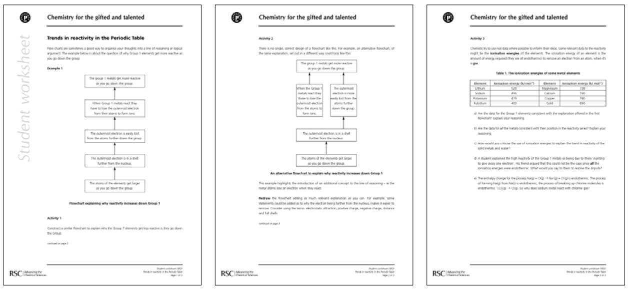
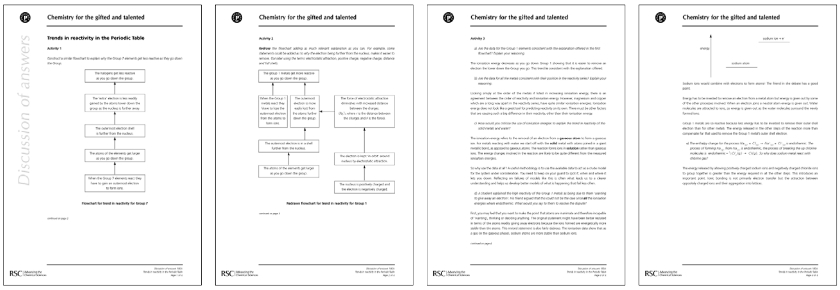
Trends in reactivity in the Periodic Table



Student worksheet: CDROM index 18SW



Discussion of answers: CDROM index 18DA

Topics

Trends in reactivity of Groups 1 and 7 and the ionic bonding model.

Level

Very able students aged 14–16.

Prior knowledge

Ionic bonding and the Periodic Table.

Rationale

This activity aims to:

- help students develop a tool (flowcharts) to aid organisation of their line of reasoning;
- help students explore links between trends in the reactivity of Groups 1 and 7 and atomic structure;
- give students the opportunity to use and critically evaluate the relevance of ionisation energy data to the reactivity series of metals;
- reinforce the idea of chemical changes being driven by energy changes; and
- challenge the idea that Group 1 metals ***want to give away*** their outer shell electron.

Use

This could be used to follow up some work on the Periodic Table where the trends in reactivity in Groups 1 and 7 have been identified. It can be used as a differentiated activity for the more able students within a group.

When the students have completed the worksheet they should be given the *Discussion of answers* sheet. They could check their own work or conduct a peer review of the work of

Trends in reactivity in the Periodic Table

Flow charts are sometimes a good way to organise your thoughts into a line of reasoning or logical argument. The example below is about the question of why Group 1 elements get more reactive as you go down the group.

Example 1

The atoms of the elements get larger as you go down the group.

↓

The outermost electron is in a shell further from the nucleus.

↓

The outermost electron is easily lost from the atoms further down the group.

↓

When Group 1 metals react they have to lose the outermost electron from their atoms to form ions.

↓

The Group 1 metals get more reactive as you go down the group.

Flowchart explaining why reactivity increases down Group 1

Flowchart adapted from:

K. Taber, *Chemical misconceptions – prevention, diagnosis and cure*, London: Royal Society of Chemistry, 2002

Activity 1

Construct a similar flowchart to explain why the Group 7 elements get less reactive as they go down the Group.

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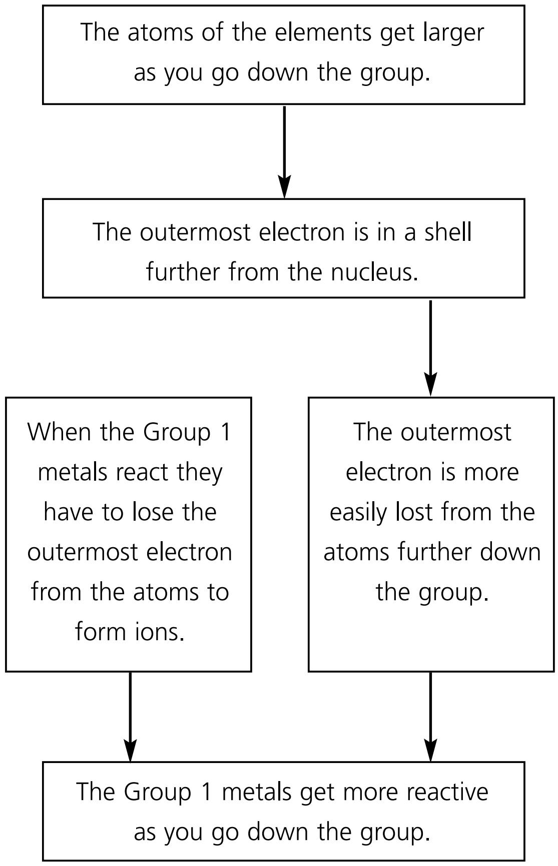
Activity 2

There is no single, correct design of a flowchart like this. For example, an alternative flowchart, of the same explanation, set out in a different way could look like this:



An alternative flowchart to explain why reactivity increases down Group 1

Flowchart adapted from:

K. Taber, *Chemical misconceptions – prevention, diagnosis and cure*, London: Royal Society of Chemistry, 2002

This example highlights the introduction of an additional concept to the line of reasoning – *ie* the metal atoms lose an electron when they react.

Redraw the flowchart adding as much relevant explanation as you can. For example, some statements could be added as to why the electron being further from the nucleus makes it easier to remove. Consider using the terms: electrostatic attraction, positive charge, negative charge, distance and full shells.

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Activity 3

Chemists try to use real data where possible to inform their ideas. Some relevant data to the reactivity might be the **ionisation energies** of the elements. The ionisation energy of an element is the amount of energy required (they are all endothermic) to remove an electron from an atom, when it's a **gas**.

Table 1. The ionisation energies of some metal elements

Element	Ionisation energy (kJ mol^{-1})	Element	Ionisation energy (kJ mol^{-1})
Lithium	520	Magnesium	738
Sodium	496	Calcium	590
Potassium	419	Copper	746
Rubidium	403	Gold	890

a) Are the data for the Group 1 elements consistent with the explanation offered in the first flowchart? Explain your reasoning.

b) Are the data for *all* the metals consistent with their position in the reactivity series? Explain your reasoning.

c) How would you criticise the use of ionisation energies to explain the trend in reactivity of the solid metals and water?

d) A student explained the high reactivity of the Group 1 metals as being due to them 'wanting to give away one electron'. His friend argued that this could not be the case since **all** the ionisation energies were endothermic. What would you say to them to resolve the dispute?

e) The enthalpy change for the process $Na(g) + Cl(g) \rightarrow Na^+(g) + Cl^-(g)$ is endothermic; the process of forming Na(g) from Na(s) is endothermic; the process of breaking up chlorine molecules is endothermic $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$. So why does sodium metal react with chlorine gas?

Trends in reactivity in the Periodic Table

Activity 1

Construct a similar flowchart to explain why the Group 7 elements get less reactive as they go down the Group.

When the Group 7 elements react they have to gain an outermost electron to form ions.

↓

The atoms of the elements get larger as you go down the group.

↓

The outermost electron shell is further from the nucleus.

↓

The 'extra' electron is less readily gained by the atoms lower down the group as the nucleus is further away.

↓

The halogens get less reactive as you go down the group.

Flowchart for trend in reactivity for Group 7

Flowchart adapted from:

K. Taber, *Chemical misconceptions – prevention, diagnosis and cure*, London: Royal Society of Chemistry, 2002

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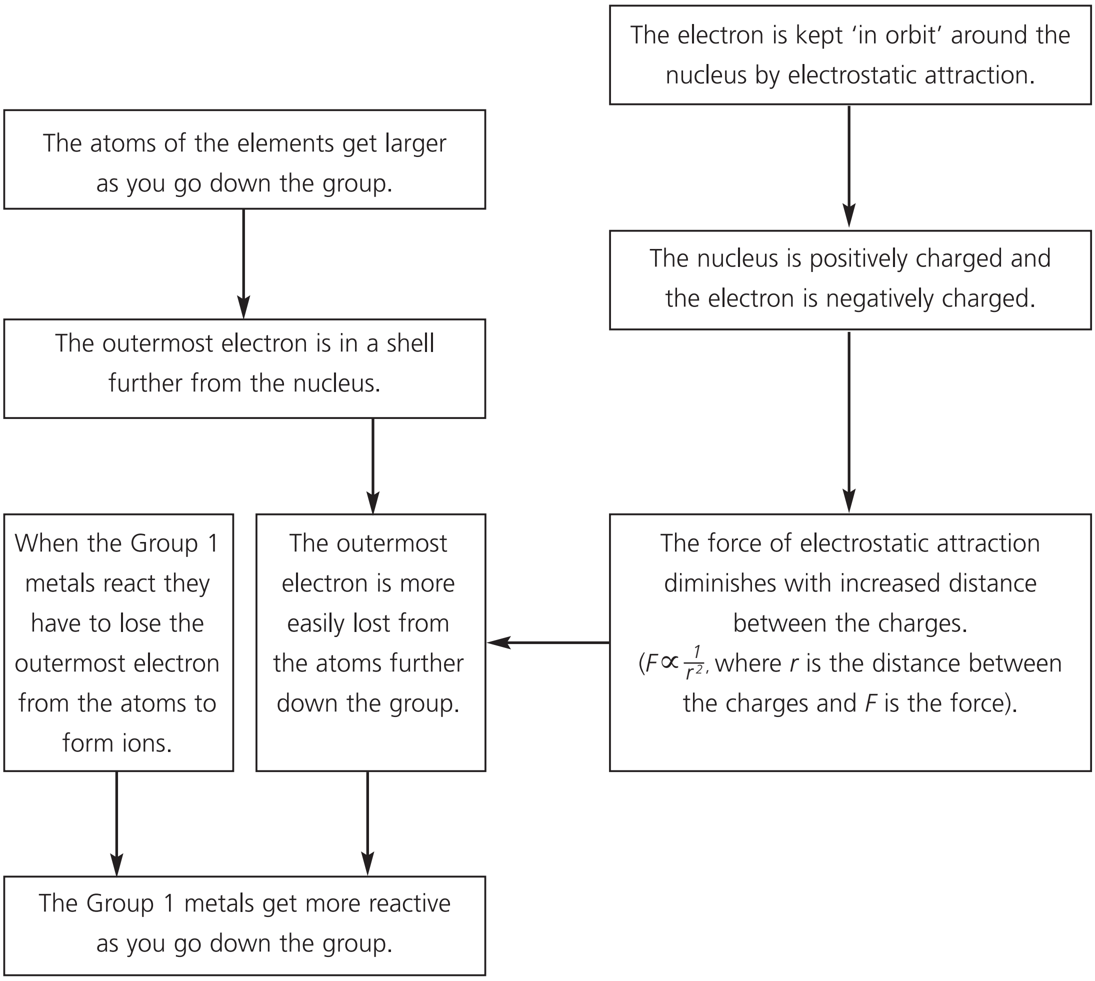
Activity 2

Redraw *the flowchart adding as much relevant explanation as you can. For example, some statements could be added as to why the electron being further from the nucleus makes it easier to remove. Consider using the terms: electrostatic attraction, positive charge, negative charge, distance and full shells.*



Redrawn flowchart for trend in reactivity for Group 1

Flowchart adapted from:

K. Taber, *Chemical misconceptions – prevention, diagnosis and cure*, London: Royal Society of Chemistry, 2002

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Activity 3

a) Are the data for the Group 1 elements consistent with the explanation offered in the first flowchart? Explain your reasoning.

The ionisation energy decreases as you go down Group 1, showing that it is easier to remove an electron the lower down the Group you go. This trend **is** consistent with the explanation offered.

b) Are the data for all the metals consistent with their position in the reactivity series? Explain your reasoning.

Looking simply at the order of the metals if listed in increasing ionisation energy, there is an agreement between the order of reactivity and ionisation energy. However, magnesium and copper, which are a long way apart in the reactivity series, have quite similar ionisation energies. Ionisation energy does not look like a great tool for predicting reactivity on its own. Therefore there must be other factors that are causing such a big difference in their reactivity.

c) How would you criticise the use of ionisation energies to explain the trend in reactivity of the solid metals and water?

The ionisation energy refers to the removal of an electron from a **gaseous atom** to form a **gaseous ion**. For metals reacting with water we start off with the **solid** metal, with atoms joined in a giant metallic lattice, as opposed to gaseous atoms. The reaction forms ions in **solution** rather than gaseous ions. The energy changes involved in the reaction are likely to be quite different from the measured ionisation energies.

So why use the data at all? A useful methodology is to use the available data to act as a crude model for the system under consideration. You need to keep on your guard to spot if, when and where it lets you down. Reflecting on failures of models like this is often what leads us to a clearer understanding and helps us to develop better models of what is happening that fail less often.

*d) A student explained the high reactivity of the Group 1 metals as being due to them 'wanting to give away an electron'. His friend argued that this could not be the case since **all** the ionisation energies where endothermic. What would you say to them to resolve the dispute?*

First, you may feel that you want to make the point that atoms are inanimate and therefore incapable of 'wanting', thinking or deciding anything. The original statement might have been better restated in terms of the atoms readily giving away electrons because the ions formed are energetically more stable than the atoms. This revised statement is also fairly dubious. The ionisation data show that as a gas (in the gaseous phase), sodium atoms are more stable than sodium ions.

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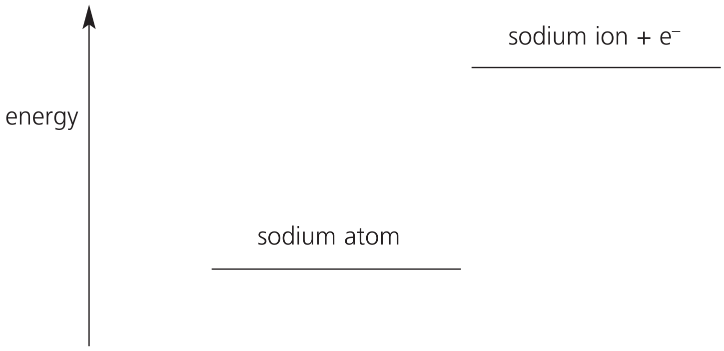

Sodium ions would combine with electrons to form atoms! The friend in the debate has a good point.

Energy has to be invested to remove an electron from a metal atom, but energy is given out by some of the other processes involved. When an electron joins a neutral atom, energy is given out. Water molecules are attracted to ions, so energy is given out as the water molecules surround the newly formed ions.

Group 1 metals are so reactive because less energy has to be invested to remove their outer shell electron than for other metals. The energy released in the other steps of the reaction more than compensate for that used to remove the Group 1 metal's outer shell electron.

e) The enthalpy change for the process $Na(g) + Cl(g) \rightarrow Na^{+}(g) + Cl^{-}(g)$ *is endothermic; the process of forming* $Na(g)$ *from* $Na(s)$ *is endothermic; the process of breaking up chlorine molecules is endothermic* $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$. *So why does sodium metal react with chlorine gas?*

The energy released by allowing positively charged sodium ions and negatively charged chloride ions to group together is greater than the energy required in all the other steps. This introduces an important point. Ionic bonding is not primarily electron transfer, but the attraction between oppositely charged ions and their aggregation into lattices.