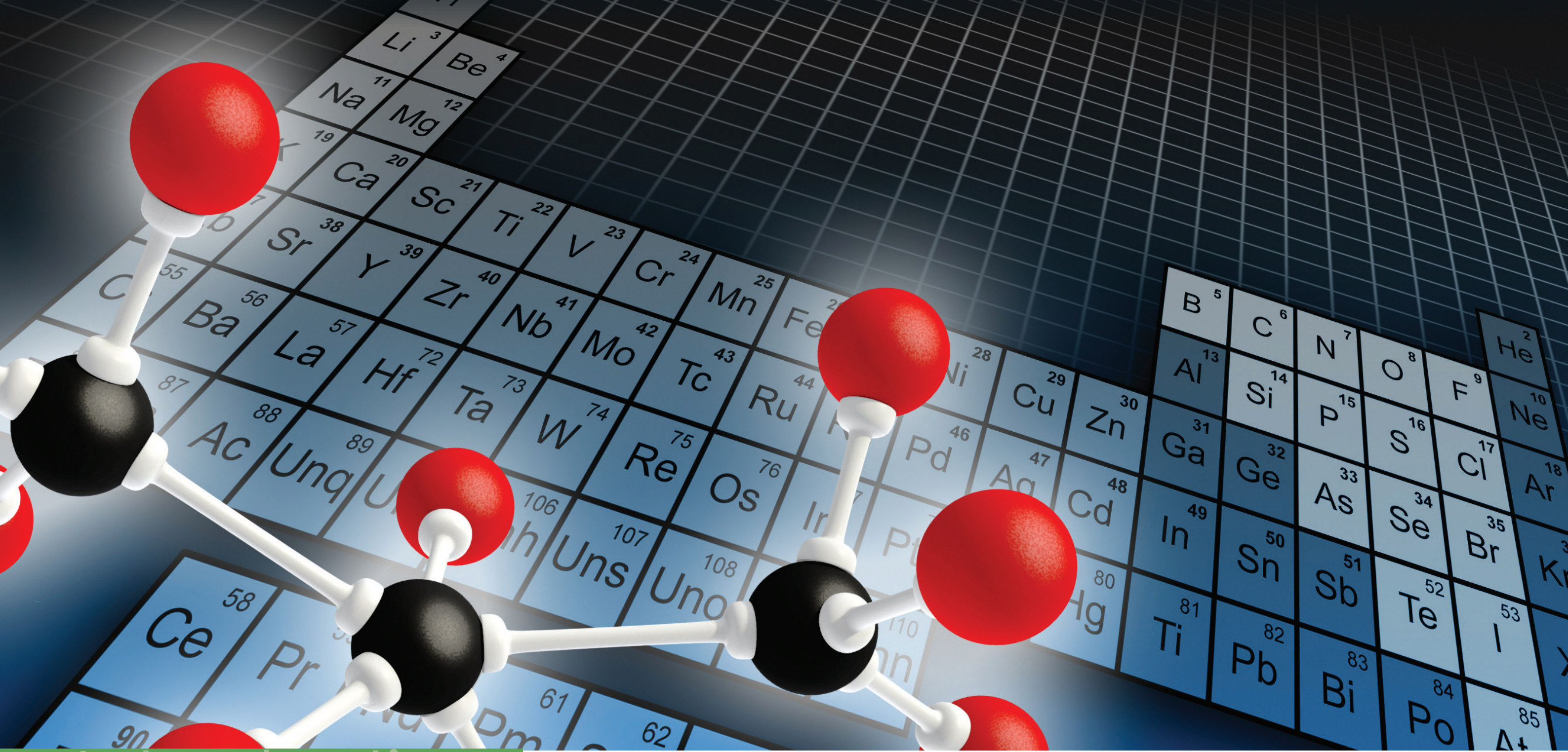
12 Group Properties and Transition Elements



Introduction

In the previous chapter, the general structure and characteristics of the Periodic Table were studied. In this chapter, trends in the physical and chemical properties of elements in selected groups, as well as the transition elements, are investigated. The lack of reactivity of the Group 0 elements is also looked at.

Chapter Opener (page 175)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

   What are elements in Group I? Are they metals or non-metals? Give examples of changes in the elements on going down the elements in the Group.

   Answer: Lithium, sodium, potassium, rubidium and caesium. They are all metals. Going down the group, their size and density would increase.

   What name is given to the elements in Group VII? Are they metals of non-metals? Give examples of changes in the elements on going down the elements in the Group.

   Answer: The halogens. They are non-metals. Going down the group, the elements change from gas to liquid to solid (at room temperature), melting points, boiling points and densities increase.

   In which group of the Periodic Table is helium? Why is helium used to fill airships?

   Answer: In Group 0. Helium is used to fill airships because of its low density and it does not burn.

2. Carry out an 'Inquiry Preview.'

Learning Outcomes

After completing this chapter, students should be able to:

- describe lithium, sodium and potassium in Group I (the alkali metals) as a collection of relatively low-density metals showing a trend in melting point and in their reaction with water
- describe chlorine, bromine and iodine in Group VII (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with solutions of other halide ions
- describe the elements in Group 0 (the noble gases) as a collection of monatomic elements that are chemically unreactive and hence important in providing an inert atmosphere
- describe the lack of reactivity of the noble gases in terms of their electronic structures
- describe the transition elements as metals having high melting points, high density, variable oxidation state and forming coloured compounds
- state that transition elements and/or their compounds are often able to act as catalysts

Teaching pointers

12.1 Where are the Major Groups Positioned? (page 176)

Get the class to look at the elements in Table 12.1 on page 176 of the Textbook, to name as many as they can and to list some facts about those they are already familiar with. This information can form an 'advance organiser' for the chapter.

(page 176)

Mystery Clue

They are called the rare-earth elements as they were originally thought to be rare in the Earth's crust. Other rare earth elements include cerium and neodymium.

Teaching pointers

12.2 What are the Group I Elements? (page 176)

1. The study of the group properties of the alkali metals consists of two parts:
   (a) The common features of the alkali metals: soft, dull metals (shiny underneath), low density, low boiling point, rapid reaction with water to produce hydrogen.
   (b) The trends down the group: decrease in melting point, increase in density and increase in reactivity.
2. Show the class samples of lithium, sodium and potassium metals. Demonstrate that these metals are soft by cutting them with a knife. Observe that they are dull on the surface but shiny underneath. Refer to Table 12.1 on page 177 of the Textbook to show that these metals all have low densities and low melting points (compare with iron which has a density of 7.8 g/cm^3 and a melting point of 1535 °C).
3. Following the demonstration, pose this question to the class: "Sodium reacts vigorously with water. How would you expect lithium to react?" [Answer: Lithium reacts less vigorously than sodium.]. Test this suggestion by placing a piece of lithium in water. Lithium fizzes a lot in water.
4. The reactions of the alkali metals can also be demonstrated with video clips. This method is safer as it does not require the actual demonstrations of the experiments in the laboratory. With video clips, the reactions of rubidium and caesium can be shown. These video clips can be found on the Internet (refer to 'Notes for Teachers' on the next page) and in CD-ROMs such as *Chemistry Set 2000* (preferred) and *Science and Nature: Elements*.

5. A demonstration of the reaction of sodium with water is included in Experiment 13.1 in the Practical Workbook. Teachers could decide to do the demonstration at this point and then refer back to it when Experiment 13.1 is done.

Skills Practice (page 166)

1. **(a)** Lithium, sodium and potassium (all have densities < 1 g/cm^3)
2. The hydrogen gas igniting from the heat generated in the reaction.
3. **(a)** One
   (b) (i) Solid
   (ii) Dull grey (silvery underneath)
   (iii) Soft
   (c) (i) More vigorously
   (ii) $2Rb(s) + 2H_2O(l) \longrightarrow 2RbOH(aq) + H_2(g)$
   (iii) It is alkaline.
4. **(a)** Rb^+
   (b) Rb_2O

Notes for Teachers

IT Link

You may find the following links useful, either for background information or for class use.

Reactions of alkali metals with water:
http://www.powerlabs.org/chemlabs/sodium.htm
http://www.webelements.com/sodium/
http://www.webelements.com/potassium/
http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/007_SODIUMANDPO.MOV

Cutting of alkali metals and reaction with water:
http://www.seilnacht.com/film/english.html

Teaching pointers

12.3 What are the Group VII Elements? (page 179)

1. As with the alkali metals, begin this section with the *common* properties of the halogens. Halogens have low melting and boiling point, are non-metals and have diatomic molecules. Then discuss the *trends* down the group. The physical state changes from gases in fluorine and chlorine to liquid in bromine to solid in iodine. Down the group, the melting and boiling point increases, reactivity decreases (as shown by displacement reactions) and the colour of the elements becomes darker.
2. Show the class sealed samples of the halogens in sturdy bottles. The halogens are very toxic so care is needed to avoid any skin contact. Chlorine is the most common halogen. The smell associated with a swimming pool is due to chlorine dissolved in the water.
3. Note that astatine and its compounds are not found in nature. Astatine is an unstable element which was first made by scientists in 1940.

4. Discuss the toxic nature of chlorine. Chlorine was the first poison gas to be used as a weapon during World War I. Mention the physiological effects of chlorine to bring out the horror of chemical warfare. See also the Extension activity Chemistry and Poetry. (In Chapter 17, when the Haber process is discussed, mention the role of Fritz Haber in the use of chlorine and other poisonous gases in World War I.)
5. A demonstration of the reaction of sodium with water is included in Experiment 13.1 in the Practical Workbook. Teachers could decide to do the demonstration at this point and then refer back to it when Experiment 13.1 is done.
6. Compare the reactivity of the Group VII elements with the Group I elements, which increase down the group.
7. The displacement by a more reactive halogen of a less reactive halogen from a solution of its ions is an example of a displacement reaction. These reactions are investigated in Experiment 12.1.
8. Other displacement reactions are investigated in later chapters: displacement of metals (Chapter 13), displacement of ammonia (Chapter 17) and displacement in redox reactions (Chapter 21).

Experiment 12.1: (PWB page 57)

In this experiment, students investigate displacement reactions of chlorine using small-scale apparatus. The chlorine is produced from the reaction between bleach (sodium hypochlorite) and dilute acid. Alternatively, the reactions could be carried out in test-tubes using aqueous chlorine. Ensure that students understand the meaning of the term *displacement*.

As the experiment investigates only the displacement reactions of chlorine, investigations with other reactions could be demonstrated as follows:

- Add aqueous bromine to aqueous potassium iodide. Iodine is formed but the colour change is not obvious as bromine is already coloured.
- Repeat the experiment with a drop of iodine solution in aqueous potassium bromide. There is no reaction. The fact that there is no colour change is also not obvious as the iodine solution is already coloured.

Note: You may omit the demonstrations if you feel that students will be confused.

Notes on the experiment

- A small reaction vessel is placed in the Petri dish. One way to obtain this is to cut the curved bottom off a small plastic pipette.
- If test-tubes are used for the experiment, the aqueous chlorine should be added from a dropping pipette, one drop at a time into the halide solution. Aqueous chlorine can be prepared by bubbling chlorine gas through water until it is saturated with gas. Alternatively, aqueous chlorine could be prepared by adding 14 cm^3 of 2 mol/dm^3 of HCl to 20 cm^3 household bleach solution and making up the solution to 1 dm^3 in a volumetric flask with distilled or deionised water. As chlorine water gradually changes to hydrochloric acid, it must be freshly prepared.
- In the reaction between chlorine and aqueous potassium iodide, the colour changes from colourless in potassium iodide solution to dark brown and then black (iodine solid).
- After the experiment is completed, remove any excess halogen solutions by adding sodium hydroxide until the mixture is colourless. Flush the mixture down the sink with plenty of water.

Skills Practice (page 180)

1. (a) Covalent bonds. The bonds are strong.
   (b) Weak as there are no covalent/strong bonds between the molecules.
2. As the forces between the halogen molecules are weak, little (heat) energy is needed to separate the molecules. Thus, the halogens have low melting and boiling points.
3. Melting points increase. With alkali metals, melting points decrease down the group.
4. (a) Bromine is more reactive than halogen than iodine.
   (b) $Br_2(aq) + 2NaI(aq) \longrightarrow 2NaBr(aq) + I_2(aq)$
5. Bromine is less reactive than chlorine.

Notes for Teachers

Physiological effects of chlorine gas
Chlorine irritates the skin and eyes. Breathing small amounts of chlorine for short periods of time adversely affects our respiratory system. The effects range from coughing and vomiting to difficulty in breathing, chest pain and retention of fluids in the lungs leading to death.

IT Link

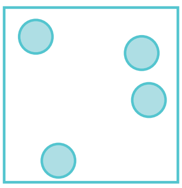
A video showing the burning of sodium in chlorine:
http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA0/Movies/NACL1.html
http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/021_SODIUMCHLOR.MOV

Teaching pointers

12.4 What are the Group 0 Elements? (page 181)

Ensure that students understand the uses of the noble gases are due to the related ideas of
(a) the lack of reactivity of the elements, and
(b) their stable electronic structures.

Skills Practice (page 182)

1. 

Note: Neon molecules are monatomic. Therefore, they consist of single atoms.

2. Noble gas atoms are stable and do not form bonds with other noble gas atoms. Hence, molecules of noble gases are monatomic and consist of single atoms. The halogen elements are unstable. A chlorine atom combines with another chlorine atom to form a diatomic molecule.
3. These metals are welded by surrounding the metal with an unreactive noble gas, such as argon, during the welding. This provides an inert atmosphere which prevents the metal from reacting with air.

Notes for Teachers

Stability of noble gases

In 1916 (just three years after Bohr proposed the idea of electron shells), chemists Kossel and Lewis realised that all the noble gases, except helium, had an octet of outer shell electrons. They suggested that this arrangement was responsible for the stability of the noble gases. This forms the basis of modern theories of bonding. Consequently in the same year, Kossel and Lewis explained the formation of ions and proposed the idea of the ionic bond (Chapter 6).

Teaching pointers

12.5 What are the Transition Elements? (page 182)

1. Discuss the transition elements as the "in between" elements between the Group I and Group III elements due to their electronic structures. The class could complete a table such as that shown in the notes below for the transition metals in Period 4.
2. Transition metals produce the colours in many gemstones. Refer to "Chemistry in Society" in Chapter 6 and show the class the coloured salts of some transition metals.
3. The discussion on variable valency and catalysts could be kept brief at this time and then referred to and discussed in depth when these topics are covered in later chapters.

(page 183)

Mystery Clue

Transition metals have high densities. As praseodymium is in the same period as tungsten (W), it could be expected to have a density at least that of tungsten (its actual value is higher at 6.8 g/cm³). A melting point of 1000–1500 °C might be predicted (the actual value is 931 °C).

Note: Use this example to again illustrate the use of the Periodic Table in making predictions but also that these must be checked by experiment to see if they are accurate.

Notes for Teachers

Electronic structures of the transition elements

The table below shows the proton numbers and electronic structures for the transition metals in Period 4.

Metal	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc
Symbol	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Proton number	21	22	23	24	25	26	27	28	29	30
Electronic structure	2.8.9.2	2.8.10.2	2.8.11.2	2.8.12.2	2.8.13.2	2.8.14.2	2.8.15.2	2.8.16.2	2.8.17.2	2.8.18.2

Like the Group II elements, there are 2 outer shell electrons.

Electrons begin to fill up the third shell.

In zinc, the third shell now has the maximum possible number of electrons (18).

Each element in the table has two electrons in its outer shell (the fourth shell). In this respect, the elements are like calcium (2.8.8.2). However, scandium, the first transition metal, has nine electrons in its third shell. For the other metals, the number of electrons in the third shell increases up to the maximum number of 18 for this shell in zinc (2.8.18.2).

Gallium (Ga), the element after zinc, has the electronic structure 2.8.18.3. As it has three outer shell electrons, gallium is in Group III. Thus, the electronic structures of the transition metals put them into a separate part of the Periodic Table between Groups II and III.

Skills Practice (page 183)

1. Fe_2O_3, $CoCl_2$, Cu_2O, V_2O_5

2. **(a)** Metal Y — high density and has a coloured compound.
   (b) X — magnesium; Z — potassium

Chemistry in Society (page 184)

Filling Gaps in the Periodic Table

This bulletin provides information on how the gaps in Mendeleev's Periodic Table were filled as well as information on the scientists who discovered these missing elements. Make links to previous work such as carbon dating in chapter 5, Mendeleev's table in chapter 11 and noble gases in this chapter.

As a revision exercise, get the class to name all the element mentioned in the text, locate them in the Periodic Table and write their symbols. (They are: Barium, Ba. Radium, Ra. Nitrogen, N. Oxygen, O. Argon, Ar. Helium, He. Neon, Ne. Krypton, Kr. Xenon, Xe.)

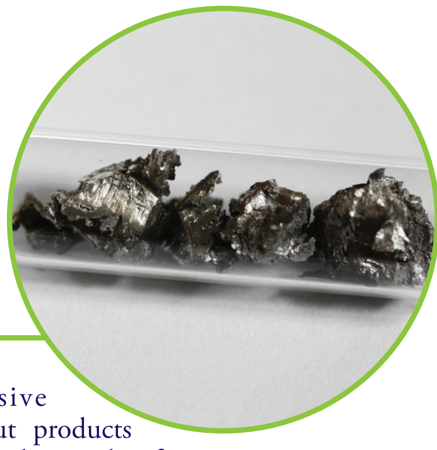
Exercise

1. Researchers are to wear special protective clothing which helps to protect against radiation. Laboratories have specific procedures regarding the receipt, handling and disposal of radioactive materials and also for spills of such materials.
2. Curiosity ensured Ramsay did not stop his work after discovering argon but used this knowledge to discover other gases. These gases do not seem to fit in Mendeleev's Periodic Table, thus Ramsey's discoveries led to novel ideas which are later accepted.
3. Reasons may include the following:
   – Proton numbers increase by one from Group 0 to Group I.
   – The outer shell of a noble gas is full and the next group of elements have a new shell containing one electron, which makes it a Group I element.
4. Both are in the same group of the Periodic Table (Group II) and therefore have the same number of outer shell electrons (two).
5. Noble gases are colourless and unreactive. They consist of monatomic molecules and have stable electronic structures.

Teaching Notes for

Solving the Mystery (page 185)

What place does praseodymium have in our world?

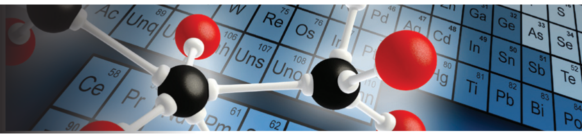


Infer
Dy, Nd, Sm, Tb. All these elements are in the same rare earth series as praseodymium.

Connect
Examples include mobile phones and computers.

Further Thought
Yes. Rechargeable batteries (and thus hybrid cars), renewable energy (wind turbines and solar panels) and mobile phones are examples of technologies that could be affected by a shortage of these metals. A shortage will also mean the elements, and the products that use them, will become more expensive and put products out of the reach of large parts of the global population. However, if manufacturers can quickly substitute other materials for rare earths, the problem will not be as serious.

12 Chapter Review



Self-Management

Misconception Analysis (page 173)

1. **True** As a group, the Group I metals are the most reactive. For example, they react with air, react vigorously with cold water and react explosively with dilute acids.
   Note: The most reactive individual element is actually fluorine.

2. **False** The reactivity of Group I elements increases down the group but for the Group VII elements, reactivity decreases down the group.

3. **False** The Group I elements are all metals. But Group VII consist of a solid (iodine), a liquid (bromine) and gases (fluorine and chlorine).

4. **False** Chlorine displaces a halogen from halides that are lower in the group. For example, chlorine displaces bromine from bromides but not fluorine from fluorides as it is more reactive than bromine but less reactive than fluorine.

5. **True** The noble gas elements are monatomic, i.e. they have one atom in their molecules.

6. **False** Helium atoms have two outer shell electrons; all the other noble gas elements have eight outer shell electrons.

Practice

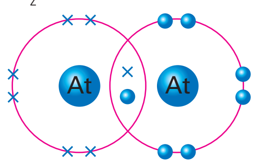
Structured Questions (page 187)

1. (a) The density of sodium is less than that of water because it floats on water.
   (b) It is floating on a layer of hydrogen gas.
   (c) The sodium melts into a shape of a ball.
   (d) (i) An alkali, sodium hydroxide, is produced.
   (ii) $2Na(s) + 2H_2O(aq) \longrightarrow 2NaOH(aq) + 2H_2(g)$
   (e) $2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$
   (f) (i) I would expect a less vigorous reaction.
   (ii) I would expect a more vigorous reaction (an explosion).

2. (a) Sodium has larger atoms as it has two electron shells compared with one for lithium.
   (b) (i) Their atoms have the same number of outer shell electrons.
   (ii) Lithium atoms forms Li^+ and sodium atoms forms Na^+.
   (iii) The formulae for lithium sulfate and sodium sulphate are Li_2SO_4 and Na_2SO_4 respectively.
   (c) (i) Sodium has the higher density. (Densities increase down the group.)
   (ii) Lithium has the higher melting point. (Melting points decrease down the group.)

3. (a) (i) Fluorine, F_2; chlorine, Cl_2; bromine, Br_2; iodine, I_2.
   (ii) Non-metals
   (b) The elements become darker down the group and change from gas to liquid to solid.
   Down the group, the elements change from a pale yellow gas (fluorine) to a darker greenish-yellow gas (chlorine) to a reddish-brown liquid (bromine) to a shiny black solid (iodine).
   (c) (i) All the Group VII elements have seven outer shell electrons.
   (ii) All the Group VII elements form ions with a charge of –1.
   (d) Down the group, the melting points and boiling points of the Group VII elements increase, their colour becomes darker and their reactivity decreases. (Any two)

4. (a) Solid
   (b) (i) At_2
   (ii)



   (iii) Covalent bond
   (iv) At^-
   (c) (i) NaAt
   (ii) Less vigorously. Reactivity of Group VII elements decreases down the group.

6. (a) (i) E.g. Conducts electricity, has a high density, has a high melting point, has compounds with different valency, forms coloured compounds.
   (ii) E.g. Compounds of different valency – copper(I) oxide Cu_2O and copper(II) oxide CuO. Compounds with different colours – Copper(II) oxide is black, copper(II) sulfate is blue.
   (b) $CuBa_2O_3$.

Free Response Questions (page 188)

1. Responses to this question may include the following points:
   – Like sodium and potassium, lithium and rubidium are also Group I metals. They have one outer shell electron each.
   – Physical properties: Like sodium and potassium, lithium and rubidium are likely to be soft, easy to cut, have a dull surface but are shiny underneath.

- Chemical properties: Like sodium and potassium, lithium and rubidium are likely to react with water to form the metal hydroxide and hydrogen gas. Down the group, the reactivity of the Group I elements increase. Lithium is above sodium in the group and so is expected to react less vigorously than sodium. Rubidium is below potassium and is expected to react more vigorously than potassium.

2. Responses to this question may include the following points:
   Group I:
   - Densities increase down the group
   - Melting points and boiling points decrease down the group.
   - Reactivity with water increases down the group. For example, lithium fizzes a lot, but potassium catches fire and explodes.

Extension (page 188)

Chemistry and Poetry

A copy of the poem showing the effects of chlorine gas on soldiers is included below. The poem is only suitable for students with a good grasp of English. It includes a description of the death of a soldier caused by chlorine poisoning during World War I. It was written in 1918 by the English poet Wilfred Owen, who himself was killed just seven days before the end of the war. The title of the poem is **'Dulce et Decorum Est'**. The name of the title comes from the line "Dulce et decorum est, pro patria mori" by the Latin poet Horace, which means "It is sweet and fitting to die for one's country". Owen concludes his poem by stating that this statement is a lie.

Dulce Et Decorum Est

Bent double, like old beggars under sacks,
Knock-kneed, coughing like hags, we cursed through sludge,
Till on the haunting flares we turned our backs
And towards our distant rest began to trudge.
Men marched asleep. Many had lost their boots
But limped on, blood-shod. All went lame; all blind;
Drunk with fatigue; deaf even to the hoots
Of disappointed shells that dropped behind.
GAS! Gas! Quick, boys! – An ecstasy of fumbling,
Fitting the clumsy helmets just in time;
But someone still was yelling out and stumbling
And floundering like a man in fire or lime. –
Dim, through the misty panes and thick green light
As under a green sea, I saw him drowning.

In all my dreams, before my helpless sight,
He plunges at me, guttering, choking, drowning.

If in some smothering dreams you too could pace
Behind the wagon that we flung him in,
And watch the white eyes writhing in his face,
His hanging face, like a devil's sick of sin;
If you could hear, at every jolt, the blood
Come gargling from the froth-corrupted lungs,
Obscene as cancer, bitter as the cud
Of vile, incurable sores on innocent tongues, –
My friend, you would not tell with such high zest
To children ardent for some desperate glory,
The old Lie: Dulce et decorum est

Websites with poem and explanatory notes and pictures:
http://www.warpoetry.co.uk/owen1.html
http://barney.gonzaga.edu/~bpiermat/poem/DulceetDecorumEst.html

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