

## Investigating bonding spectrums

This resource accompanies the infographic poster **The bonding spectrum** in *Education in Chemistry* which you can download and print to display in your classroom: [rsc.li/3YZ52jC](https://rsc.li/3YZ52jC)

### Learning objectives

- 1 Understand the types of bonding and intermolecular forces that occur in a range of elements and compounds.
- 2 Understand that bonding type is not always clear-cut and can gradually change across a range of substances.
- 3 Understand how physical properties depend on the type of bonding.

This resource is designed as an open-ended formative assessment that you can use once learners have met the main types of strong bonding and intermolecular forces. The resource allows learners to check their understanding and resolve any lingering misconceptions through discussion of their responses with their peers or you, their teacher. You can use it as a classroom activity individually or in pairs, or as a homework exercise. In the latter case, ask students to separate out the different substances needed for each question in class beforehand.

The activity consists of a set of questions, plus ten diagrams showing the bonding and structure of a range of elements and compounds. The diagrams are printed so that they can be cut out to produce a set of cards that learners can arrange while they are thinking through the questions. This initial sorting phase gives learners an opportunity to reinforce their knowledge and understanding of bonding as they apply it to particular examples. The questions then probe the depth of their understanding by asking learners to explain the changes between types of bonding in terms of electron sharing, electron mobility and electrostatic attraction.

The diagrams on the cards are similar to those used in another popular RSC resource, **Spot the bonding**, from *Chemical Misconceptions: Prevention, diagnosis and cure: Volume 2*, by Keith Taber, available at [rsc.li/3s8gWep](https://rsc.li/3s8gWep). It would be beneficial for learners to try **Spot the bonding** before they move on to the less clear-cut cases in this activity to remind them of different representations of the main types of bonding and structure.

### Instructions

1. Print and cut out the bonding cards on page 3 of the student sheet. These are labelled A to J for ease of reference without identifying the substances.
2. Ask learners to answer the questions on pages 1 and 2 of the student sheet, with access to the cards, working individually or in groups.

## Differentiation

This is an open-ended activity that you can adapt according to the level of support or challenge appropriate for different learners. As a formative assessment exercise, it is intended to stimulate discussion about the models we use for bonding. You can do this at a suitable level for the learners based on the responses given.

For learners who need more support you can break the activity down into its three distinct parts, with the relevant bonding diagrams already selected. This will reduce the initial cognitive load and allow learners to focus on one bonding spectrum at a time.

For learners lacking the confidence to attempt the questions requiring more in depth explanation (eg 2(b)(ii), 3(c), 4(b)), you can reframe the questions into a multiple-choice format.

For example, for question 2(b)(ii) give options for the response, such as:

- Type of bonding: covalent/polar covalent/ionic.
- Extent of electron sharing between atoms: equally shared/unevenly shared/not shared at all.
- Electrostatic attractions: between shared electrons and nuclei/between oppositely charged ions.

For learners who are already confident with the topic, the less structured approach on the student sheet gives them the flexibility to demonstrate what they know and understand about the models we use for bonding at this level. They will be unlikely to come up with all the points given in the teacher notes, so the activity and its following discussion will help them move on even further.

## Answers to questions (plus extra notes)

### 1. Introduction

(a) The tendency for an atom of the element to attract shared electrons when forming a chemical bond. (Wording does vary slightly between specifications, so check which version your learners need to know.)

- (b) i. Metallic bonding with a giant structure.  
ii. Covalent bonding with either a simple molecular or giant structure.  
iii. Ionic bonding with a giant structure.  
iv. Covalent bonding with either a simple molecular or giant structure.

(This question reminds learners of the simple pre-16 level prediction of bonding type depending on whether the elements are metals or non-metals. It is important for them to know that they now need to move beyond this model.)

**2. The spectrum from covalent to ionic bonding**

(a) Cards **A (aluminium chloride)**, **C (chlorine)** and **I (potassium chloride)**.

(b)

Substance	Electronegativity difference	Type of bonding
Chlorine	$3.2 - 3.2 = 0$	Non-polar covalent bonding with the pair of electrons equally shared. Atoms held by electrostatic attraction between the nuclei and the shared pair.
Aluminium chloride	$3.2 - 1.6 = 1.6$	Polar covalent bonding with each pair of electrons shared unequally – nearer to the more electronegative chlorine. These include two coordinate (dative covalent) bonds formed by donation of a lone pair of electrons from chlorine to the aluminium. Atoms held by electrostatic attraction between the nuclei and the shared pairs.
Potassium chloride	$3.2 - 0.8 = 2.4$	Ionic bonding with (almost) no sharing of electrons. Ions held by electrostatic attraction between their opposite charges.

(Learners are unlikely to make all the points above without prompting, but any that get missed first time can be brought out in the subsequent discussion).

(For ionic bonding, learners may suggest 'electron transfer'. This is valid to explain how the ions might have formed, but not how the ions are bonded).

(c) Chlorine, aluminium chloride, potassium chloride

(d) Either (i) electrical conductivity when molten, which changes from no conductivity to good conductivity, or (ii) melting/boiling point or enthalpy change of melting/boiling, which changes from low to high (as the structure also changes from simple molecular to giant).

**3. The spectrum of strength of electrostatic attraction between molecules and ions**

(a) Cards **H (methanol)**, **F (methanol)**, **J (sodium methoxide)** and **D (ethane)**. (The formulae of these compounds have been given in the question as learners may not have studied enough organic chemistry to be familiar with their names).

(b)

Compound	Type of bonding / intermolecular force
Ethane	London / induced dipole / dispersion forces (Check your learners' specification for accepted names for these forces).  Non-polar molecules held together by the very weak electrostatic attraction between temporary dipoles that form by random movement of electrons. (There is little overall dipole due to the small difference in electronegativity between C and H (0.4), plus the symmetry of the molecule).
Methanal	Permanent dipole / dipole-dipole forces (+ London forces etc. as above.)  Polar molecules held together by the weak electrostatic attraction between permanent dipoles that exist over the C=O bond, due to the difference in electronegativity of 0.8.
Methanol	Hydrogen bonding (+ permanent dipole and London forces etc. as above.)  Polar molecules held together by the electrostatic attraction between stronger permanent dipoles that exist over the O-H bond due to the difference in electronegativity of 1.2.  (The strength of hydrogen bonding can also be attributed to the particular interaction between the exposed H nucleus and the lone pair on the electronegative atom of the neighbouring molecule – but this is not usually required).
Sodium methoxide	Ionic bonding (+ London forces as above.)  Sodium methoxide is ionic due to the large difference in electronegativity of 2.5 between Na and O.  The ions are held together by the strong electrostatic attraction between the opposite charges of Na <sup>+</sup> and CH <sub>3</sub> O <sup>-</sup> .

(Learners may have referred to the covalent bonding in the examples above. Help them clarify the difference between bonding within the molecule and bonding between molecules). (Learners may question why various types of 'forces' are the answer to questions about 'bonding'. This gives you the opportunity to reinforce that that all types of bonding result from electrostatic forces – something not always appreciated by learners).

(c) Either (i) melting/boiling point, which increases with the strength of the forces between the molecules/ions, or (ii) solubility in non-polar and polar solvents, where molecules with little or no overall polarity dissolve better in non-polar

solvents, and molecules higher polarity/hydrogen bonding/ions dissolve better in polar solvents and/or water.

#### 4. The spectrum from covalent to metallic bonding

(a) Cards **E (germanium)**, **B (diamond)** and **G (lead)**.

(b) Diamond (carbon, 2.6), germanium (2.0), lead (1.8).

(c)

Element	Type of bonding
Diamond	Covalent bonding with each pair of electrons shared between particular carbon atoms (ie not delocalised). Atoms held by electrostatic attraction between the nuclei and the shared pair.
Germanium	As for diamond at 273 K, (although there is a low conductivity suggesting that the electrons are not so strongly held to each particular pair of atoms.)
Lead	Metallic bonding with the electrons delocalised, so they can move through the structure and are not shared between any particular atoms. Ions held by electrostatic attraction between their positive charge and the delocalised electrons.

(Learners may need more support with this question as this spectrum is not covered by the infographic poster. However, it is reasonable to suggest that as the electronegativity decreases, the atoms will have less hold on the bonding electrons, leading to a greater extent of delocalisation.)

As germanium is heated, the greater kinetic energy of the bonding electrons allows them to break free from the particular atoms and become delocalised. (This property of germanium can be demonstrated by a simple conductivity experiment. Details can be found online from the Institute of Physics at <https://spark.iop.org/conductivity-germanium>.)