Ri Christmas Lectures® 2012: The Modern Alchemist

Teaching Resource - Group 1: The Alkali Metals

Overview:

This resource contains information regarding Group 1 of the Periodic Table - The Alkali Metals. Included is an overview of the elements that make up the group, and their structure, general reactivity, and specific examples of their reactions. The resource is supported by links to useful materials, and video clips from the 2012 Christmas Lectures®.

What are the Alkali Metals?

- Lithium
  - Lithium is a silver-grey metal; it is the least dense of all metals, with a density of 533 kg m^{-3}. Lithium reacts strongly with moisture, forming corrosive lithium hydroxide; therefore it should be handled carefully. Treatment with lithium is also a common form of anti-depressant therapy.
- Sodium
  - Sodium is a silver grey, soft, ductile metal. It is most commonly seen in everyday life as Sodium chloride, otherwise known as table salt. It is also present in street lighting as the common yellow glow of Sodium vapour lamps. Sodium is also extremely important in the body, where it is involved in nerve impulses.
- Potassium
  - Potassium is a soft, silver metal; however when exposed to air it tarnishes quickly. Interestingly, Potassium is both essential for the human biological system and has a naturally radioactive isotope. Despite this, the natural radioactivity from Potassium is low (it has a half life of 1.248×10^9 years, see Teaching Resource - Radioactivity on the RSC Learn Chemistry website for more details on half-life).
- Rubidium
  - Rubidium is again a soft metal, however, it is pyrophoric and with ignite spontaneously in moist air. The most common use of Rubidium outside research is as a component of photoelectric cells. The name Rubidium comes from the Latin 'rubidius' which was chosen due to the red lines present within its atomic emission spectrum.
- Caesium
  - Caesium is a low melting point metal, which in its pure state is silver. However, minute oxygen impurities mean that most Caesium is seen to be golden. This, combined with its low melting point sometimes lead to Caesium being compared to 'liquid gold'. Caesium is named after the 'sky blue' lines within its atomic emission spectrum. Due to its high

reactivity, the uses of Caesium are somewhat limited. However, it is commonly used as the heart of atomic clocks. In 2011 the UK National Physical Laboratory revealed they had an atomic clock based around Caesium which would not be expected to gain or lose a second in more than 138 million years.

- Francium
  - Francium is a highly radioactive metal, which has no general uses. The half life of the longest lived isotope ^{223}Fr is only 22 minutes; this combined with its high radioactivity make applications almost impossible.

Structure and Trends:

Element	Electronic Configuration	Atomic Radius (pm)	First Ionisation Energy (kJ mol^{-1})
Lithium	[He] $2s^1$	182	520.221
Sodium	[Ne] $3s^1$	227	495.845
Potassium	[Ar] $4s^1$	275	418.810
Rubidium	[Kr] $5s^1$	303	403.031
Caesium	[Xe] $6s^1$	343	375.704
Francium	[Rn] $7s^1$	348	392.956

- Electronic Structure:

  The Group 1 elements (the alkali metals) are similar in that they all have one outer electron. This means there is only one electron in the outermost energy level of any given alkali metal. Therefore, if this electron is removed, the atom gains a Noble gas-like electronic configuration, corresponding to the next lowest Noble Gas.

  Note, that if electron configurations (orbitals) are not considered, i.e. for GCSE students, then it is sufficient to know that each alkali metal contains only one electron in its outermost electron shell (as is suggested by the group number, 1).

- Atomic Radii:

  As you go down the elements that make up group 1, you see that the atomic radii increase. Although extra protons are being added to the nucleus, each extra period adds a new electronic energy level (shell) to the atom which is fully populated. These shells reduce the attractive force from the nucleus that the outermost electrons experience, allowing them to move further from the nucleus, thus increasing the atomic radius. This effect is known as electronic 'shielding' and comes about due to differences in orbital penetration (more information is available here[1], although this is of a higher level than is required by the curriculum).

[1] ChemWiki, UC Davis, http://chemwiki.ucdavis.edu/index.php?title=Physical_Chemistry/Quantum_Mechanics/Quantum_Theory/Trapped_Particles/Atoms/Multi-Electron_Atoms/Penetration_%26_Shielding

- First Ionisation Energy & Reactivity:

  As can be seen in the table above, the first ionisation energies of the group 1 metals decreases as you descend the group. This is due to the increased shielding and increased atomic radii which are explained above. The combination of these effects leads to less of the attractive force of the nucleus being felt by the outermost electron, therefore decreasing the amount of energy needed to take it from the atom.

  The changes in first ionisation energy have a direct effect on the reactivity of the alkali metals. As one electron needs to be lost in order to achieve a Noble gas-like electronic configuration, alkali metals tend to react in such a way as to lose one electron, forming positively charged ions (cations). If it is easier to remove the outermost electron (a lower ionisation energy) then the element is more reactive. Therefore, the alkali metals increase in reactivity as you descend the group.

Reactions of the Alkali Metals

Alkali Metals will react strongly with oxidising agents which allow for removal of the single outer electron present within all alkali metal atoms; thus forming positively charged ions (cations). In this case, they tend to form ionic compounds (such as salts with the halogens, see Teaching Resource - Group 7(17) - The Halogens on the RSC Learn Chemistry website).

Some examples of the reactions of the alkali metals are with oxygen or water. Examples of both of these types of reactions are shown in the video clips below.

Video Clip - Reactions of Caesium and Sodium with Air

The Alkali Metals - Reactions with Oxygen

Running Time - 2 min 30 secs

As shown in the video, the alkali metals will react with oxygen from the air, forming metal oxides; these are visible as the tarnish that can be seen developing on any freshly cut surface of an alkali metal sample.

The alkali metals react more strongly with oxygen as you go down group one; hence lithium reacts slowly, while Caesium will tarnish instantly, combined with possible sparks (as seen in the video).

The reactions of Caesium and Sodium with Oxygen can be shown with the following equations:

$$4Na + O_2 \rightarrow 2Na_2O$$

Sodium + Oxygen → Sodium Oxide

Or

$$4Cs + O_2 \rightarrow 2Cs_2O$$

Caesium + Oxygen → Caesium Oxide

Potentially, the reaction of Sodium with air could be demonstrated by freshly cutting an oil free piece of Sodium metal.

A further exercise could be for the group to then write out equations for the reactions of each alkali metal with oxygen. Also, it is worth exploring why the oxides of the alkali metals are of the structure M_2O as opposed to MO; ensuring reference is made to the ability of the oxygen atom to gain two electrons.

Video Clip - Reaction of Sodium and Water

The Alkali Metals - Reactions with Water

Running Time - 2 min 07 secs

As shown in the video, Sodium reacts violently with water. The equation for this reaction is shown below:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

Sodium + Water → Sodium Hydroxide + Hydrogen gas

The explosion of the second piece of Sodium was caused by the ignition of hydrogen gas by the heat of the reaction. Again, the reactivity of the alkali metals with water increases down the group; meaning the reaction of Caesium with water is much more violent than that of Sodium and water.

The reaction of Sodium with water could be demonstrated to the group. If possible, the reaction of Potassium and water should also be demonstrated, although this is also more violent than that of Sodium. Videos of the reactions of Rubidium and Caesium with water are available from the RSC Learn Chemistry website (Rubidium, Caesium).

A further teaching resource concerning flame tests, and the emission spectra of the alkali metals is also available through the RSC Learn Chemistry website[2].

View the full 2012 Ri Christmas Lectures® - The Modern Alchemist, along with behind the scenes footage, and related content, at the Ri Channel[3].

[2] Learn Chemistry, www.rsc.org/learn-chemistry
[3] The Ri Channel, www.richannel.org