multiple-choice instrument to determine high school students' understanding of ionisation energy

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Appendix A

Assessment objectives on ionisation energy in the A-level syllabus for 2001

Atomic structure

1. Explain the factors influencing the ionisation energies of elements.
2. Explain trends in ionisation energies across a period and down a group of the Periodic Table.
3. Deduce the electronic configurations of elements from successive ionisation energy data.
4. Interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table.

Chemical energetics

Apply Hess' Law to construct simple energy cycles, e.g., Born-Haber cycle, and carry out calculations involving such cycles and relevant energy terms (including ionisation energy and electron affinity).

The periodic table: Chemical periodicity

Periodicity of physical properties of the elements: variation with proton number across the third period (sodium to argon)

1. Explain the variation in first ionisation energy.
2. Deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information of physical and chemical properties.

Appendix B

The Ionisation Energy Diagnostic Instrument (IEDI)

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 at the back of the answer sheet.

For Questions 1 to 4, please refer to the statement below.

Sodium atoms are ionised to form sodium ions as follows:



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.
C I do not know the answer.

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.

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.
C I do not know the answer.

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.

3. The Na(g) atom is a more stable system than the $\text{Na}^+(\text{g})$ ion and a free electron.

- A True.
B False.
C I do not know the answer.

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.
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.
 - C This should not happen as the Na⁺ ion will not lose any more electrons.
 - D I do not know the answer.

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 for the remaining electrons is stronger.
 - (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.
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.
 - C. I do not know the answer.

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) In this situation, the effect of an increase in nuclear charge in magnesium is greater than the repulsion between its paired electrons in the 3s orbital.
 - (4) 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.
 - (5) The 3s electrons of magnesium are further from the nucleus compared to those of sodium.
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.
 - C. I do not know the answer.

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) In this situation, the effect of an increase in nuclear charge in aluminium is greater than the repulsion between the electrons in its outermost shell.
- (4) In this situation, the effect of an increase in nuclear charge in aluminium is less than the repulsion between the electrons in its outermost shell.
- (5) The paired electrons in the 3s orbital of magnesium experience repulsion from each other, whereas the 3p electron of aluminium is unpaired.

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.
 - C. I do not know the answer.

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 experiences greater shielding from the nucleus compared to the 3s electron of sodium.
- (4) The 3p electron of aluminium is further away from the nucleus compared to the 3s electron of sodium.
- (5) In this situation, the effect of an increase in nuclear charge in aluminium is greater than the shielding of the 3p electron by the 3s electrons.

8. Silicon, phosphorus and sulfur 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.
 - C. I do not know the answer.

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) In this situation, the effect of an increase in nuclear charge in phosphorus is greater than the repulsion between its 3p electrons.

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 sulfur ($1s^2 2s^2 2p^6 3s^2 3p^4$)?
- A. The first ionisation energy of phosphorus is greater than that of sulfur.
 - B. The first ionisation energy of phosphorus is less than that of sulfur.
 - C. I do not know the answer.

Reason

- (1) More energy is required to overcome the attraction between the paired 3p electrons in sulfur.
- (2) 3p electrons of sulfur are further away from the nucleus compared to that of phosphorus.
- (3) The 3p sub-shell of phosphorus is half-filled, hence it is stable.
- (4) In this situation, the effect of an increase in nuclear charge in sulfur is greater than the repulsion between its 3p electrons.
- (5) In this situation, the effect of an increase in nuclear charge in sulfur is less than the repulsion between its 3p electrons.

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 sulfur ($1s^2 2s^2 2p^6 3s^2 3p^4$)?
- A. The first ionisation energy of silicon is greater than that of sulfur.
 - B. The first ionisation energy of silicon is less than that of sulfur.
 - C. I do not know the answer.

Reason

- (1) Sulfur will have its 3p sub-shell half-filled if an electron is removed.
- (2) The 3p electrons of sulfur are further away from the nucleus compared to that of silicon.
- (3) In this situation, the effect of an increase in nuclear charge in sulfur is greater than the repulsion between its 3p electrons.
- (4) In this situation, the effect of an increase in nuclear charge in sulfur is less than the repulsion between its 3p electrons.