

Chemical stability

Target level

This probe may be used at post-16 level, or with students in the 14–16 age range who have studied atomic structure.

Topics

Relative stability of atoms and ions.

Rationale

Research has shown that students entering post-16 chemistry courses may have acquired the notion that species with octet configurations or full outer shells are always more stable than species with other configurations. These judgements are sometimes made regardless of the context, and any other factors that might be relevant. These ideas are discussed in Chapter 6 of the Teachers' notes.

This set of probes asks students to compare the stability of various triads of related species. There are seven probes in the set. The first four compare an atom with two of its ions, and are suitable for able students in the 14–16 year age range as well as for more advanced students. The other three probes introduce more subtle points, and are suitable for students on post-16 courses.

When these materials were piloted teachers found the probes useful and the student responses interesting. It was found that for many students 'the complete shell of electrons was regarded as automatically conferring stability'. One teacher noted that 'it is clear that the complete shell of electrons dominates their thinking. We have spent some time looking at stability in terms of energy changes and forces between charged particles, so it shows me how easily people revert to simple and familiar ideas'.

Instructions

The probes may be used in a number of ways. It is suggested that it is most useful to distribute copies of the various probes in such a way that each student has a different task to their neighbours, and then – after allowing time to complete the sheet - moving to a discussion of the responses (either in groups or in the whole class).

Each student in a 14–16 year old group will require a copy of one of the worksheets:

- **Chemical stability (1)** – Na^+ / Na / Na^{7-}
- **Chemical stability (2)** – Cl^{7+} / Cl / Cl^-
- **Chemical stability (3)** – C^{4+} / C / C^{4-}
- **Chemical stability (4)** – Be^{2+} / Be / Be^{6-}

Each student in a post-16 group will require a copy of one of the worksheets above, or one of

- **Chemical stability (5)** – Cl (1.8.8) / Cl (2.7.8) / Cl (2.8.7)
- **Chemical stability (6)** – Cl / Cl^- / Cl^{11-}
- **Chemical stability (7)** – O / O^- / O^{2-}

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Resources

- Student worksheets
 - Chemical stability (1–7)

Feedback for students

A sheet of answers and feedback points for discussion is provided for teachers.

Chemical stability – answers

Teachers' feedback sheet for class discussion

Note: species with 'octet' or 'full shell' structures tend to predominate within stable chemical systems (molecules, ionic lattices, metallic lattices etc). Students may commonly extrapolate to believe that any species with such a structure (eg Na^{7-}) is always more stable than a species without such a structure. However, when the chemical species are considered in isolation, it is often the case that neutral atoms are more stable than the related ions. This must not be seen as an absolute rule though, as first electron affinities may be exothermic.

Chemical stability (1) – Na^+ / Na / Na^{7-}

1. The neutral atom is more stable, in the sense that the ion will spontaneously attract an electron, but the atom will not spontaneously emit an electron. Students may reasonably argue that they were thinking of real chemical contexts, where the cation is commonly found as part of real chemical substances (sodium metal, sodium chloride etc), unlike the metal. (The separate probe **Stability and reactivity** may be useful to follow up any ambiguity in terms of the context of the question).
2. Clearly the Na^{7-} ion would be highly unstable, but some students will suggest it is more stable than the neutral atom due to its octet structure (full [sic] outer shell). However, in fact it is 10 electrons short of a full outer shell.
3. Clearly the Na^{7-} ion would be highly unstable, but some students will suggest it is equally as stable as the cation due to its octet structure (full [sic] outer shell).

Chemical stability (2) – Cl^{7+} / Cl / Cl^-

4. A great deal of energy is required to ionise a chlorine atom to give a 7+ cation, but some students may feel the cation is more stable due to its octet structure.
5. Chlorine has an exothermic electron affinity, so the chloride ion may be considered more stable than the atom, despite the atom's neutrality.
6. A great deal of energy is required to ionise a chlorine atom to give a 7+ cation, but some students may feel the two ions are equally stable due to their octet structures. (It is possible some may suggest that the cation is more stable, as it has a full outer shell - although many students are likely to assign full shells to both of these ions.)

Chemical stability (3) – C^{4+} / C / C^{4-}

7. A great deal of energy is required to ionise a carbon atom to give a 4+ cation, but some students may feel the cation is more stable due to its full shell structure.
8. The C^{4-} ion would be unstable, but some students will suggest it is more stable than the neutral atom due to its octet structure (full [sic] outer shell).
9. Both of the ions would be highly labile. Some students may feel both are stable because they have full shells, whilst others may suggest that the anion is more stable as it has an octet, or because it has more full shells.

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Chemical stability (4) – Be^{2+} / Be / Be^{6-}

10. Energy is required to ionise the atom to form the cation, so the neutral atom should be considered more stable. (However, see the comments on Question 1 about the context in which students might consider the question.)
11. The highly charged anion is clearly unstable compared the neutral atom, although some students may feel that the octet structure on the anion makes it more stable.
12. The highly charged metal anion is clearly unstable compared the moderately charged metal cation. Some students may feel both are stable because they have full shells, whilst others may suggest that the anion is more stable as it has an octet, or because it has more full shells.

Chemical Stability (5) – Cl (1.8.8) / Cl (2.7.8) / Cl (2.8.7)

13. Neither of these configurations are stable, and both would be expected to undergo spontaneous transition to 2.8.7. The 1.8.8 structure will emit a greater energy quanta as the electron drops from the $n=3$ to the $n=1$ level (cf the quantum jump from $n=3$ to $n=2$ in the 2.7.8 species). Some students may feel that both are stable as they have octets in the outer shells, and 1.8.8 may be considered more stable as it has two octets.
14. 2.8.7 is the ground state of the chlorine atom and is more stable. The excited state (2.7.8) will decay to the ground state. Some students may feel that the excited state is more stable as it has an octet in the outer shell.
15. 2.8.7 is the ground state of the chlorine atom and is more stable. The excited state (1.8.8) will decay to the ground state. Some students may feel that the excited state is more stable as it has an octet in the outer shell.

Chemical stability (6) – Cl / Cl^- / Cl^{11-}

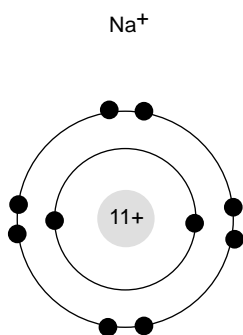
16. Chlorine has an exothermic electron affinity, so the chloride ion may be considered more stable than the atom, despite the atom's neutrality.
17. The common Cl^- anion is clearly more stable than the highly charged Cl^{11-} ion. Cl^- has an outer octet of electrons (but not a full shell), and Cl^{11-} has a full outer shell (but more than an octet).
18. The neutral atom is clearly more stable than the highly charged Cl^{11-} ion. However, Cl^{11-} has a full outer shell and may be considered more stable by some students.

Chemical stability (7) – O / O^- / O^{2-}

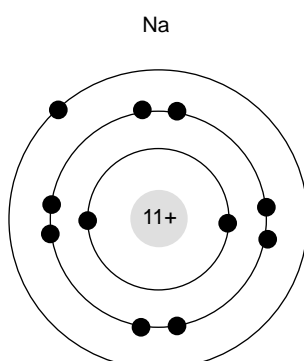
19. Oxygen has an exothermic electron affinity, so the O^- ion may be considered more stable than the atom, despite the atom's neutrality.
20. Although the oxide is O^{2-} and is common, the O^- anion will actually repel away another electron, so is more stable than O^{2-} . (See the comments about chemical context in Q1). The electron affinity for the oxygen atom is -142 kJ mol^{-1} , but the electron 'affinity' [sic] of the O^- ion is endothermic: $+844 \text{ kJ mol}^{-1}$.
21. The O^{2-} ion, although common is, in isolation, less stable than the neutral atom. (The sum of the two electron affinity values is endothermic – see Question 20.)

Chemical stability (1)

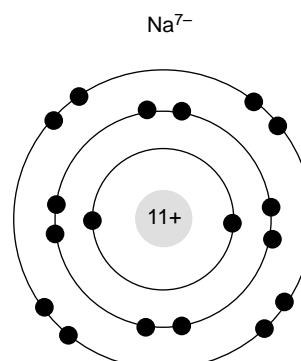
The diagrams below represent three chemical species:-



Sodium ion with electronic configuration of 2.8



Sodium atom with electronic configuration of 2.8.1



Sodium ion with electronic configuration of 2.8.8

1. Tick one of the four statements:

- Na⁺ is more stable than Na
- Na⁺ and Na are equally stable
- Na⁺ is less stable than Na
- I do not know

Why did you think this was the answer?

2. Tick one of the four statements:

- Na is more stable than Na⁷⁻
- Na and Na⁷⁻ are equally stable
- Na is less stable than Na⁷⁻
- I do not know

Why did you think this was the answer?

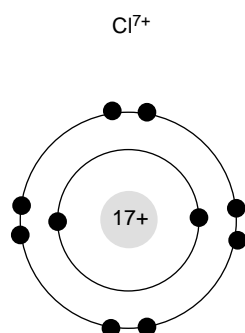
3. Tick one of the four statements:

- Na⁷⁻ is more stable than Na⁺
- Na⁷⁻ and Na⁺ are equally stable
- Na⁷⁻ is less stable than Na⁺
- I do not know

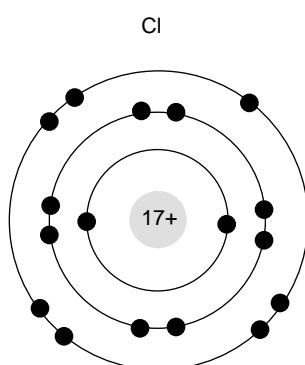
Why did you think this was the answer?

Chemical stability (2)

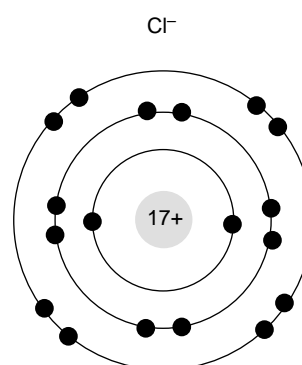
The diagrams below represent three chemical species:



Chloride ion with electronic configuration of 2.8



Chlorine atom with electronic configuration of 2.8.7



Chloride ion with electronic configuration of 2.8.8

4. Tick one of the four statements:

- Cl^{7+} is more stable than Cl
- Cl^{7+} is more stable than Cl^-
- Cl^{7+} is less stable than Cl
- I do not know

Why did you think this was the answer?

5. Tick one of the four statements:

- Cl is more stable than Cl^-
- Cl and Cl^- are equally stable
- Cl is less stable than Cl^-
- I do not know

Why did you think this was the answer?

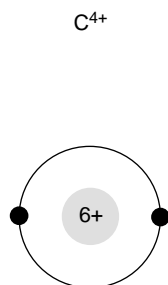
6. Tick one of the four statements:

- Cl^- is more stable than Cl^{7+}
- Cl^- and Cl^{7+} are equally stable
- Cl^- is less stable than Cl^{7+}
- I do not know

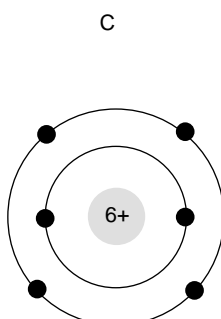
Why did you think this was the answer?

Chemical stability (3)

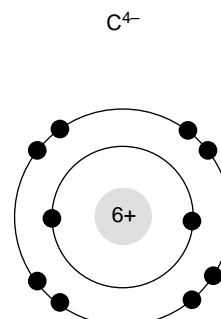
The diagrams below represent three chemical species:-



Carbon ion with electronic configuration of 2



Carbon atom with electronic configuration of 2.4



Carbon ion with electronic configuration of 2.8

7. Tick one of the four statements:

- C^{4+} is more stable than C
- C^{4+} and C are equally stable
- C^{4+} is less stable than C
- I do not know

Why did you think this was the answer?

8. Tick one of the four statements:

- C is more stable than C^{4-}
- C and C^{4-} are equally stable
- C is less stable than C^{4-}
- I do not know

Why did you think this was the answer?

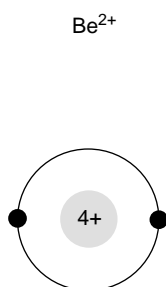
9. Tick one of the four statements:

- C^{4-} is more stable than C^{4+}
- C^{4-} and C^{4+} are equally stable
- C^{4-} is less stable than C^{4+}
- I do not know

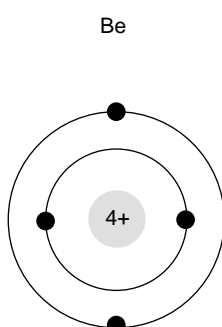
Why did you think this was the answer?

Chemical stability (4)

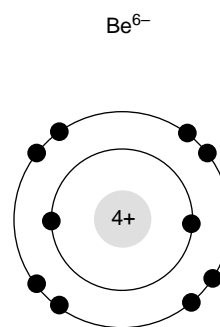
The diagrams below represent three chemical species:-



Beryllium ion with electronic configuration of 2



Beryllium atom with electronic configuration of 2.2



Beryllium ion with electronic configuration of 2.8

10. Tick one of the four statements:

- Be^{2+} is more stable than Be
- Be^{2+} and Be are equally stable
- Be^{2+} is less stable than Be
- I do not know

Why did you think this was the answer?

11. Tick one of the four statements:

- Be is more stable than Be^{6-}
- Be and Be^{6-} are equally stable
- Be is less stable than Be^{6-}
- I do not know

Why did you think this was the answer?

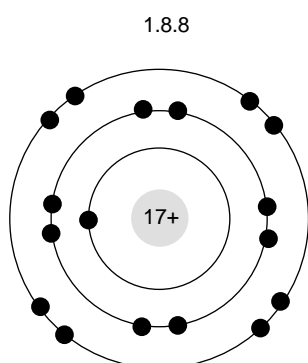
12. Tick one of the four statements:

- Be^{6-} is more stable than Be^{2+}
- Be^{6-} and Be^{2+} are equally stable
- Be^{6-} is less stable than Be^{2+}
- I do not know

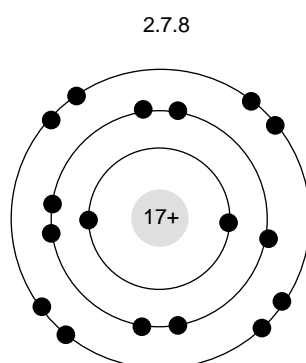
Why did you think this was the answer?

Chemical stability (5)

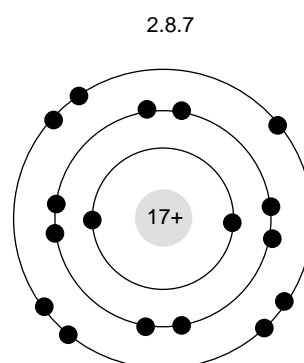
The diagrams below represent three chemical species:-



Chlorine atom with electronic configuration of 1.8.8



Chlorine atom with electronic configuration of 2.7.8



Chlorine atom with electronic configuration of 2.8.7

13. Tick one of the four statements:

- 1.8.8 is more stable than 2.7.8
- 1.8.8 and 2.7.8 are equally stable
- 1.8.8 is less stable than 2.7.8
- I do not know

Why did you think this was the answer?

14. Tick one of the four statements:

- 2.7.8 is more stable than 2.8.7
- 2.7.8 and 2.8.7 are equally stable
- 2.7.8 is less stable than 2.8.7
- I do not know

Why did you think this was the answer?

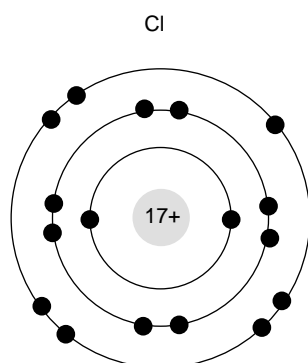
15. Tick one of the four statements:

- 2.8.7 is more stable than 1.8.8
- 2.8.7 and 1.8.8 are equally stable
- 2.8.7 is less stable than 1.8.8
- I do not know

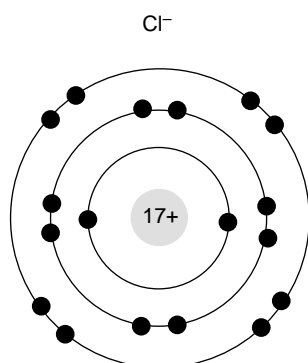
Why did you think this was the answer?

Chemical stability (6)

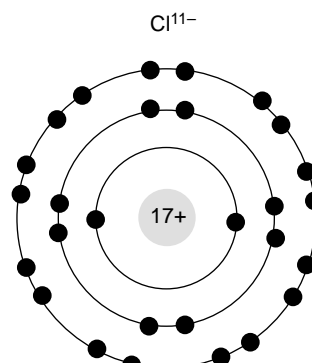
The diagrams below represent three chemical species:



Chlorine atom with electronic configuration of 2.8.7



Chloride ion with electronic configuration of 2.8.8



Chloride ion with electronic configuration of 2.8.18

16. Tick one of the four statements:

- Cl is more stable than Cl⁻
- Cl and Cl⁻ are equally stable
- Cl is less stable than Cl⁻
- I do not know

Why did you think this was the answer?

17. Tick one of the four statements:

- Cl⁻ is more stable than Cl¹¹⁻
- Cl⁻ and Cl¹¹⁻ are equally stable
- Cl⁻ is less stable than Cl¹¹⁻
- I do not know

Why did you think this was the answer?

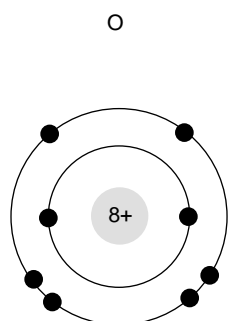
18. Tick one of the four statements:

- Cl¹¹⁻ is more stable than Cl
- Cl¹¹⁻ and Cl are equally stable
- Cl¹¹⁻ is less stable than Cl
- I do not know

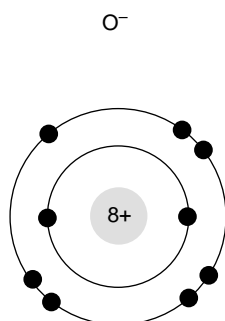
Why did you think this was the answer?

Chemical stability (7)

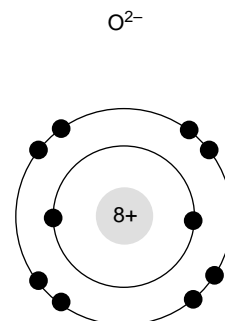
The diagrams below represent three chemical species:



Oxygen atom with electronic configuration of 2.6



Oxygen ion with electronic configuration of 2.7



Oxide ion with electronic configuration of 2.8

19. Tick one of the four statements:

- O is more stable than O^-
- O and O^- are equally stable
- O is less stable than O^-
- I do not know

Why did you think this was the answer?

20. Tick one of the four statements:

- O^- is more stable than O^{2-}
- O^- and O^{2-} are equally stable
- O^- is less stable than O^{2-}
- I do not know

Why did you think this was the answer?

21. Tick one of the four statements:

- O^{2-} is more stable than O
- O^{2-} and O are equally stable
- O^{2-} is less stable than O
- I do not know

Why did you think this was the answer?

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