Paper 3 and Paper 4

CC4 The Periodic Table

There are over 100 known elements. The modern periodic table is a chart that arranges these elements in a way that is useful to chemists. Thanks to the periodic table, chemists can make sense of patterns and trends, which lets them predict the properties of elements. This works even if only a few atoms of an element exist. The periodic table shown here includes photos of most of the elements. If an element is very rare or difficult to obtain, it shows a photo of the relevant scientist or research laboratory involved in discovering or naming the element, or a diagram representing the arrangement of its electrons.

The learning journey

Previously you will have learnt at KS3:

- about chemical symbols for elements
- that Dmitri Mendeleev designed an early periodic table
- about periods and groups in the periodic table
- about metals and non-metals, their properties and their positions in the periodic table.

In this unit you will learn:

- how Mendeleev arranged the elements known at the time in a periodic table
- how Mendeleev predicted the existence and properties of undiscovered elements
- how Henry Moseley helped to confirm Mendeleev's ideas
- how the elements are arranged in the modern periodic table
- how to use the periodic table to predict and model the arrangement of electrons in atoms.

CC4a Elements and the periodic table

Specification reference: C0.1; C1.13; C1.14

Progression questions

- What are the symbols of some common elements?
- How did Mendeleev arrange elements into a periodic table?
- How did Mendeleev use his table to predict the properties of undiscovered elements?

A Towels come in all sorts of sizes, colours and patterns, just as the elements have different properties. How would you organise them?

The Russian chemist Dmitri Mendeleev (1834–1907) faced a problem early in 1869. He was busy writing the second volume of his chemistry textbook and could not decide which elements it made sense to write about next. His solution was to construct a table that led to the **periodic table** we know today.

Organising elements

Chemists had discovered 63 elements by 1869, and they were keen to organise them in a helpful way. Mendeleev arranged these elements in order of increasing **relative atomic masses** (called atomic weights then). Unlike other chemists who had tried this before, Mendeleev did not always keep to this order, and he left gaps in his table.

Mendeleev sometimes swapped the positions of elements if he thought that better suited their **chemical properties** and those of their compounds. For example, fluorine, chlorine, bromine and iodine are non-metals that do not easily react with oxygen, whereas tellurium is a metal that burns in air to form tellurium dioxide. Iodine has a lower relative atomic mass than tellurium, so Mendeleev should have placed it before tellurium according to this **physical property**. Instead, he placed iodine after tellurium so that it lined up with fluorine, chlorine and bromine (elements with similar chemical properties to iodine). Even though Mendeleev used the most accurate relative atomic masses then available, he justified this swap by stating that the value for tellurium must be incorrect.

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ,

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,1.
			Fe=56	Ru=104,4	Ir=198.
			Ni=Co=59	Pd=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be=9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,3	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204.
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

B Mendeleev's published 1869 table. The question mark after the relative atomic mass of tellurium, Te, shows that he thought this was incorrect. He swapped the positions of iodine and tellurium so that iodine ended up in the same line as other elements with similar properties.

Mendeleev assumed that elements would continue to be discovered, so he left gaps for them. This helped him to position the existing elements so that vertical columns contained elements with increasing relative atomic mass, and horizontal rows contained elements with similar chemical properties.

6 **1** What information about the elements did Mendeleev use to produce his first table?

7 **2** Explain why Mendeleev swapped the positions of iodine and tellurium in his table.

Making predictions

Mendeleev continued to work on his table. By 1871, he had settled on a table in which elements with similar properties were arranged into vertical columns, just as today.

Series	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1	H 1							
2	Li 7	Be 9.4	B 11	C 12	N 14	O 16	F 19	
3	Na 23	Mg 24	Al 27.3	Si 28	P 31	S 32	Cl 35.5	
4	K 39	Ca 40	? 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Co 59 Ni 59 Cu 63
5	(Cu 63)	Zn 65	? 68	? 72	As 75	Se 78	Br 80	
6	Rb 85	Sr 87	Y 88	Zr 90	Nb 94	Mo 96	? 100	Ru 104 Rh 104 Pd 106 Ag 108
7	(Ag 108)	Cd 112	In 113	Sn 118	Sb 122	Te 125	I 127	
8	Cs 133	Ba 137	Di 138	Ce 140				
9								
10			Er 178	La 180	Ta 182	W 184		Os 195 Ir 197 Pt 198 Au 199
11	(Au 199)	Hg 200	Tl 204	Pb 207	Bi 208			
12				Th 231		U 240		

C Mendeleev's 1871 table with his relative atomic masses. The red boxes are gaps left for elements not known at the time. Di, 'didymium', was later shown to be a mixture of two elements, neodymium and praseodymium.

Mendeleev used the gaps in his table to make **predictions** about the properties of undiscovered elements, based on the properties of nearby elements. One set of predictions was for an element he called eka-aluminium. When gallium was discovered shortly afterwards in 1875, its properties closely fitted those Mendeleev had predicted for eka-aluminium.

Property	Eka-aluminium, Ea	Gallium, Ga
relative atomic mass	about 68	70
density of element (g/cm³)	about 6.0	5.9
melting point of element (°C)	low	29.8
formula of oxide	Ea_2O_3	Ga_2O_3
density of oxide (g/cm³)	about 5.5	5.88
reacts with acids and alkalis?	yes	yes

D Mendeleev's predicted properties of eka-aluminium and the properties of gallium. He also successfully predicted the properties of scandium (discovered in 1879), germanium (1886) and polonium (1898).

Exam-style question

Suggest *two* reasons why other scientists did not accept Mendeleev's periodic table when it was first published. *(2 marks)*

Did you know?

A 313 km diameter crater on the far side of the Moon was named in honour of Mendeleev by the Russian scientists in charge of the Luna 3 space probe. The probe, launched in 1959, was the first to photograph the far side of the Moon. Element 101 is also named after Mendeleev.

6 **3** Mendeleev amended the relative atomic masses of some elements between 1869 and 1871. Give the symbol of one element for which its value was approximately doubled.

7 **4** Explain how Mendeleev's 1871 table shows he was unsure where to place three elements.

7 **5** Explain why the discovery of gallium was seen as a successful test of Mendeleev's periodic table.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 What were the key features of Mendeleev's periodic table?

Extend

E1 How did Mendeleev think creatively to produce his table?

E2 What evidence supported Mendeleev's ideas?

CC4b Atomic number and the periodic table

Specification reference: C1.15; C1.16; C1.17; C1.18

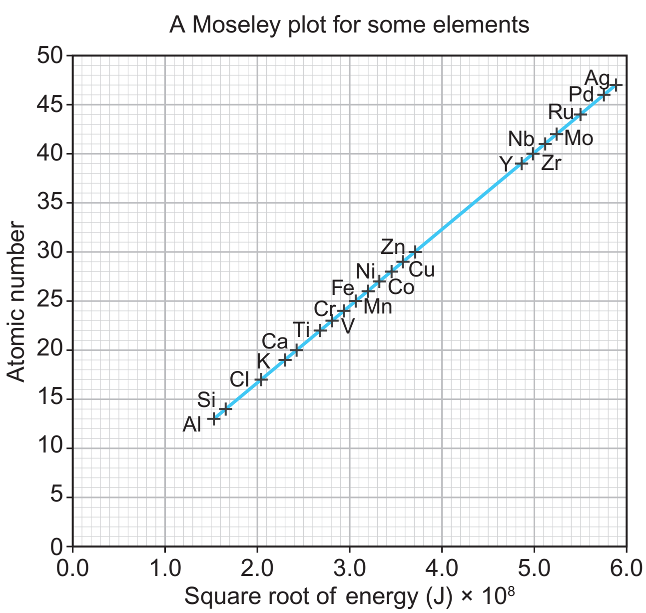
Progression questions

- Why was Mendeleev right to alter the order of some elements in his table?
- What is an element's atomic number?
- How are the elements arranged in the modern periodic table?

A The modern periodic table is easily recognised. There are many fun versions including this one advertising a science park.

Development of the periodic table continued after Mendeleev's first tables. An entire group of **inert** or very unreactive elements was discovered near the end of the 19th century. Even though chemists had not predicted their existence, they were easily fitted into the periodic table as group 0. However, pair reversals such as iodine and tellurium were not properly explained, and there were still gaps. This began to change in 1913 due to a physicist called Henry Moseley.

7 **1** Suggest why chemists in Mendeleev's time did not predict the existence of group 0 elements such as neon.



B There is a linear relationship between atomic number and the square root of the energy of emitted X-rays.

Atomic number

When scientists were beginning to accept the periodic table, an element's atomic number was just its position in the table. Moseley showed instead that it is a physical property of an element's atoms. He fired high-energy electrons at different elements, which made them give off **X-rays**. Moseley discovered that for every step increase in atomic number there was a step change in the energy of these X-rays.

Moseley realised that an atomic number was equal to the number of positive charges in the nucleus of an atom. The particle that carries this charge, the proton, was discovered a few years later. So the **atomic number** must be the number of protons in a nucleus.

7 **2** Describe the difference between Mendeleev's atomic numbers and Moseley's modern atomic numbers.

Pair reversals

The elements in the modern periodic table are arranged in order of increasing atomic number, *Z*. When this is done:

- elements in a row or **period** are in order of increasing atomic number
- elements with similar properties are in the same column or **group**
- non-metals are on the right of the table (the other elements are metals)
- the iodine–tellurium pair reversal is explained.

Iodine exists naturally as ^{127}I but tellurium has several different isotopes. About 20% of its atoms are ^{126}Te but nearly two-thirds of its atoms are ^{128}Te or ^{130}Te, so its **relative atomic mass** is greater than that of iodine.

	group 6	group 7	
all (except oxygen) react with oxygen	oxygen, O colourless gas A_r = 16.0 Z = 8	fluorine, F pale yellow gas A_r = 19.0 Z = 9	none of them react with oxygen
none of them react with water	sulfur, S yellow solid A_r = 32.1 Z = 16	chlorine, Cl green-yellow gas A_r = 35.5 Z = 17	all react with water
	selenium, Se metallic grey solid A_r = 79.0 Z = 34	bromine, Br red-brown liquid A_r = 79.9 Z = 35	
all form compounds containing hydrogen: H_2O, H_2S, H_2Se, H_2Te	tellurium, Te silvery-white solid A_r = 127.6 Z = 52	iodine, I purple-black solid A_r = 126.9 Z = 53	all form compounds containing hydrogen: HF, HCl, HBr, HI

C These are the elements in groups 6 and 7, each with its relative atomic mass, A_r, and atomic number, *Z*.

Filling gaps

More X-ray analysis showed that just seven elements between hydrogen (*Z* = 1) and uranium (*Z* = 92) were left to be discovered. These were all discovered between 1917 and 1945. Neptunium, the first element with an atomic number above 92, was discovered in 1940. Other such 'transuranium' elements continue to be discovered, and all can be placed in the periodic table.

8 **6** Suggest why there is a gap between calcium, Ca, and titanium, Ti, in graph B.

Exam-style question

(a) Give an example, other than iodine and tellurium, of a pair of elements that would be in the wrong places if ordered by relative atomic mass. Use a periodic table to help you. *(1 mark)*

(b) Why would ordering by relative atomic mass be incorrect? *(1 mark)*

Did you know?

Not all of Mendeleev's predictions were correct. For example, he predicted an element with an atomic weight of 0.4 that he called coronium. Moseley's work showed that it could not exist because it would need to contain part of a proton.

6 **3** Give the relative atomic masses of tellurium and iodine to the nearest whole numbers.

8 **4** Use information from diagram C to explain fully why Mendeleev was correct after all to place tellurium before iodine.

7 **5** Use the periodic table at the back of the book to find the metals rubidium to tin, and the non-metals in groups 6 and 7. Describe the general positions of metals and non-metals.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 How are the elements arranged in the modern periodic table?

Extend

E1 What are the features of the modern periodic table?

CC4c Electronic configurations and the periodic table

Specification reference: C1.19; C1.20

Progression questions

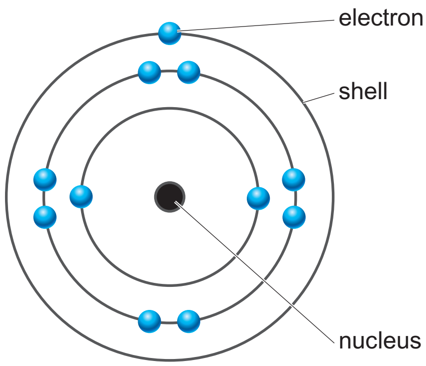
- What information does an electronic configuration give?
- How do you work out and show the electronic configuration of an element?
- How is the electronic configuration of an element related to its position in the periodic table?

A There are many pairs of empty seats on this bus. Where would *you* sit?

You have many choices where to sit on an empty bus but fewer choices when other people are already seated. **Electrons** fill shells in an atom, rather like filling a bus one seat at a time from the front.

Electron shells

In an atom, electrons occupy **electron shells** arranged around the nucleus. The shells can be modelled in diagrams as circles, with the electrons drawn as dots or crosses on each circle. The way in which an atom's electrons are arranged is called its **electronic configuration**. Sodium atoms each contain 11 electrons, and diagram B shows the electronic configuration for sodium.



B The electronic configuration of sodium shows three occupied shells.

Each shell can contain different numbers of electrons. For the first 20 elements (hydrogen to calcium):

- the first shell can contain up to two electrons
- the second and third shells can contain up to eight electrons.

Electrons occupy the shells, starting with the innermost shell and working outwards as each one becomes full. This is why, in a sodium atom, the first shell contains two electrons, the second shell contains eight electrons and the third shell contains one electron.

7 **1** Explain what is meant by the term 'electronic configuration'.

9 **2** Explain why the electrons in a sodium atom do not all occupy one shell.

Working out configurations

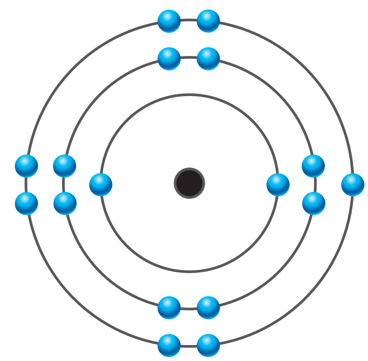
Electronic configurations can also be written out rather than drawn. For example, the electronic configuration for sodium is 2.8.1 – the numbers show how many electrons occupy a shell, and the full stops separate each shell.

You can work out the electronic configuration of an element from its atomic number, *Z*. The atomic number of chlorine is 17 – each chlorine atom contains 17 protons and so also contains 17 electrons.

To fill a chlorine atom's shells:

- 2 electrons occupy the first shell (leaving 15 electrons)
- 8 electrons occupy the second shell (leaving 7 electrons)
- 7 electrons occupy the third shell.

The electronic configuration of chlorine is therefore 2.8.7 (diagram C shows this).



C The electronic configuration of chlorine shows three occupied shells.

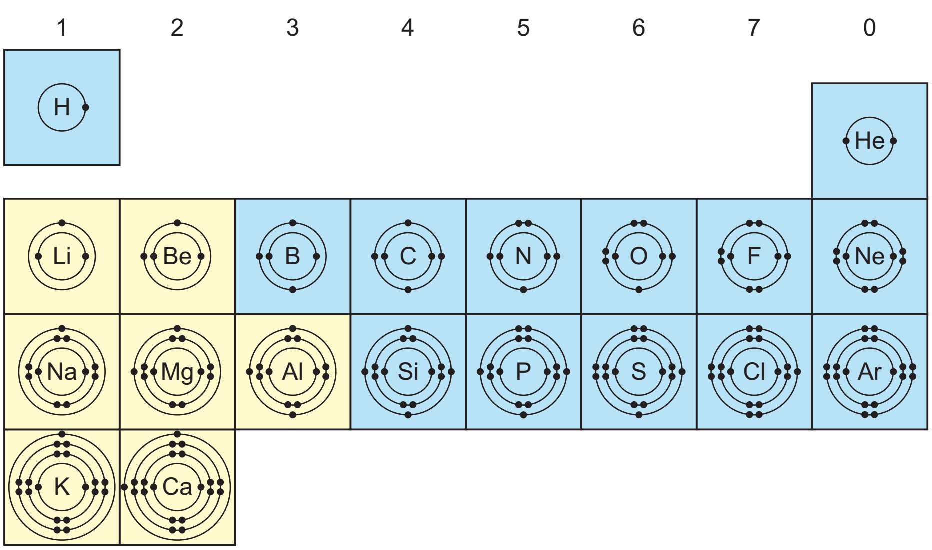
8 **3** Describe how you can determine the atomic number, *Z*, of an element from its electronic configuration.

8 **4** Write the electronic configuration of phosphorus, $Z = 15$.

Connections with the periodic table

Diagram D shows the electronic configurations for the first 20 elements in the periodic table. The electronic configuration of an element is related to its position:

- the number of occupied shells is equal to the period number
- the number of electrons in the outer shell is equal to the group number (except for group 0 elements, which all have full outer shells).



D These are the electronic configurations of the first 20 elements.

8 **5** What do the electronic configurations of sodium and the other elements in group 1 have in common?

9 **6** Explain how you can tell from their electronic configurations that sodium and chlorine are in the same period.

Exam-style question

Explain, in terms of electrons, why magnesium and calcium are in the same group in the periodic table. *(2 marks)*

Did you know?

After calcium, the third and fourth electron shells can actually contain up to 18 electrons. For this reason the International Union of Pure and Applied Chemistry (IUPAC) now recommends the use of group numbers in the range 1 to 18. In this newer numbering system, group numbers 3 to 12 refer to the block of elements between calcium and gallium. Group numbers 13 to 17 refer to the older group numbers 3 to 7, and 18 refers to group 0.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 How do you work out the electronic configuration of an element?

Extend

E1 How is the electronic configuration of an element determined, and related to its position in the periodic table?