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A LEVEL
Transition Guide

CHEMISTRY A

H432
For first teaching in 2015

KS5–HE Focus
Bonding

Version 2

www.ocr.org.uk/chemistry

Contents

A LEVEL
CHEMISTRY A

Key Stage 5 to Higher Education Transition guides focus on how a particular topic is covered at the different key stages and provide information on:

- Differences in the demand and approach at the different levels;
- Useful ways to think about the content at Key Stage 5 which will help prepare students for progression to studying the subject in Higher Education;
- Common student misconceptions in this topic.

Transition guides also contain links to a range of teaching activities that can be used to deliver the content at Key Stage 5 to Higher Education and are designed to be of use to teachers of both key stages. Central to the transition guide is a Checkpoint task which is specifically designed to help teachers determine whether students have developed deep conceptual understanding of the topic at Key Stage 5 and assess their 'readiness for progression' to Higher Education content on this topic. This checkpoint task can be used as a summative assessment at the end of Key Stage 5 teaching of the topic or by Higher Education lecturers to establish their students' conceptual starting.

Key Stage 5 to Higher Education Transition Guides are written by lecturers at named Higher Education Institutes.

This Transition Guide has been developed in collaboration with David Read from the University of Southampton.

Key Stage 5 Content

A Level Chemistry Criteria Content

- Interpretation of ionic and covalent bonding in terms of electron arrangements.

Also relates to other criteria including:

- Shapes of simple molecules
- Single and double covalent bonds
- **The structure of, and the bonding in, benzene.**

NB other concepts in organic chemistry are also relevant here, including the concept of E/Z isomerism and the electrophilic addition and substitution reaction mechanisms.

First year HE Content (Southampton)

Note that this is all material which is covered in the first few weeks of Semester 1 in Year 1.

- Shapes of atomic orbitals
- Drawing Lewis structures for simple molecules
- Valence bond theory of simple molecules including concepts of orbital overlap and covalent bond formation
- Hybridisation of orbitals ie the concept of mixing atomic orbitals to form new hybrid orbitals with an averaged energy level to prepare atomic centres for bonding (maximising orbital overlap)
- Description of the structures of methane, ethene and ethyne using the hybridisation model
- The reactions of organic molecules
- Extension of the underpinning theory to cover isoelectronic species
- VSEPR theory to determine shapes of molecules with up to 6 areas of electron density
- Determination of hybridisation states in simple molecules

Comment

The depth of coverage of covalent bonding in A-level chemistry is rather limited, and it is possible for students to achieve good grades without a solid foundation of understanding. This can then impede their ability to access the more complex models of bonding encountered early in their degree studies. Of particular concern is the fact that the shapes of s- and p-orbitals are not covered in all specifications, and the idea of 'orbital overlap' in bonding is only discussed in one specification . As such, it is unsurprising that many students currently finishing their A-level in chemistry have little concept of the nature of the covalent bond.

The relatively superficial coverage of covalent bonding at A-level inevitably causes students difficulties in coming to terms with other important concepts which are still covered at A-level, including the shapes of molecules and the nature of the bonding in alkenes and arenes. The idea of restricted rotation around a double bond is rather meaningless in the absence of an understanding of the nature of the bonding involved. All specifications expect students to be able to write mechanisms for electrophilic addition reactions of alkenes, which for those without knowledge of the properties of π-bonds becomes little more than a rote learning exercise along the lines of 'this is where the arrow goes'. Similarly, students are expected to have knowledge of the unusual stability of benzene, which must be akin to taking to the roads without first studying the Highway Code for those who have no knowledge of orbitals and the overlap between them.

Until the relatively recent past, students arriving at university to study chemistry degrees had knowledge of the role of orbitals in covalent bonding, and many were already familiar with the concept of hybridisation. As such, many academics still approach their teaching with this assumed knowledge in mind. This, coupled with the very fast pace of delivery of degree level topics, can result in an overloading of working memory which prevents students from fully assimilating complex concepts as they encounter them. Although university courses are adapting to the modern reality, it is clear that exposure to more complex models of bonding such as valence bond theory and hybridisation during A-level studies will be beneficial to students in giving them confidence in dealing with more advanced concepts. This will also reduce the burden on those who do go on to study chemistry and related subjects at degree level.

Since all A-level specifications currently include the concept of s, p and d sub-shells in their coverage of electron configuration, it is a relatively small conceptual leap to describe the shapes of these orbitals, with s- and p-orbitals being most important in this regard. Students will be aware that a covalent bond involves shared electrons, so introduction of the valance bond model, where a covalent bond is formed by the overlap of two half-filled orbitals on two different atoms, should not pose difficulties. Academics at Southampton certainly feel that all students should be familiar with the concept of orbital overlap in covalent bonding at A-level. Further extension to the hybridisation model represents a small increase in conceptual demand, but does require students to have a solid grasp of the basics of the valence bond model.

Three extension activities are proposed to support students in getting to grips with more advanced models of covalent bonding, beginning with a consideration of atomic orbitals and their overlap in the formation of covalent bonds, before moving onto hybridisation and then looking more closely at the relationship between the bonding in a molecule and its shape and reactivity.

It is intended that this material should be incorporated in the teaching schedule throughout the course, with some aspects of the content appearing at different stages of A-level chemistry. However, teachers may find it useful to deploy these activities towards the end of the second year of study to bring together a range of key concepts prior to the terminal examinations.

Activities

There are many high quality resources available to support the teaching of these topics. These are suggested as possible tools for teachers to incorporate in their teaching of the A-level chemistry content. One very good resource is the RSC 'Starters for Ten' pack 3 on 'Bonding' (http://www.rsc.org/learn-chemistry/resource/download/res00000954/cmp00001408/pdf), which includes a total of 9 different activities suited to teaching content in the A-level specifications, with each activity coming with a set of answers. The key activities relating to this content are 3.1.1. Covalent Dot-and-Cross and 3.2.4 Shapes of Molecules, but the remaining activities will also be useful. Once students are confident with drawing dot-and-cross diagrams, HE extension activity 1 could be used to introduce ideas about valence bond theory.

A drag and drop activity to support teaching of shapes of molecules is provided by ChemIT (http://chemit.co.uk/resource/Details/62). The RSC's 'Spot the Bonding' activity (http://www.rsc.org/learn-chemistry/resource/res00001097/spot-the-bonding) is a useful resource probing students' understanding of different types of bonding and how we represent them visually.

A valuable set of resources for teaching the related organic chemistry content again comes from the RSC 'Starters for Ten' series. Pack 5, 'Organic Chemistry' (http://www.rsc.org/learn-chemistry/resource/res00000954/starters-for-ten#!cmpid=CMP00001416), contains a total of 26 teaching activities. Of particular relevance to this content are 5.1.4. Isomerism, 5.2.4. Alkanes, 5.2.5. Alkanes Summary, 5.2.8. Electrophilic Addition 1, 5.2.9. Electrophilic Addition 2 and 5.2.10. Isomerism in Alkanes and Alkenes. ChemIT provides a useful illustration of bonding in ethene (http://chemit.co.uk/Resource/Details/22) , while for the more advanced content, an excellent presentation on 'The Benzene Story' can be found here: http://www.tes.co.uk/ResourceDetail.aspx?storyCode=6037245.

The Chemguide website is a useful source of information for students (and teachers) on the following topics, which are generally covered in A-level specifications:

- The high acidity of phenol: http://www.chemguide.co.uk/organicprops/phenol/acidity.html#top
- Electrophilic substitution reactions of phenol: http://www.chemguide.co.uk/organicprops/phenol/ring.html#top
- Phenylamine as a weak base: http://www.chemguide.co.uk/organicprops/aniline/amine.html
- Electrophilic substitution reactions of phenylamine: http://www.chemguide.co.uk/organicprops/aniline/bromine.html#top

The topics listed above are difficult for students to grasp if they are unfamiliar or unconfident with the nature of bonding in aromatic systems, and this is best explained using a valence bond/hybridisation approach as outlined in the HE Focussed extension activities tab. Note that these topics are also covered in the checkpoint task.

Checkpoint Task

The checkpoint task comprises a set of relatively open questions which can be posed to students either individually or in groups. It is intended that these would be used after the relevant topics have been covered in teaching, but they might also be used together as a synoptic revision exercise towards the end of the second year of A-level. A specific number of marks has not been allocated to each question as the aim is for students to give as much detail as possible to convey their understanding rather than to chase marks. A checklist of key content which should be addressed in each answer is also provided. The points in the checklist are designed to prompt the students to think about and improve their answer rather than spoon-feeding them with a model answer. The intention is to help them to develop the ability to reflect on their understanding, which is a key part of being a successful independent learner. This is particularly important, as it is clear that students embarking on chemistry degrees have become increasingly mark/grade focussed over recent years, preferring to rely on a favoured, memorable answer rather than their ability to formulate an explanation before picking it apart and refining it through reflection. A suggested approach for the use of the checkpoint task in the classroom is given later in this document.

Teacher Instructions:

www.ocr.org.uk/Images/163770-bonding-checkpoint-task-teacher-instructions-.pdf

Learner Activity:

www.ocr.org.uk/Images/163771-bonding-checkpoint-task.doc

Activities

Where should these activities be used in A-level chemistry teaching?

The purpose of these activities is to strengthen students' understanding of chemical bonding and how it influences the properties and chemical behaviour of different compounds. Teachers will want to think carefully about where best to use these activities. Activities 1 and 2 should be accessible by all students, and the learning outcomes associated with these are most appropriate in terms of helping students to build a better understanding of key A-level concepts. Activity 3 may be considered to be more effectively used as an extension activity for more able students and those with a particular interest in chemistry.

- **Activity 1** could be used when covalent bonding is introduced (normally in the early part of A-level chemistry). A key benefit of teaching this extension material is that students will develop a better understanding of how atoms are able to share electrons as well as the nature of a σ bond.
- **Activity 2** could be used after alkenes have been introduced. Students should already be familiar with the tetrahedral shape of methane at this point, and covering this material at this stage will help them to develop a much better understanding of the reasons for the reactivity of ethane.
- **Activity 3** can't really be used until after activity 2 has been completed. It seems probable that most teachers will cover shapes of molecules before teaching the organic chemistry related to activity 2. As such, activity 3 is probably best used as a synoptic task for students to complete later on in their A-level, perhaps as a revision activity (or as an extension task attached to a related revision activity).

1. Shapes of orbitals and valence bond theory

After completing this activity, students should be able to:

- Describe the shapes of s- and p-orbitals
- Describe the formation of covalent bonds as the overlap of half-filled orbitals on two different atoms (valence bond theory)
- Explain, using diagrams where appropriate, how σ-bonds are formed by the overlap of the appropriate orbitals in the following i) H_2 ($\sigma_{s\text{-}s}$), ii) Cl_2 ($\sigma_{p\text{-}p}$), and iii) HCl ($\sigma_{s\text{-}p}$)

Teacher guidance
Depending on the group, this first part of this activity could be led by the teacher, or it could be set entirely as a research task for students to work on independently. Most teachers would probably prefer to teach the first two learning outcomes on the board or using a simple PowerPoint. The third learning outcome could be set as an independent study task set either in class or for homework.
The Kent Chemistry website (see: http://www.kentchemistry.com/links/bonding/bondingflash.htm) incorporates some very helpful Flash animations and interactive quizzes, while the Adichemistry site (see: http://www.adichemistry.com/general/chemicalbond/vbt/valence-bond-theory-hybridization.html) conveys much of the same information in a static fashion. These websites will be useful for teachers seeking to boost their own knowledge and understanding, and they could also be given to students as recommended sources for their independent research.

The Chemguide website also provides useful guidance on orbital shape (see: http://www.chemguide.co.uk/atoms/properties/atomorbs.html), but this material may be rather demanding for students who are not yet confident with the basics.

2. Hybridisation in carbon compounds: the bonding in methane, ethene and ethyne

After completing this activity, students should be able to:

- Explain what is meant by the term hybridisation
- Describe and illustrate the bonding in methane, with reference to the formation of 4 sp^3 hybrid orbitals from the relevant atomic orbitals
- Describe and illustrate the bonding in ethene, with reference to the formation of 3 sp^2 hybrid orbitals from the relevant atomic orbitals and the formation of a π-bond by the overlap of two p-orbitals, one from each carbon atom.
- Describe and illustrate the bonding in ethyne, with reference to the formation of 2 sp hybrid orbitals from the relevant atomic orbitals and the formation of 2 π-bonds by the overlap of 2 pairs of p-orbitals.

Teacher guidance

As discussed previously, it is recommended that the concept of hybridisation is taught after alkenes have been introduced. Students should already be familiar with the structure of methane, and sp^3 hybridisation should be considered first with methane as the context. It is important to consider the promotion of an electron in a carbon atom from an s-orbital to a p-orbital, forming an excited state with 4 unpaired electrons before covering the concept of hybridisation (the Adichemistry website defines hybridisation as 'the intermixing of two or more pure atomic orbitals of an atom with almost same energy to give same number of identical and degenerate new type of orbitals'). After teaching about the role of sp^3 hybridisation in the bonding in methane, students could perhaps be asked to speculate on the nature of the bonding in ethene before sp^2 hybridisation is taught. Although alkynes are not on the specification, it would be useful to cover sp hybridisation in ethyne, as it completes the story and helps to consolidate the prior learning. Again, students could be asked to speculate on the matter prior to teaching.

Teachers may deem it appropriate to teach sp^3 hybridisation in class and set an independent study task to cover the rest of the material.

Chemguide is a very good source of material for teachers wishing to brush up on their knowledge of this topic or to point students to as a source of information for an independent research activity:

sp^3 http://www.chemguide.co.uk/basicorg/bonding/methane.html

sp^2 http://www.chemguide.co.uk/basicorg/bonding/ethene.html

sp http://www.chemguide.co.uk/basicorg/bonding/ethyne.html

For further guidance, these Khan academy videos explain sp3 and sp2 hybridisation fairly well, but they are probably unsuitable for showing directly to students (http://www.khanacademy.org/science/organic-chemistry/gen-chem-review/hybridization/v/sp3-hybridized-orbitals-and-sigma-bonds and http://www.khanacademy.org/science/organic-chemistry/gen-chem-review/hybridization/v/pi-bonds-and-sp2-hybridized-orbitals).

3. Hybridisation and molecular shape

As stated above, teachers may prefer to use this activity as an extension task for more able students and those with a particular interest in chemistry.

After completing this activity, students should be able to:

- Describe the hybridisation in the following molecules and relate it to molecular shape and bond angles: BeH_2, BH_3, CH_4, NH_3, H_2O
- *Extension work could include coverage of*: HCN, CO_2, allenes ($H_2C{=}C{=}CH_2$) and compounds where d-orbitals are involved in hybridisation eg PCl_5, SF_6

Teacher guidance:
Students should already be familiar with VSEPR as a means of working out molecular shapes (even if they haven't used the term VSEPR), and it would be useful to recap the shapes of the molecules listed in the first learning outcome before considering the hybridisation. The Adichemistry website is a useful source of information about hybridisation in these molecules, and students could be directed to the URLs listed below to complete an independent research task.

$BeCl_2$: http://www.adichemistry.com/general/chemicalbond/vbt/hybridization-illustrations.html#sp-HYBRIDIZATION

BCl_3: http://www.adichemistry.com/general/chemicalbond/vbt/hybridization-illustrations.html#sp2-HYBRIDIZATION

CH_4, NH_3, H_2O: http://www.adichemistry.com/general/chemicalbond/vbt/hybridization-illustrations.html#sp3-HYBRIDIZATION

PCl_5: http://www.adichemistry.com/general/chemicalbond/vbt/hybridization-illustrations.html#SP3D-HYBRIDIZATION

SF_6: http://www.adichemistry.com/general/chemicalbond/vbt/hybridization-illustrations.html#SP3D2-HYBRIDIZATION

A great deal of detailed information regarding valence bond theory and hybridisation in these sorts of molecules can be found in this very useful document posted by Illinois Central College (http://faculty.icc.edu/bcook/c130xp13.pdf).

Resources, links and support

Science Spotlight – Our termly update Science Spotlight provides useful information and helps to support our Science teaching community. Science Spotlight is designed to keep you up-to-date with Science here at OCR, as well as to share information, news and resources. Each issue is packed full with a series of exciting articles across the whole range of our Science qualifications: www.ocr.org.uk/qualifications/by-subject/science/science-spotlight/

Find resources and qualification information through our science page: www.ocr.org.uk/qualifications/bysubject/science/

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To find out more about GCSE and A Level reform please visit: http://www.ocr.org.uk/qualifications/gcse-and-a-level-reform

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