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AS AND A LEVEL

Delivery Guide

CHEMISTRY A

H032, H432
For first teaching in 2015

Theme: Bonding

Version 3

AS AND A LEVEL
CHEMISTRY A

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.

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Curriculum content

2.2.2 Bonding and structure

(a) ionic bonding as electrostatic attraction between positive and negative ions, and the construction of 'dot-and-cross' diagrams

(b) explanation of the solid structures of giant ionic lattices, resulting from oppositely charged ions strongly attracted in all directions e.g. NaCl

(c) explanation of the effect of structure and bonding on the physical properties of ionic compounds, including melting and boiling points, solubility and electrical conductivity in solid, liquid and aqueous states

(d) covalent bond as the strong electrostatic attraction between a shared pair of electrons and the nuclei of the bonded atoms

(e) construction of 'dot-and-cross' diagrams of molecules and ions to describe:

(i) single covalent bonding

(ii) multiple covalent bonding

(iii) dative covalent (coordinate) bonding

(f) use of the term 'average bond enthalpy' as a measurement of covalent bond strength

(g) the shapes of, and bond angles in, molecules and ions with up to six electron pairs (including lone pairs) surrounding the central atom as predicted by electron pair repulsion, including the relative repulsive strengths of bonded pairs and lone pairs of electrons

(h) electron pair repulsion to explain the following shapes of molecules and ions: linear, non-linear, trigonal planar, pyramidal, tetrahedral and octahedral

(n) explanation of the solid structures of simple molecular lattices, as covalently bonded molecules attracted by intermolecular forces, e.g. I_2, ice

(o) explanation of the effect of structure and bonding on the physical properties of covalent compounds with simple molecular lattice structures, including melting and boiling points, solubility and electrical conductivity

Curriculum content

2.2.2 Bonding and structure

(i) electronegativity as the ability of an atom to attract the bonding electrons in a covalent bond; interpretation of Pauling electronegativity values

(j) explanation of:

- (i) a polar bond and permanent dipole within molecules containing covalently-bonded atoms with different electronegativities
- (ii) a polar molecule and overall dipole in terms of permanent dipole(s) and molecular shape

(k) intermolecular forces based on permanent dipole–dipole interactions and induced dipole–dipole interactions

(l) hydrogen bonding as intermolecular bonding between molecules containing N, O or F and the H atom of –NH, –OH or HF

(m) explanation of anomalous properties of H_2O resulting from hydrogen bonding, e.g.:

- (i) the density of ice compared with water
- (ii) its relatively high melting and boiling points

3.1.1 Periodicity

(d) explanation of:

- (i) metallic bonding as strong electrostatic attraction between cations (positive ions) and delocalised electrons
- (ii) a giant metallic lattice structure, e.g. all metals

(e) explanation of the solid giant covalent lattices of carbon (diamond, graphite and graphene) and silicon as networks of atoms bonded by strong covalent bonds

(f) explanation of physical properties of giant metallic and giant covalent lattices, including melting and boiling points, solubility and electrical conductivity in terms of structure and bonding

(g) explanation of the variation in melting points across Periods 2 and 3 in terms of structure and bonding (see also 2.2.2 o).

Approaches to teaching the content

Assessment of what students already know is an important component of making teaching decisions. The key is to have students make connections among the various interrelated concepts in bonding. Students have limited knowledge from GCSE with few connections and even fewer cross-connections. If there are gaps in students' understanding or if they are missing conceptual links, learning new material is going to be difficult. In fact students do not arrive in the classroom with a clean slate to which knowledge is added.

The scientific educational literature is full of research that has been done about the difficulty students have in understanding chemical bonding. Many of these misconceptions are robust and remain even after teaching the topic. Common difficulties are: why bonding occurs, confusing ionic bonding with covalent bonding – more in the next section.

Have you ever wondered if we teach the topic chemical bonding in the correct order? Chemical bonds are still taught as pure ionic and covalent; additionally, the role of electronegativity in bonding is often not made clear in ionic bonding. Researchers believe that there are four limitations in the teaching approach:

- Bonding concepts are arranged on the basis of bond strength – students struggle with the concept of bond strength.
- Teaching order is by tradition ionic, covalent, polar covalent, hydrogen bonds and London forces.
- Electronegativity is introduced when polar bonds are introduced.
- The teaching order is not in line with the bond strength.

The major problems associated with this order of teaching are that students learn that all types of bonding are independent of each other and that there is no association between them. Researchers have proposed the covalent, polar covalent and ionic bonding sequence for effective teaching. That way you are comparing the product aspect of bonding rather than the process aspect of bonding.

Teachers working with pre-16 students tend to over-rely on the 'octet rule' as an infallible tool for students to use in determining formulae and bonding. This so-called rule contributes to the students' problems with bonding. This rule has limited application in bonding, and therefore should not be used in teaching chemical bonding, because the octet rule only works reliably for carbon, nitrogen, oxygen and aluminium.

A range of different terms is used to describe bonds, especially intermolecular bonds. These include 'van der Waals', 'London forces', 'intermolecular forces', 'attractive forces' and 'attractions'. Such language over-complicates the picture. Terms such as 'induced dipole-dipole bonds' or 'permanent dipole – permanent dipole bonds' are much more descriptive. We need to be consistent in using our bonding terminology.

Teachers should be aware that their own knowledge of content can cause issues with how information is presented. They should take care not to oversimplify the content.

Common misconceptions or difficulties students may have

- Students confuse electron transfer (the process) and electrostatic attraction (the outcome). The latter is ionic bonding.
- Often there is a belief that mobile electrons cause conduction, even in ionic compounds. In ionic compounds, it is the free *ions* that carry electrical charge.
- Confusion over electrical conductance – the key idea is that ionic compounds will conduct when molten or in solution because then the ions are mobile.
- Mistakenly thinking that ions formed by the loss of electrons have a negative charge – whereas it is of course positive as the electron has a negative charge.
- Why do Group 13 and 15 elements rarely form ionic compounds and Group 14 elements never form ionic compounds?
- Students often think that boiling simple covalent molecules involves breaking the covalent bonds. Covalent bonds are intramolecular whereas boiling breaks intermolecular forces.
- They also think that all molecules obey the octet rule – they will meet examples where the octet rule is not adhered to here.
- Students mistakenly think that any molecule that contains polar bonds must itself be polar – the polarities can cancel out, as in symmetrical molecules.
- Students become confused between intermolecular forces and covalent bonds – covalent bonds are *intramolecular*.
- Students often confuse the conduction of electricity by metals and graphite (electrons) with that of ionic compounds (ions).
- They see the formulae of ionic compounds written as 'KCl' or '$CaCl_2$'. There is no distinction between these formulae and 'NH_3' or 'H_2O', which are covalent.
- There are only two types of bonds – covalent and ionic. The vast majority of compounds fall between these two extremes.
- Covalent bonds are weaker than ionic bonds.
- Students find it difficult to describe how London forces are formed.

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

The understanding of bonding is linked in with earlier topics in the syllabus, such as Formulae and equations and Oxidation numbers. It is important to highlight that bonding plays a very important role in Chemistry and will come back in the following topics: Alkanes, Alkenes, Bond enthalpies, Haloalkanes, Transition elements, Alcohols, Amines, Amino acids, and Carboxylic acids.

Activities

The importance of hydrogen bonding:
https://sciencing.com/importance-hydrogen-bonding-2514.html

This article can be shared with students to highlight that hydrogen bonding is important in many chemical processes and has important links to Biology. It is responsible for water's unique solvent capabilities, holds complementary strands of DNA together, and determines the three-dimensional structure of folded proteins including enzymes and antibodies.

Play hangman with the keywords. Teacher writes out the amount of letters on the board. Students need to find the correct keyword and then explain what this keyword means.

Pass around a model of the NaCl structure. Get the students to describe it in their own words.

Demonstrations of water boiling and sugar dissolving, ice melting, iodine subliming and propanone evaporating can all be used to investigate students' thinking about chemical bonding – make the events explicit by carrying them out in the students' presence and using molecular models to probe thinking about which bonds break and form.

Play 'True or false'. Students draw an element card each and say whether a covalent bond or ionic bond would form.

Write down a few concept terms on the board so that students can use them to setup a concept map. Compare this concept map with one made after they have studied the topic.

ICT: Research the boiling points of the hydrides of the Group 16 elements.

ICT: Research the anomalous properties of water.

The instructional activities provided in this section are not exhaustive; they are only representative of innumerable effective activities a teacher may choose to use. Variety is key. The instructional activities are randomly grouped. The classroom teacher must determine the most effective instructional strategy for her/his students. The provided instructional strategies should be used as pre- and post-assessments, and should be used with students independently, in pairs, in small groups and as a whole class. A varied approach is crucial in meeting the needs of all students.

Activities

Shapes of molecules
Students could make a poster on shapes to consolidate their knowledge.
An example poster from Compound Interest is linked below.

https://www.compoundchem.com/2014/11/13/vsepr/

Identifying period 3 elements, Learner Resource 1

The activity is a practical investigative approach to period 3 elements. All the period 3 elements are on display and the students need to think about the structure and bonding. Clue cards are available in Teacher Resource 2, and answers are given in Teacher Resource 1.

The relationship between bonding, structure and properties, Learner Resource 2

Investigating the relationship between bonding, structure and physical properties of substances. Students would be able to predict the bonding and structure in unknown compounds.

Using molymods
Students build the different molecular shapes using Molymods; Molymod sells a 'Shapes of Molecules' box.

http://www.molymod.com

Quiz on ionic and covalent bonding
Quick 5-minute plenary to check students' basic understanding.

An interactive quiz on ionic and covalent bonding, made by John Ewart, can be accessed here:

http://www.ewart.org.uk/science/structures/struct_index.htm

Molecular shape simulations
Explore molecule shapes by building molecules in 3D. How does molecule shape change with different numbers of bonds and electron pairs? Students can find out by adding single, double or triple bonds and lone pairs to the central atom. Then, they compare their models to real molecules.

http://phet.colorado.edu/en/simulation/molecule-shapes

Molecule polarity simulator
When is a molecule polar? Students change the electronegativity of atoms in a molecule to see how it affects polarity. They can see how the molecule behaves in an electric field. They change the bond angle to see how shape affects polarity. They can see how it works for real molecules in 3D. They can see can change the electronegativity of the atoms and see how it effects it polarity.

http://phet.colorado.edu/en/simulation/molecule-polarity

VSEPR interactive tutorial and quiz
An interactive tutorial and quiz. This computer course is designed to teach the user the VSEPR rules. Once the user is familiar with the rules, a set of worked examples is available to show how the rules are applied to unfamiliar molecules. Then there is a set of problems in which the user must determine the geometry of a series of molecules which will be randomly selected by the computer.

http://www.chem.ox.ac.uk/vrchemistry/vsepr/intro/vsepr_splash.html

Bonding, structure and properties card sort
A card sort activity. The cards can be laminated for use as a starter or revision activity. Four types of bonding structures – metallic, giant ionic, giant covalent, simple covalent and pictures, descriptions, properties and example elements/compounds to arrange under the headings.

https://www.tes.co.uk/teaching-resource/Bonding-card-sort-6005849

The properties of water animation
A four minute animation that describes the properties of water that support life. These properties include solvency, cohesion and adhesion, high surface temperature, high heat capacity, high heat of vaporisation, and varying density.

https://www.youtube.com/watch?v=aVmU3CLxvgU

Intermolecular bonding and properties activity
This activity allows students to investigate the effect of the different types of intermolecular forces on the properties of substances.'

http://www.ocr.org.uk/Images/221142-intermolecular-bonding-teacher-instructions.pdf

Activities

Density of ice demo
Ice cubes are floated on cooking oil and students observe what happens to the liquid water produced as the ice melts and the density changes.

http://www.rsc.org/learn-chemistry/resource/res00001776/the-density-of-ice

The migration of ions: practical evidence for the ionic model.
In an electrolysis experiment, the ions migrate towards electrodes of opposite charge. In this experiment the migration of an intensely coloured purple plume of manganate(VII) ions is seen to move towards the positive terminal.

http://www.rsc.org/learn-chemistry/resource/res00000418/the-migration-of-ions-evidence-for-the-ionic-model

Bonding quizzes
RSC's 'Starter for Ten' pack on bonding.

https://edu.rsc.org/resources/bonding-starters-16andndash18/4010264.article

Chemical misconceptions: Spot the bonding
This resource provides a quick way of auditing students' awareness and understanding of different bond types.

http://www.rsc.org/learn-chemistry/resource/res00001097/spot-the-bonding

Learner resource 1

In groups of three or four you will be completing the following task in the lab.

There are 8 elements labelled 1–8. They are all from period 3 of the periodic table.

Do not open any of the containers.

Element	Hazard
Sodium	Highly flammable; reacts violently with water to produce flammable gases. Corrosive. Keep away from sulfur. Store under paraffin oil.
Magnesium	Highly flammable. Keep away from chlorine.
Aluminium	Low hazard. Keep away from halogens.
Silicon	Low hazard.
White/yellow Phosphorus	Spontaneously flammable in air. Very toxic. Store under water. Keep away from sodium.
Sulfur	Keep away from sodium, magnesium and aluminium.
Chlorine	Toxic gas, keep in fume cupboard. Dangerous for the environment. Keep away from magnesium and aluminium.
Argon	Low hazard

Learner Resource 1

1. Identify which element is which, explain how you decided this, and describe the element.

Element	Number	Justification	Description
Sodium			
Magnesium			
Aluminium			
Silicon			
Phosphorus (P_4)			
Sulfur (S_8)			
Chlorine (Cl_2)			
Argon			

Learner Resource 1

2. Identify the structure and bonding in each element (clues are available). What happens to the structure when you boil the element?

Element	Structure and bonding	What happens to the structure when you boil it?
Sodium		
Magnesium		
Aluminium		
Silicon		
Phosphorus (P_4)		
Sulfur (S_8)		
Chlorine (Cl_2)		
Argon		

**3. The melting points (K) for period 3 elements are 84, 172, 317, 371, 392, 922, 934, 1683 K. Which goes with which element? Justify your answer.
Assign the melting points to the correct elements and justify your answers.**

Element	Melting point (K)	Justification in terms of structure and bonding – compare to other elements
Sodium		
Magnesium		
Aluminium		
Silicon		
Phosphorus (P_4)		
Sulfur (S_8)	392	
Chlorine (Cl_2)		
Argon		

Learner resource 2

Objective

- Be able to carry out simple tests on substances.
- Be able to relate properties to bonding and structure.
- Be able to predict the bonding and structure in unknown compounds.

Equipment/materials

- Copper, Cu or zinc, Zn
- Iodine, I_2 or glucose, $C_6H_{12}O_6$
- Sodium chloride, NaCl or magnesium oxide, MgO
- Silicon(IV) oxide, SiO_2
- Nylon, $-[HN(CH_2)_6NH{\cdot}CO(CH_2)_4CO]_{n}-$
- Conduction circuit
- Test tubes and spatula
- Cyclohexane
- Unknown substances: A10, B10 and C10
- Bunsen burner (restricted use)

Safety

- Wear eye protection.
- Cyclohexane is harmful and highly flammable.
- Naked flames in one part of lab only.
- Transfer test tubes producing unpleasant fumes to fume cupboard.
- Iodine is harmful. Do not inhale.

Highly flammable

Harmful

Procedure

1) Carry out the following tests on the substances in the materials list:
   (a) Using the conduction circuit and holding the plugs 1 cm apart, find out to what extent the pure substance conducts electricity using the ammeter reading.
   (b) Heat a small sample in a test tube to see if it melts or decomposes. Remember to transfer tubes that are emitting unpleasant gases to a fume cupboard immediately.
   (c) Test the substance for its solubility in cyclohexane. Use small amounts of the substance and keep the cyclohexane away from naked flames.
   (d) Test the substance for its solubility in water. Use small amounts of the substance initially and then test the conduction of the resulting solution.
2) Now repeat the tests on the unknown substances. Always treat an unknown substance as a maximum hazard.

Analysis of results

- Record results in an appropriate format.
- Predict the type of bonding you would expect in each substance.
- In each case identify the type of bonding involved as well as the type of structure, using your results.
- For the unknown substances, deduce the type of bonding involved as well as the type of structure.

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From the examiner…

- Do not confuse bonding and structure.
- Structure is either giant or simple molecular.
- Be able to discuss the different types of intermolecular forces.
- When discussing boiling points make it clear whether it is intermolecular bonds, covalent bonds, ionic bonds or metallic bonds that are being broken.

Questions

1) Explain the statement: 'Giant structures do not have free ions but some conduct electricity relatively well.'
2) Water and carbon dioxide have a simple molecular structure but at room temperature one is a liquid whereas the other is a gas. Explain this in terms of intermolecular bonding.
3) The melting point of sodium is much lower than the melting point of aluminium. Use your knowledge of metallic bonding to account for this.
4) Silicon dioxide does not melt in a Bunsen flame but nylon softens very easily. Use ideas about large molecules to account for this difference.
5) Predict, with reasons, the results of carrying out this experiment on copper sulfate.

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Teacher resource 1

1. Identify which element is which, explain how you decided this, and describe the element.

Element	Number	Justification	Description
Sodium	6	It is metallic shiny grey, stored in a liquid (oil). Labelled as flammable and corrosive.	Shiny, grey solid under oil/liquid.
Magnesium	8	It is metallic shiny grey and Mg is often found in ribbon form.	Shiny, grey solid ribbon.
Aluminium	2	It is metallic shiny grey. Malleable and non-hazardous.	Shiny, grey solid strip.
Silicon	1	Dark grey solid, looks different from the metals. Non-hazardous.	Dark grey shiny rock/solid.
Phosphorus (P_4)	7	Phosphorus is white/yellow. Labelled as flammable and toxic.	White solid with yellow inside. In a liquid (water).
Sulfur (S_8)	4	Sulfur is yellow.	Yellow pieces of solid.
Chlorine (Cl_2)	5	Chorine is a green gas.	Green gas.
Argon	3	Argon is a colourless gas.	Colourless gas.

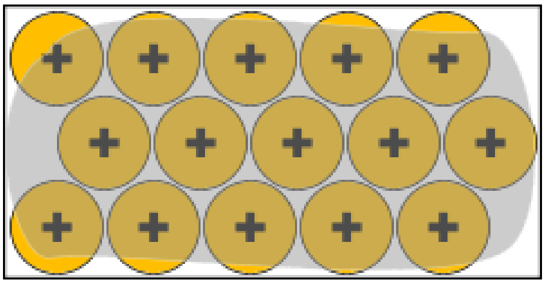
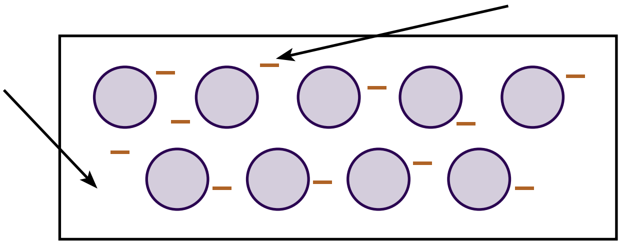
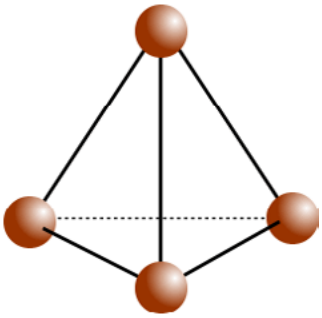
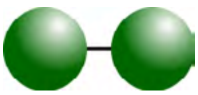
2. Identify the structure and bonding in each element (clues are available). What happens to the structure when you boil the element?

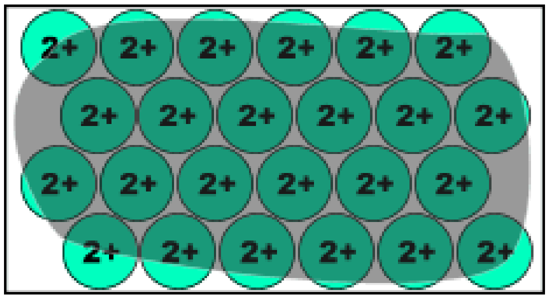
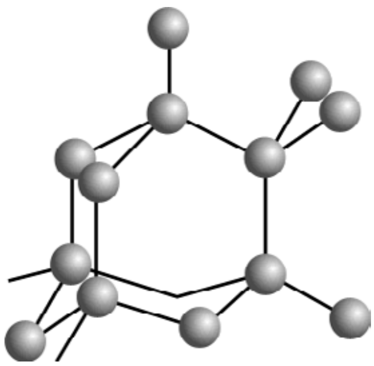
Element	Structure and bonding	What happens to the structure when you boil it?
Sodium	Giant metallic lattice	Break strong metallic bonds/overcome the attraction between the metal ions and the delocalised electrons.
Magnesium	Giant metallic lattice	Break strong metallic bonds/overcome the attraction between the metal ions and the delocalised electrons.
Aluminium	Giant metallic lattice	Break strong metallic bonds/overcome the attraction between the metal ions and the delocalised electrons.
Silicon	Giant covalent lattice	Break strong covalent bonds.
Phosphorus (P_4)	Simple molecular (lattice/covalent)	Break weak London forces between the molecules.
Sulfur (S_8)	Simple molecular (lattice/covalent)	Break weak London forces between the molecules.
Chlorine (Cl_2)	Simple molecular (lattice/covalent)	Break weak London forces between the molecules.
Argon	Simple atomic	Break weak London forces between the atoms.

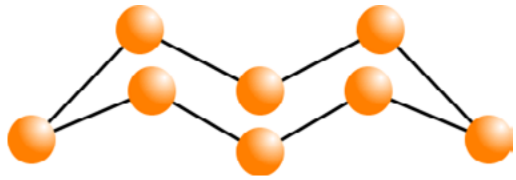
3. **The melting points (K) for period 3 elements are 84, 172, 317, 371, 392, 922, 934, 1683 K. Which goes with which element? Justify your answer. Assign the melting points to the correct elements and justify your answers.**

Element	Melting point (K)	Justification in terms of structure and bonding. Compare to other elements
Sodium	371	Giant metallic lattice, lots of strong metallic bonds to break so high melting point.
Magnesium	922	Giant metallic lattice, lots of strong metallic bonds. More delocalised electrons added to sea of electrons, 2e per atom. Mg^{2+} rather than Na^{+} so stronger attraction between the metal ions and delocalised e, harder to separate. Mg > Na.
Aluminium	934	Giant metallic lattice, lots of strong metallic bonds. More delocalised electrons added to sea of electrons, 3e per atom. Al^{3+} rather than Na^{+} so stronger attraction between the metal ions and delocalised e, harder to separate. Al > Mg > Na. Al^{3+} is smaller than the others so packs more closely together.
Silicon	1683	Giant covalent lattice, lots of strong covalent bonds to break, takes lots of energy.
Phosphorus (P_4)	317	Simple molecular, breaking weak London forces between molecules. P_4 > Cl_2 >Ar, so has more e^-, so stronger London forces, so higher melting point.
Sulfur (S_8)	392	Simple molecular S_8 > P_4 > Cl_2 > Ar, more electrons, stronger London forces.
Chlorine (Cl_2)	172	Simple molecular, only breaking weak London forces between molecules to boil. S_8 > P_4 > Cl_2 > Ar, less e than S_8 and P_4, so weaker London forces.
Argon	84	Only London forces holding atoms together, fewer electrons than other molecular elements.

Teacher resource 2

Sodium 	**Structure and bonding clues Sodium**
Aluminium (ions are smaller than Mg) 	**Structure and bonding clues Aluminium**
Phosphorus Made up of P_4 molecules 	**Structure and bonding clues Phosphorus**
Chlorine 	**Structure and bonding clues Chlorine**

Electrons	**Boiling point clue number 3**
London forces	**Boiling point clue number 4**
Structure and bonding clues Magnesium	Magnesium 
Structure and bonding clues Silicon	Silicon (like diamond) 

Structure and bonding clues Sulfur	Sulfur Made up of S_8 molecules 
Structure and bonding clues Argon	Argon 
Boiling point clue number 1	Start with the lowest boiling point first
Boiling point clue number 2	What is the difference between the metals?

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