

AS and A LEVEL

Delivery Guide

CHEMISTRY B (SALTERS)

H033/H433

For first teaching in 2015

Atomic structure, periodicity and inorganic chemistry






Version 2

AS and A LEVEL CHEMISTRY B (SALTERS)

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

If you have any feedback on this Delivery Guide or suggestions for other resources you would like OCR to develop, please email resources.feedback@ocr.org.uk

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Content (from A Level)

Learners should be able to demonstrate and apply their knowledge and understanding of:

EL(d) balanced full and ionic chemical equations, including state symbols

EL(e) conventions for representing the distribution of electrons in atomic orbitals; the shapes of s- and p-orbitals

EL(f) the electronic configuration, using sub-shells and atomic orbitals, of:

- (i) atoms from hydrogen to krypton
- (ii) ions of the s- and p-block of periods 1 to 4
- (iii) the outer sub-shell structures of s- and p-block elements of other periods

EL(g) how knowledge of the structure of the atom developed in terms of a succession of gradually more sophisticated models; interpretation of these and other examples of such models

EL(h) fusion reactions: lighter nuclei join to give heavier nuclei (under certain conditions of high temperature and pressure); this is how certain elements are formed

EL(m) the periodic table as a list of elements in order of atomic (proton) number that groups elements together according to their common properties; using given information, make predictions concerning the properties of an element in a group; the classification of elements into s-, p- and d-blocks

EL(n) periodic trends in the melting points of elements in periods 2 and 3, in terms of structure and bonding

EL(o) the relationship between the position of an element in the s- or p-block of the periodic table and the charge on its ion; the names and formulae of NO_3^- , SO_4^{2-} , OH^- , NH_4^+ , HCO_3^- , Cu^{2+} , Zn^{2+} , Pb^{2+} , Fe^{2+} , Fe^{3+} ; formulae and names for compounds formed between these ions and other given anions and cations

EL(p) a description and comparison of the following properties of the elements and compounds of Mg, Ca, Sr and Ba in group 2: reactions of the elements with water and oxygen, thermal stability of the carbonates, solubilities of hydroxides and carbonates

EL(q) the term *ionisation enthalpy*; equations for the first ionisation of elements; explanation of trends in first ionisation enthalpies for periods 2 and 3 and groups and the resulting differences in reactivities of s- and p-block metals in terms of their ability to lose electrons

EL(r) charge density of an ion and its relation to the thermal stability of the group 2 carbonates

EL(s) the solubility of compounds formed between the following cations and anions: Li^+ , Na^+ , K^+ , Ca^{2+} , Ba^{2+} , Cu^{2+} , Fe^{2+} , Fe^{3+} , Ag^+ , Pb^{2+} , Zn^{2+} , Al^{3+} , NH_4^+ , CO_3^{2-} , SO_4^{2-} , Cl^- , Br^- , I^- , OH^- , NO_3^- ; colours of any precipitates formed; use of these ions as tests e.g. Ba^{2+} as a test for SO_4^{2-} ; a sequence of tests leading to the identification of a salt containing the ions above

EL(t) the terms *acid*, *base*, *alkali*, *neutralisation*; techniques and procedures for making soluble salts by reacting acids and bases and insoluble salts by precipitation reactions

EL(u) the basic nature of the oxides and hydroxides of Group 2 (Mg–Ba)

DF(k) the origin of atmospheric pollutants from a variety of sources: particulates, unburnt hydrocarbons, CO , CO_2 , NO_x , SO_x ; the environmental implications and methods of reducing these pollutants

ES(h) a description of the following physical properties of the halogens: appearance and physical state at room temperature, volatility, solubility in water and organic solvents

ES(k) the reactions between halide ions (Cl^- , Br^- and I^-) and silver ions (Ag^+) and ionic equations to represent these precipitation reactions, the colours of the precipitates and the solubility of silver halides in ammonia

ES(l) the preparation of HCl ; the preparation of HBr and HI by using the halide and phosphoric acid; the action of sulfuric acid on chlorides, bromides and iodides

ES(m) the properties of the hydrogen halides: different thermal stabilities, similar reaction with ammonia and acidity, different reactions with sulfuric acid

ES(n) the risks associated with the storage and transport of chlorine; uses of chlorine which must be weighed against these risks, including: sterilising water by killing bacteria, bleaching

A Level only Cl(i) the chemical reactions occurring during industrial processes

A Level only Cl(j) the following aspects of nitrogen chemistry:

- (ii) the appearance and names of the oxides of nitrogen, N_2O , NO , NO_2
- (iii) interconversion of the nitrate(V) ion, nitrate(III) ion, ammonium ion, oxides of nitrogen
- (iv) tests for nitrate(V) and ammonium ions

A Level only Cl(k) given examples of industrial processes:

- (i) costs of raw materials, energy costs, costs associated with plant, co-products and by-products
- (ii) the benefits and risks associated with the process in terms of benefits to society of the product(s) and hazards involved

Approaches to teaching the content

Atomic structure

The existence of sub-shells and orbitals is introduced early on in the module *Elements of life (EL)* as an immediate follow-on from the Bohr model of the atom taught at GCSE level. This can provide a lead-in to the history of atomic theory. Note that this relies heavily on learners understanding evidence from atomic emission spectra and ionisation enthalpies. It can therefore work well to introduce the more familiar Bohr model alongside the supporting evidence, including emission spectra. The evidence from first ionisation enthalpies can then be presented and used as a rationale for the need to adjust the 'GCSE model', thus leading into the discussion of sub-shells and orbitals.

(Note that this specification uses the term *ionisation enthalpy*, but learners are likely to encounter the term *ionisation energy* in other resources. Learners can treat these terms as equivalent.)

Intermolecular bonding and solubility

The three main types of bonding (ionic, metallic and covalent) are introduced in *EL*, as is the solubility of ionic compounds and periodic trends in melting and boiling points. However, intermolecular bonding is left until later in the course, in *The ozone story (OZ)*. This may result in difficulties when it comes to learners making sense of periodic trends, precipitation reactions, and indeed of the properties of ionic compounds that are discussed. Learners are told that covalent molecules are not charged and therefore have weak interactions between molecules, resulting in low melting and boiling points. At the same time, they are told that ionic compounds have very strong forces of electrostatic attraction within the lattice, resulting in high melting and boiling points. Without an understanding of the polar nature of water molecules, learners are then expected to take at face value the fact that many ionic substances dissolve readily in water.

Teachers could instead choose to introduce intermolecular bonding in *EL* to help learners make sense of periodic trends and solubility. One of the traditional reasons for avoiding this approach has been that the atomic structure and bonding topics are already very 'dry' and theoretical subjects involving little practical work. However, a qualitative comparison of the energy needed to break apart an ionic lattice versus the energy released on ion-dipole bond formation will help set learners up for a more quantitative comparison later in the course. In the discussion of the solubility of halogens in water versus non-polar solvents (in *Elements from the sea, ES*), similar basic explanations of molecule polarity should be used and meaningless phrases such as 'like dissolves like' should be avoided.

More detailed coverage of intra- and intermolecular bonding is given in the *Bonding and structure delivery guide*.

Thermal decomposition reactions

The thermal decomposition reactions of Group 2 carbonates are often covered at GCSE level, but with very little treatment of the relative stability of the compounds. In *EL*, learners learn that carbonates become less stable with higher charge density of the cation, causing distortion of the carbonate ion. The trend in charge density is connected to ideas about atomic structure – smaller ions have higher charge density.

Molecular ions, acids and salts

The formation of ions from atoms within the s- and p-blocks should be fairly straightforward for learners (although oversimplification by using the 'octet rule' can cause its own difficulties – see below). If learners are not taught anything about d-block elements at this stage, it can be rather arbitrary to introduce the charges on ions such as zinc, copper and iron. However, an overtly detailed treatment of the electronic structure of d-block metals could introduce too much confusion at this stage as it does not explain why copper readily forms compounds containing 2+ ions. It will probably suffice to say that many transition metals form ions of different charges because there are only small differences between the ionisation energies of electrons in their outer shell.

Molecular ions have always been a sticking point for some learners, perhaps because they are overly reliant on the idea of the octet rule and electron transfer to rationalise the charges on ions originating from single atoms and therefore have no system for dealing with such a complex entity as the nitrate ion. One way of dealing with this is introducing the idea of ion formation by loss or gain of a hydrogen ion, which can link in with the study of acids and bases. Learners should already be somewhat familiar with the idea that hydrogen chloride molecules dissociate into hydrogen ions and chloride ions when added to water, and they should be able to draw 'dot-and-cross' diagrams and equations to represent this process. They should then be able to extrapolate from here to the dissociation of water, H_2SO_4 and HNO_3 . By relating the formation of these anions to the loss of one or two hydrogen ions they are more likely to remember the charge on these ions.

The ammonium ion should have already been introduced during the discussion of dative covalent bonding, earlier in *EL*. Ammonia's action as a base can now be illustrated in the reaction between ammonia and water molecules to produce hydroxide ions. (Although pH calculations are not required at this stage, a qualitative treatment of pH as a measure of hydrogen ion concentration would be useful here.)

The rules for solubility of compounds, and the procedures for preparation of soluble and

insoluble salts, can be quite bewildering for learners to take on board. Encourage them to spot patterns – in particular the ions which always form soluble compounds. The insolubility of other cation/anion combinations should be linked closely with the tests for those ions. Another pattern that may be useful to point out to learners would be the link between the difference in cation/anion size and solubility for Group 2 compounds. The disparate trends in solubility for hydroxides and carbonates are extremely difficult to rationalise, even when hydration energy and lattice enthalpy are taken into account in the second year of the A Level course. However, pointing out that the bigger the difference between sizes of ions, the more likely the compound is to be soluble, should help learners to remember. This rule also applies for the solubility of silver halides.

Practical procedures

Practical procedures for identification of unknown compounds should be approached via a mixture of straightforward tasks with a high level of instruction alongside more challenging, open-ended tasks which demand more creative approaches. Learners should be questioned regularly about each step of a procedure, such as why nitric acid is used rather than any other acid during halide tests, or why barium chloride cannot be used independently to identify sulfate. During salt preparation, learners should also be encouraged to justify and evaluate each stage of the procedure.

Titration is used in the preparation of soluble salts, and can be introduced after learners have already learned to use the technique to calculate unknown solution concentrations. When reintroducing the technique in the preparation of soluble salts, learners could be asked (and given example equipment) to come up with their own experimental design rather than sticking to a rote set of instructions, as a means of starting the development of investigative practical skills.

Ionic equations

Learners should be encouraged to identify the formula of the product and write the ionic equations in salt preparation practicals. A 'backwards' approach can be used, finding the formula first, then separating this into its component ions, rather than worrying about the exact composition of the initial mixtures. Approaches where learners can practise removing spectator ions themselves would also be helpful – for example, learners could use personal whiteboards or ions on cut-out cards. This allows them to make their own mistakes and to visualise what is happening in the equation more clearly.

Ionic equations are then revisited during acid–base reactions. Here it should be emphasised that there are still ions that remain unchanged and in solution, and the similarities with precipitation reactions highlighted: new bonds are formed, this time between hydrogen ions and hydroxide ions. By the time learners are attempting ionic equations in the context of halogen chemistry in *ES*, they should be more practised in the art of identifying

spectator ions. Once redox equations have been covered, it is important to give learners an opportunity to practise mixed questions where the type of chemical reaction needs to be identified by the learner, so that they create their own context.

Common misconceptions or difficulties learners may have

Chemical vocabulary and conventions

In the transition from GCSE to A Level, many learners are thrown off by the fact that they appear to be being asked the same questions that they were asked at GCSE, but that their 'GCSE style' answers are no longer getting them the marks. Learners often start the course with a surprisingly limited understanding of even the most fundamental of terms – such as atom, ion or molecule – and it is worth spending time finding out where the main misconceptions lie. Crosswords may seem trivial but they help to reinforce definitions, as do simple games like Pictionary or Taboo – all can be used to reinforce key vocabulary.

Concept mapping is a useful tool: provide learners with a sheet of A4 or A3 paper that already has the key terms for a topic written randomly across it. Learners should make connections between words that they see as linked, but only if they write an explanation for the link. This is a much more effective and challenging exercise than producing a 'spider diagram' – where learners are encouraged to separate their ideas into sections, rather than link them. It can also be very valuable as there are often one or two words in a topic where learners cannot see a connection, identifying areas that might need revisiting.

It is easy to forget, as teachers, how many basic rules and conventions we take for granted. While some things are explicitly taught (such as the rules for naming simple –ides and –ates), often learners are unaware that (with the peculiar exception of hydroxides) compound formulae tend to list elements in order of increasing electronegativity (or, for learners who don't yet know about electronegativity, from left to right on the periodic table).

Although probably familiar with the endings –ide and –ate, learners don't always appreciate that these are always terms for anions. This is a very useful distinction for them to be able to make when introduced to hydrogen compounds, and would hopefully avoid confusion over words in the halogens topic. It is also worth pointing out that ammonia becomes 'ammonium' when it gains a positive charge, giving it the same ending as more familiar ions such as potassium and lithium.

Although learners should be relatively familiar with the use of chemical formulae and symbol equations by the start of A Level, there are certain conventions which can need clarification. The formulae of lithium chloride and hydrogen chloride look very similar and, other than state symbols, make no reference to the fact that one refers to the empirical formula of a giant lattice and the other the formula of a discrete molecule. Similarly, no distinction is made between elements that exist as giant lattices (C, Mg) and those that exist as atoms.

Finally, state symbols are often seen as something of an afterthought (or something that learners only include when asked for), meaning that they do not always appreciate the differences between, for example, HCl as a gas and HCl in solution. This means that they can find ionic equations rather arbitrary as they are instructed to split up HCl , but not water, into separate ions.

As the course progresses and the volume of specialist vocabulary begins to grow, it becomes increasingly more likely that learners will confuse terms that seem to mean similar things. In particular this can be a problem for 'overlapping terms' such as base/alkali or clear/colourless. Venn diagrams could be used here to allow learners to see examples of situations where either both terms, or only one term, applies. Confusion can also be a problem for properties of elements or compounds which have similar definitions or exhibit similar trends, such as first ionisation enthalpy vs electronegativity. For these confusions, it is worth asking learners to produce lists of the main similarities and differences between the two terms.

Some terms that were (if defined at all) considered to be exclusive of each other, such as base and salt, can cause difficulties during the preparation of salts. In one preparation learners are told to prepare 'an insoluble carbonate salt', and in another learners are told to use carbonate as a base to prepare a soluble salt by reaction with an acid. It is worth discussing how a carbonate compound can be considered as both a base in its own right, and as the product of reaction of the hydrogen carbonate ion with a base.

Finally, learners run into difficulties when non-specific vocabulary is believed to mean something very unchanging and specific. Solubility is a classic example of this – use of 'soluble' and 'insoluble' may help to simplify matters when learning simple qualitative tests for ions, but care must be taken to avoid these terms becoming concreted, as in the second year of the course in *Oceans (O)* learners will have to understand that all compounds are soluble to a greater or lesser extent when learning about the solubility product. When discussing solubility in *EL*, learners could carry out their own research into solubility values for particular compounds so that they see the numerical data associated with the terms, and understand the conditions used.

Atomic structure

At GCSE the subject of atomic structure is often introduced at a fairly late stage in the study of chemistry and there are several main consequences of this. Firstly, existing misconceptions and frameworks are often deeply rooted and difficult to overcome. The use of vocabulary may become sloppy as learners, without any real understanding of what atoms, ions or molecules are, use the words interchangeably and often incorrectly. Finally, the importance of this topic in providing an underpinning for other topics is often overlooked.

At A Level, the topic is (quite rightly) prioritised and positioned at the start of the specification. The Bohr model of the atom is revisited and its familiarity can sometimes

lead learners and teachers alike to rush through the topic, leaving existing misconceptions unaddressed. The introduction of sub-shells and orbitals is a challenge for learners and they can often become demotivated and disheartened at the prospect that 'everything we learned at GCSE is wrong'. Many learners even come into A Level 'pre-warned' by previous teachers or older learners that they will have to throw out all their existing knowledge.

The frustration that learners encounter is due to a lack of appreciation that what they are taught is not 'how atoms are' but simply a model that best explains empirical observations. Learners should be encouraged to study the history of the atomic model, not for its own sake, but in order to see when and why our ideas about atomic structure had to change in order to account for new evidence. It may help to give learners some real life examples of where we use models all the time – the London Underground map is a great one to use as it is an example most are familiar with. Here the diagram does not look anything like the complicated reality, but it is sufficient for most people's needs in getting from one station to another.

Formation of ions

Although learners do not usually have a problem with working out the corresponding charges on ions formed from elements within the periodic table, a tendency to become overly reliant on the 'octet rule' can develop which causes a myriad of problems later in the course. By teaching that the noble gas configuration is more stable 'because it has a full outer shell', learners become removed from explanations for reactivity in terms of energy changes and instead state that all atoms become more stable if they have a full outer shell, and that elements react to form compounds in order to gain a full outer shell.

Both these ideas are at odds with the teaching at A Level and even GCSE. Saying that sodium and chlorine react together in order to form full outer shells is a nonsense when learners are taught that in sodium metal the outer electrons are already delocalised, and that chlorine exists as diatomic molecules. Similarly, the idea that a sodium ion is more stable than a sodium atom does not correlate with the idea that ionisation is always an endothermic process. However, despite these disparities it is not uncommon for the 'full outer shell' reasoning to persist in learners and it presents challenges when it comes to explaining why transition metal atoms can form ions in multiple oxidation states, or why innumerable other reactions occur at all!

When teaching ion formation, it is useful to completely separate the process from the formation of ionic compounds at the start. The ions should be referred to as the 'most likely' ions that form and the energetic reasons for this examined in terms of ionisation enthalpies. Examples of reactions should be given where ionic compounds are formed with no electron transfer at all – such as evaporation of water from a salt solution, or precipitation reactions – so that learners can see the processes do not need to be linked. When complex enthalpy cycles are introduced in *O*, it is extremely useful to use these not only to find the lattice

enthalpy of existing compounds, but also to calculate the enthalpy of formation for unstable compounds such as MgCl .

Precipitation reactions

Precipitation reactions are conceptually very difficult for learners to understand. As well as there being many microscopic events behind the process, even the macroscopic observations can be hard to interpret as learners do not always make the link between opacity of a mixture and the formation of a solid. Any uncertainty in terminology should be highlighted when discussing the process as it is not uncommon for learners to use terms such as 'clear precipitate' or 'cloudy solution'!

Visual representations of the process of precipitation should be used frequently – there are several good animations and presentations available online – and, when more familiar with the concept, learners should be allowed to draw their own representations. These should include diagrams of the starting solutions as well as the final mixture. When learners produce soluble salts from either acid/alkali neutralisation or the excess method, it would also help to include visualisations here so that learners can clearly see the similarities and differences.

Atmospheric chemistry

In the module *Developing fuels (DF)*, learners are introduced early to the ideas of acid rain and climate change and, indeed, have most likely covered the topics in some detail in their various GCSE subjects. The fact that these are 'crossover topics' that appear in other subjects (such as biology and geography) can be a mixed blessing as learners struggle to use the specific terminology demanded of a chemistry course. The effects of acid rain are often described in too vague a manner, such as 'destroys habitats' or 'causes erosion' – learners need to be encouraged to link the damaging effects of pollutants to their chemical behaviour, for example 'reacts with and erodes metals/limestone'.

There is quite a prevalent confusion amongst learners regarding the correct use of terms such as 'harmful', 'toxic', 'corrosive' and 'irritant' – with innocuous substances such as carbon dioxide labelled as 'harmful' due to their damaging effects on the climate, and acids being referred to as toxic because they 'kill trees and fish' (it is perhaps worth questioning learners as to the contents of their stomach next time they describe hydrochloric acid as being toxic).

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course.

Nitrogen chemistry (A Level only)

The interconversion of nitrogen compounds (taught at the beginning of the second year of the A Level course in *The chemical industry, CI*) as part of the nitrogen cycle is an area which not only crosses over into many other areas of the chemistry syllabus, but also into A Level biology. The common names for nitrate(V) and nitrate(III) should be pointed out as

learners will not always make the connection (in fact, some learners do not even realise that the oxidation and reduction processes studied in biology are the same as those studied in chemistry). This is an excellent part of the course to revisit oxidation numbers, and also the difference between a species gaining *hydrogen* as opposed to gaining *hydrogen ions*.

Nitrogen chemistry provides an excellent opportunity to revisit and bring together concepts such as multiple covalent bonding, dative bonding and shapes of molecules. Bond lengths and enthalpies can be discussed – both in terms of the low reactivity of the dinitrogen molecule, and as evidence for the delocalised nature of nitrate ions. The oxidation numbers of nitrogen in its various compounds can also be linked with the electronegativity of the atoms involved, with the oxidation number of the nitrogen depending on how many bonds it forms to more or less electronegative elements.

Bonding and intermolecular bonding

Changes in the nature of bonding play such a key role in chemical reactions that it is no surprise that the concept should be revisited on numerous occasions throughout the course. Solubility and precipitation, the physical trends in Group 2 and the halogens, periodic trends across Periods 2 and 3, or the changes in state that result from reduction of nitrate ions to dinitrogen molecules are just some of the examples where ideas about bonding need to be made specific.

Chemical bonding is such a key theme, in fact, that it can be argued that every topic can and should include questions that reinforce learners' understanding of it. If this seems like an onerous task, a more valuable cognitive exercise for learners at the end of a topic would be to ask them to create their own questions to show how bonding ideas fit into the content covered.

Energy and entropy changes

The endothermic nature of the decomposition of carbonates make it an ideal candidate for the application of a Hess cycle in order to determine enthalpy changes. If a number of different carbonates are compared, the link can be made between the ease of decomposition and the magnitude of the positive enthalpy change. In the second year of the course, carbonate decomposition reactions also provide excellent exercises in determining feasible temperatures of reactions based on $\Delta_{\text{tot}}S$ calculations.

(A Level only) Trends in the solubility of Group 2 hydroxides and carbonates can be revisited in the application of Hess cycles to $\Delta_{\text{sol}}H$ calculations. Although it is difficult to obtain accurate $\Delta_{\text{hyd}}H$ enthalpies for the ions involved, qualitative comparisons can be made which go some way to explaining the trends. As discussed in the section on ion formation above, calculation of Δ_fH values can be used as a justification for the formation of compounds containing only one type of ion for elements within the s- and p-blocks.

(A Level only) Learners should be able to use ideas about charge density to explain why magnesium oxide, for example, has a higher lattice enthalpy (or 'stronger electrostatic attractions within the lattice' if lattice enthalpy has not been introduced) than barium oxide. It should follow, then, that magnesium oxide is energetically more likely to form than barium oxide and hence magnesium carbonate is less stable than barium carbonate. Barium carbonate, by the same argument, is of course easier to break down due to its smaller lattice enthalpy – however, the effect of the cation here is smaller since the carbonate ion is already very large, weakening the ionic attractions. The distortion of the anion can then be introduced at a later stage, when learners are more familiar with the comparisons between experimental and theoretical values for lattice enthalpy.

Redox and transition metals (A Level only)

Learners will have already carried out many reactions involving d-block metals before they are explicitly studied on the course in the module *Developing metals (DM)*. When introducing detailed electronic configurations at the start of the course in *EL*, it may be preferable to include the d-block metals. The advantages are that learners have a more complete picture that allows them to see why metals such as iron can form ions of varying oxidation numbers, and why iron(II) compounds are often spontaneously oxidised to form iron(III). The main disadvantage is that, if oversimplified, learners could be confused by the exceptions presented by copper and chromium.

Again, learners should be encouraged to consider both the energy needed to form a cation, along with the energy released on formation of an ionic compound, to justify the presence of a multitude of different oxidation states for transition metal compounds. The colours of hydroxide precipitates can be revisited and learners can now be provided with an explanation for these. The introduction of catalysis in *DF* can now be more fully explained utilising ideas about partially filled d orbitals. It is important at this stage that the flame colours and atomic emission spectra studied in *EL* are not confused with the absorption of visible light caused by the splitting of the d sub-shell.

Atmospheric chemistry

In *OZ*, learners study the reactions that occur in the formation and destruction of the ozone layer. It is definitely worth at this stage going back over the ideas studied in *DF* about atmospheric pollution. Learners need to be made aware of the distinctions in particular between the problems causing climate change and those leading to ozone depletion. Since both involve the absorption of radiation in the atmosphere, learners become easily confused. The fact that the same gas can have different environmental impacts depending on its location in the atmosphere should also be stressed – for example, the detrimental effect of ozone in photochemical smog vs its beneficial effect in the stratosphere.

Chemical misconceptions II – Definitions in chemistry (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00001088/definitions-in-chemistry>

This resource is an ideal tool to elicit learners' misconceptions and understandings of basic terms (element, compound, atom, molecule) right at the start of the course.

Build an atom simulator (PhET, University of Colorado)

<http://phet.colorado.edu/en/simulation/build-an-atom>

This simulation can be used either independently by learners or as the focus of a class activity via an interactive whiteboard or projector. A number of different worksheets are available in the links below the simulation but in particular it can be used to help learners visualise the different properties of subatomic particles more clearly.

Analogy for the atom (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00001100/an-analogy-for-the-atom>

These worksheets form the basis of an activity in which learners consider the strengths and weaknesses of using analogies when describing the structure and behaviour of atoms. It encourages them to think in more detail about the commonly accepted 'solar system' analogy often used to explain electron shells.

Atomic structure Checkpoint Task

[This task](#) provides learners with a selection of key scientists, in chronological order, accompanied by a brief reminder of their contributions towards the atomic structure model. Learners are also given a selection of statements which describe experimental observations. Working in groups of two or three, learners read through the statements and decide upon the **simplest** model of the atom that is still sufficiently detailed to explain the observation. For example, the production of a beam of charged particles from the heating of a metal can be explained simply by the fact that atoms contain electrons, but periodic properties can only be explained if the Bohr model of the atom is used.

Models of the hydrogen atom (PhET, University of Colorado)

<https://phet.colorado.edu/en/simulation/hydrogen-atom>

This simulation compares the real observations obtained from irradiating hydrogen atoms with light with the expected observations generated by each model of the atom. Worksheets and teaching resources are provided below the simulation on the web page. The De Broglie and Schrödinger models are probably only helpful for

Rutherford experiment simulation (Michael W. Davidson and The Florida State University)

<http://micro.magnet.fsu.edu/electromag/java/rutherford/>

This website simulates the Rutherford 'gold foil' experiment and is accompanied by a clear explanation of how the experiment challenged the existing atomic model.

Element battleships Lesson Element

<https://www.ocr.org.uk/Images/170279-element-battleships-activity.docx>

<https://www.ocr.org.uk/Images/170278-element-battleships-teacher-instructions.pdf>

This activity is designed to help learners to become more familiar with the use of notation used to depict electronic configurations at both GCSE and AS Level. The attached 'Battleship Grids' can be laminated or placed inside a plastic wallet to allow repeated use. Learners try to find the location of their opponents' 'battleships' on a grid based on the first twenty elements of the periodic table. The catch is that learners must use the electronic configurations rather than the names of elements (e.g. 2,8,1). This encourages them both to practise saying the configurations, and to associate the configurations with position on the periodic table. This resource can then be adapted for the introduction of sub-shells at AS Level, with learners using the s, p and d notations on a grid that also includes d-block elements.

Gridlocks games – Atomic structure (Royal Society of Chemistry)

Mass number and atomic number:

<http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/atomic-structure.html>

Subatomic particles: http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/SubAtomicParticles16_19.html

Sub-shells and orbitals: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/sub-shells.html>

These games are designed around the principle of Sudoku puzzles. The minimum requirement is that learners complete the first table on each worksheet as this then consolidates their knowledge of atomic number and subatomic particles. The Gridlock puzzles themselves can be challenging for learners who are not familiar with the concept of Sudoku, but other learners can explain. By allowing only a fixed length of time to work on the puzzles learners often want to go back to them at a later stage, providing motivation to revise the topics. The games can be completed online or printed.

Starters for ten (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00000954/starters-for-ten#!cmpid=CMPO0001407>

These short worksheets can be used as a starter to test knowledge learned in a previous lesson, or alternatively can be used as a plenary activity. There are sections on atomic structure and periodic trends.

Interactive periodic table (Royal Society of Chemistry)

<http://www.rsc.org/periodic-table>

This periodic table is a useful way for learners to explore periodic trends in melting and boiling points, electronegativity and ionisation energy. As well as being displayed on the table, clicking on individual elements allows learners to collect numerical data which can then be used in graphical exercises.

Trends in physical properties – Group 2 and Period 3 (Creative Chemistry)

<https://www.creative-chemistry.org.uk/alevel/core-inorganic/periodicity/trends8>

<https://www.creative-chemistry.org.uk/alevel/core-inorganic/periodicity/trends4>

This website groups together the trends occurring down Group 2 (elements only) and across Period 3. Data are displayed both as graphs and in table form and each trend includes an explanation. The pages can also be printed in pdf format.

Element cards Lesson Element

<https://www.ocr.org.uk/Images/208117-element-cards-activity.pdf>

Two activities are suggested in which learners use questions about the properties of elements to work out the card their opponent is holding. These activities can be used to reinforce ideas about trends in periods and groups, and the characteristic properties within groups.

Chemical misconceptions II – Predicting the melting temperature of carbon (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00001093/predicting-the-melting-temperature-of-carbon>

This worksheet should be introduced before learners start to study periodicity. It provides a useful tool to bring up any misconceptions or misunderstanding learners may have picked up at GCSE level. Learners examine more closely the relationship between structure and physical properties, and also about the way giant substances are represented in chemical equations. This resource thus brings together ideas about trends in properties and ideas about structure and bonding.

Reaction of Group 2 elements with water

<http://www.youtube.com/watch?v=B2ZPrg9IVe0>

This is a very short but clear video demonstrating the trend in reactivity of Group II elements with water. This can also be carried out as a class practical or demonstration but the results are often obscured by the presence of thick oxide layers.

Ionisation energy – True or False? (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00001101/ionisation-energy>

This activity is quite challenging and is designed to elucidate common misconceptions and to prompt discussion. It is best to allow learners to discuss the answers in small groups as this will make them challenge each other rather than simply guessing. The answers provided with the worksheet include explanations and discussion points.

Problem based practical activities – Carbonate rocks! (Royal Society of Chemistry)

<https://edu.rsc.org/download?ac=12886>

In this activity, learners need to link together their knowledge of the decomposition of metal carbonates with their ability to devise an experimental procedure and to analyse empirical data. After answering a series of 'pre-lab' questions, learners are presented with the problem of identifying four different samples containing metal carbonates or hydrogen carbonates.

Chemical misconceptions II – Precipitation (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00001096/precipitation>

Another excellent probe of learners' misconceptions from the Royal Society of Chemistry. Three worksheets help learners to make sense of what is happening during a precipitation reaction by considering the individual particles present in the initial solutions. The worksheets aim to avoid the common misconception by learners that ionic solids are formed only when electrons are transferred.

Gridlocks – Ions and solubility (Royal Society of Chemistry)

More Sudoku-like puzzles designed to reinforce and apply knowledge.

Ionic formulae 1: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/IonicFormulae1.html>

Ionic formulae 2: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/IonicFormulae2.html>

Anion tests: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/AnionTests.html>

Hydroxide precipitates: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/HydroxidePrecipitates.html>

Halide ion tests: <http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/HalideIonTests.html>

Reactions of sodium halides with concentrated sulfuric acid:
<http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/HalidesAndH2so4.html>

Investigating the solubility of silver halides (Practical Chemistry)

<https://edu.rsc.org/resources/solubility-trends-of-metal-halides-on-microscale/1888.article>

A microscale class practical demonstrating the trends in solubility of Group 1, Group 2 and silver halides.

Solubility of sulfates and carbonates (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00000512/the-periodic-table-solubility-of-sulphates-and-carbonates-of-groups-1-and-2>

Another microscale class practical investigating the solubility of sulfates and carbonates of Group 1 and Group 2 metals.

Acid–base solutions simulator (PhET, University of Colorado)

<http://phet.colorado.edu/en/simulation/acid-base-solutions>

This simulation can be used to help learners visualise the link between strong and weak acids and dissociation, along with the effects of concentration on pH and the processes that occur on a molecular level during neutralisation.

Making and testing ammonia (Practical Chemistry)

<https://edu.rsc.org/resources/making-and-testing-ammonia/433.article>

A class practical in which learners generate small quantities of ammonia and then test its solubility in water and basic properties.

Ammonia fountain demonstration (Practical Chemistry)

<https://edu.rsc.org/resources/ammonia-fountain-experiment/979.article>

This demonstrates very clearly the high solubility of ammonia in water and the basic nature of the solution formed. The set-up is quite complicated and requires a fume cupboard – an alternative video link is given below.

Ammonia fountain video

<https://www.youtube.com/watch?v=-z4liRirdv0>

A video demonstrating the high solubility of ammonia in water, as an alternative to the demonstration above. The video does not show the preparation of ammonia.

Making magnesium carbonate – preparation of an insoluble salt by precipitation (Practical Chemistry)

<https://edu.rsc.org/experiments/making-magnesium-carbonate-the-formation-of-an-insoluble-salt-in-water/431.article>

Class practical demonstrating the precipitation method of salt preparation. Although perhaps not so visually striking as the preparation of lead iodide, this is certainly preferable in terms of safety considerations!

Preparing a soluble salt by titration (Practical Chemistry)

<http://www.nuffieldfoundation.org/practical-chemistry/titrating-sodium-hydroxide-hydrochloric-acid>

Learners titrate sodium hydroxide with hydrochloric acid to produce a solution of sodium chloride, then evaporate the water. This practical assumes no knowledge of solution concentrations or mole calculations – an indicator is first used to determine the correct titre needed to neutralise the hydroxide, then these measurements are used to produce a salt solution free of indicator. This also means that solutions do not need to be prepared to a high degree of accuracy.

Preparing a soluble salt by the excess method (Practical Chemistry)

<https://edu.rsc.org/experiments/preparing-salts-by-neutralisation-of-oxides-and-carbonates/1762.article>

Magnesium carbonate and copper(II) oxide are reacted with sulfuric acid to produce the corresponding sulfates. It may be desirable, depending on lesson time, to carry out both experiments in separate lessons, or to split the class into different groups and have each group only carry out one preparation.

Which set of ionic compounds? (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00000680/which-set-of-ionic-compounds>

This is a 'creative problem solving' activity in which learners work in pairs or groups to plan a procedure that would help them identify four unknown ionic compounds. They can then carry out the procedure if given the compounds.

Four solutions (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00000664/four-solutions>

Another problem solving practical activity, in which learners are given four unlabelled solutions. They are told the solutions are copper(II) chloride, hydrochloric acid, silver nitrate and sodium nitrate, and need to devise an experimental procedure that will help them identify each one.

Gridlocks – Atmospheric chemistry (Royal Society of Chemistry)

Pollutants in air: http://www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-2/PollutantsInTheAir14_16.html

Some reactions of sulfur dioxide (Royal Society of Chemistry)

<http://www.rsc.org/learn-chemistry/resource/res00000534/some-reactions-of-sulphur-dioxide?cupid=CMP00000605>

This is a microscale experiment that involves the generation of small quantities of sulfur dioxide in a closed petri dish. The gas is then allowed to diffuse into droplets containing universal indicator, acidified potassium manganate and a mixture of iodide and iodate. The acidic nature of sulfur dioxide, as well as its action as a reducing agent, can then be investigated.

Classic chemistry experiments (Royal Society of Chemistry)

RSC's classic book provides instructions for a wide range of class practical work. The book itself can be purchased through the link below, but some experiments are available for free online.

<https://edu.rsc.org/resources/collections/classic-chemistry-experiments>

The links below go straight to each experiment.

25. Reactivity of Group 2 metals

<http://www.rsc.org/learn-chemistry/resource/res00000409/the-reactivity-of-the-group-2-metals>

51. Reactions of calcium carbonate

<http://www.nationalstemcentre.org.uk/elibrary/resource/9666/reactions-of-calcium-carbonate>

66. The effect of heat on metal carbonates

<http://www.rsc.org/learn-chemistry/resource/res00000450/the-effect-of-heat-on-metal-carbonates>

80. Testing salts for anions and cations

<http://www.rsc.org/learn-chemistry/resource/res00000464/testing-salts-for-anions-and-cations>

89. Halogen compounds

<http://www.rsc.org/learn-chemistry/resource/res00000473/halogen-compounds>

Revision crossword Lesson Elements

Printable crosswords on the following topics are available:

- [Atomic structure](#)
- [The s-block elements](#)
- [Periodicity](#)
- [The halogens](#)

Ferocious elements (Teachers TV)

<http://www.tes.co.uk/teaching-resource/Teachers-TV-Periodic-Table-Ferocious-Elements-6038964/>

This is a fairly simplistic video at the start and initially goes through the trends in reactivity of Group 1 metals. Teachers may wish to skip forward to 9.20, where the video starts to compare the physical properties and reactivity of halogens. The reactions of iodine, bromine, chlorine and fluorine with hydrogen are demonstrated along with some more spectacular reactions of fluorine with other metals and non-metals.

Reaction of hydrogen and chlorine

<http://www.youtube.com/watch?v=50eKJZKfMBg>

Video of the reaction between hydrogen and chlorine.

Microscale reactions of chlorine (Practical Chemistry)

<https://edu.rsc.org/resources/microscale-reactions-of-chlorine/530.article>

Chlorine is generated on a small scale in a petri dish, and is used to investigate its properties including reaction with water and displacement reactions with halide salts.

Formation of silver halide precipitates

<http://www.youtube.com/watch?v=8RmVwz2fNGc>

A video showing the colours of the different silver halide precipitates (not the solubility).

Properties of hydrogen chloride (Practical Chemistry)

<https://edu.rsc.org/resources/the-properties-of-hydrogen-chloride/834.article>

This is a particularly good experiment for demonstrating the solubility of hydrogen chloride, but the fountain demonstration should be practised first and always carried out in a fume cupboard. The class practical is a good reminder of simple acid reactions and can be carried out independently of the demonstration.

Alternatively, this demonstration can be shown on video:

<http://www.youtube.com/watch?v=ttF0atEChG8>

Reactions of solid halides with concentrated sulfuric acid

<https://www.youtube.com/watch?v=zOA-03SOYX8>

This video is a useful alternative to demonstrating these experiments in the laboratory, particularly in those situations where a fume cupboard is not available.

Nitrogen chemistry tarsia puzzle Lesson Element (A Level only)

<https://www.ocr.org.uk/Images/208123-nitrogen-chemistry-tarsia-puzzle-activity-teacher-instructions.pdf>

When the correct pairings of 'question and answer' sides are made, the puzzle produces a 3 × 4 rectangle (blank sides are a clue to the sides of the rectangle). This is useful revision for the oxidation states, names and formulae of different nitrogen-containing species.

Although it may seem difficult to put esoteric concepts such as detailed atomic structure into context, there are numerous resources that allow learners to examine the empirical evidence for atomic structure models. In *Elements of life (EL)*, the importance of nuclear composition on the 'identity' of elements is examined in the context of nuclear fusion in stars. Extension can be provided by discussion radioactivity and its applications, for example in carbon-dating.

The work of Mendeleev can be used as a context for periodicity and it should be emphasised that the modern periodic table was derived from periodic properties alone, not from any real understanding of atomic structure itself.

The periodic variation in properties for Period 2 and 3 elements can be put into the context of their everyday uses and of the way they are extracted. For example, the fractional distillation of air can be used as an illustration of the differing boiling points of nitrogen, oxygen and argon; the relative melting points, reactivity and conductivity of metals can be applied to the context of how those metals are used.

The reactions of Group 1 and 2 metals and their compounds are straightforward to illustrate with practical activities but can also be put into context in relation to their uses and occurrences in real life. Solubility rules are particularly relevant to real life contexts; learners can examine the causes and treatments for water hardness, the mineral deposits that cause 'stalactites', the way many drugs are created as sodium salts to aid absorption into the bloodstream, or the pros and cons of using extremely soluble fertilisers such as ammonium nitrate.

The thermal decomposition of carbonates can be linked with atmospheric chemistry if the atmospheres of Mars and Venus are compared with that of the earth. The history of the Venusian atmosphere provides an interesting example of a 'runaway greenhouse effect' caused by positive feedback. The chemical 'scrubbers' used to remove acidic oxides from power stations also helps to put acid-base reactions into context, as can the application of Group 2 hydroxides and carbonates to acidic soils and lakes.

In *Elements from the sea (ES)* the applications of redox and displacement reactions are illustrated by the industrial extraction of halogens from sea water or from salt rock deposits. Whether a halogen is extracted by electrolysis or by displacement is determined by its reactivity and power as an oxidising agent, just as in the extraction of metals. It may be worth discussing with learners why hydrochloric acid is such a commonly used industrial acid, rather than hydrobromic or hydroiodic – this can be linked to the reducing power of the halide ions.

A Level only. There are many common chemicals that can be used to put industrial processes into context, as required in *The chemical industry (CI)*. Many learners learn the nitrogen cycle without realising the massive significance that the Haber process plays in replenishing

nitrogen in the soil – without inorganic fertilisers the planet would be unable to sustain anywhere near the current human population. The industrial production of nitric acid via ammonia puts the redox reactions of nitrogen into context and the production of nitrous oxides by lightning provides a link with the production of nitrous oxides within internal combustion engines. The use of ammonium nitrate as a fertiliser links ideas about acid-base reactions and solubility.

How carbon dating works (HowStuffWorks.com)

<http://science.howstuffworks.com/environmental/earth/geology/carbon-14.htm>

This website will help to put the formation and decay of isotopes into a real world context and provides a very clear account of how radioactive carbon-14 is formed in the atmosphere and incorporated into living organisms.

Star death and the creation of elements (Wonders of the Universe, BBC)

<http://www.youtube.com/watch?v=DEw6X2Bhly8>

Relatively simple but nice explanation of the stages that lead to the formation of elements in stars, delivered by Brian Cox.

Chlorine: ensuring rail transportation safety (American Chemistry Society)

<http://www.americanchemistry.com/Policy/Rail-Transportation/Issue-Brief-on-Chlorine-Rail-Transportation-Safety.pdf>

This document can be used as a comprehension exercise in which learners need to extract information from the article and summarise in their own words – a good exercise for developing chemical literacy skills. In particular learners should use the article to help weigh up the risks associated with chlorine, the reasons necessitating its transport and the control measures put in place to minimise hazards.

Haber process crossword (Creative Chemistry)

<https://www.creative-chemistry.org.uk/funstuff/xword/haber>

Can be completed online using a Java plugin or can be downloaded as a pdf file. Summarises the conditions and raw materials needed for the Haber process.

Centre for Industry Education Collaboration (University of York)

<http://www.ciec.org.uk/secondary.html>

This website lists a number of useful resources for the post-16 study of industrial applications of chemistry. In particular the online book 'Essential Chemistry Industry' is extremely useful to use as a starting point for learners to investigate discrete chemical processes or materials and contains some excellent information on the use of catalysts. 'Chemistry in Action' contains some interactive teaching units aimed at getting learners to apply their knowledge and solve industry-related problems.

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