

Chapter 8 — Periodic Table and Periodicity

2. Questions for Short Answers

1. Why was atomic number chosen to arrange the elements in the periodic table?

Ans: The atomic number is the number of protons in the nucleus, which is fixed and unique for every element and also decides the number of electrons and hence the electronic configuration of the atom. When the elements are arranged in the ascending order of their atomic numbers from left to right, their electronic configurations change in a regular way and their properties are found repeating after regular intervals. This gives a table in which elements of similar properties fall in the same vertical column. Mendeleev had arranged the elements by their atomic masses, but Moseley later showed that arranging them by atomic number removes the irregularities, so atomic number is the correct basis of the modern periodic table.

2. What is the significance of the word periodic?

Ans: The word periodic means 'repeating after a regular interval'. In the modern periodic table the electronic configuration of the elements keeps changing as we move from left to right in a period, so the elements of a period show a gradual change in their properties. When a shell is completed the same kind of outermost configuration starts again in the next period, and elements having the same number of outermost electrons come one below the other in a group. As a whole the table therefore shows the repetition of the properties of elements after regular intervals, and this trend is called periodicity — which is exactly what the word periodic signifies.

3. Why does the size of a period increase as we move down the periodic table?

Ans: Each period represents the completion of a shell, and the number of elements in a period is fixed by the number of electrons which that shell and its subshells can accommodate. The first period fills only the 1st shell and has 2 elements. The 2nd and 3rd periods fill the s and p subshells and have 8 elements each. From the 4th period onwards the d-subshell also starts being filled, so these periods are long and contain 18 elements each. In the 6th and 7th periods the f-subshell is filled as well, which adds a series of fourteen elements to each, making them very long with 32 elements each. So the period gets bigger as we move down simply because more subshells become available to be filled.

4. In a group, the elements have the same number of electrons in the outermost shell. Why is it so?

Ans: The vertical columns of the periodic table are called groups, and the table is built by arranging the elements in the increasing order of their atomic numbers so that the electronic configuration repeats after regular intervals. Each time a shell is completed a new period begins and the filling of the outermost shell starts over from the beginning. Therefore the element which comes at the same position in the next period has exactly the same number of electrons in its outermost shell as the one above it, only in a higher shell. That is why all the elements of a group have the same outermost-shell configuration — for example ns^1 for group 1 and ns^2np^5 for group 17 — and this is also why they show similar chemical properties.

5. Do you expect calcium to be more reactive than sodium? Give the reason of your answer.

Ans: No, sodium is more reactive than calcium. Sodium belongs to group 1 and has only one electron in its outermost shell, which it loses very easily to form a Na^+ ion; its first ionization energy is only $+496 \text{ kJ mol}^{-1}$. Calcium belongs to group 2 and has two electrons in its outermost shell, and to form its Ca^{2+} ion it must lose both of them, which needs much more energy. Moreover, as we move from left to right in a period the nuclear charge increases and the valence electrons are held more strongly, so chemical reactivity of the metals gradually decreases. For both these reasons calcium is less reactive than sodium.

6. Which element has the maximum atomic radius and which element has the minimum atomic radius in the third period?

Ans: In a period the size of the atoms decreases generally from left to right, because electrons are being added to the same outermost shell while the charge on the nucleus keeps increasing, and this pulls the electrons closer to the nucleus. The third period starts with sodium and ends with argon. Therefore sodium (Na), the first element of the period, has the maximum atomic radius, and argon (Ar), the last element, has the minimum atomic radius. Among the elements which form bonds, chlorine has the smallest covalent radius of the period.

7. Why are the most electronegative elements present in sixth and seventh groups?

Ans: Electronegativity is the electron-attracting ability of an atom, and it increases from left to right in a period and decreases from top to bottom in a group. The elements of the oxygen family and the halogen family lie towards the right-hand side of the table and are the smallest atoms of their periods, so their nuclei attract the shared pair of electrons very strongly. They

also need only two electrons and one electron respectively to complete their octets, so they have a strong tendency to pull electrons towards themselves. For these reasons the most electronegative atoms — F (4.0), O (3.4), N (3.0) and Cl (3.2) — are found in this region, at the top right-hand corner of the periodic table.

8. The first ionization energy value of magnesium is less than the second one. Give reason.

Ans: Magnesium has two electrons in its outermost shell, and they can be removed only one by one. The first electron is removed from a neutral magnesium atom, where the number of protons and electrons is equal, so the attraction on it is comparatively weak and only $+737 \text{ kJ mol}^{-1}$ is needed. After this electron has gone, the particle left behind is a positively charged Mg^+ ion which has one proton more than the number of its electrons. The remaining electrons are therefore held much more tightly by the nucleus, and the ion is also smaller in size. Much more energy, $+1450 \text{ kJ mol}^{-1}$, is thus needed to pull the second electron away, so the second ionization energy is always greater than the first.

9. Is it possible for two metals or two non-metals to form an ionic bond?

Ans: No. An ionic bond is formed by the transference of one or more electrons from one atom to another, so one of the two atoms must be able to lose electrons easily and the other must be able to gain them easily. Metals are electropositive — they have few outermost electrons and low ionization energy, so both of them would want to lose electrons and neither would accept them. Non-metals are electronegative — both of them would want to gain electrons and neither would give them up. Therefore two metals join by a metallic bond and two non-metals join by a covalent bond in which electrons are shared. An ionic bond can only be formed between a metal and a non-metal.

10. Which element has the least value of ionization energy and which element has the highest value of electronegativity?

Ans: Ionization energy decreases from top to bottom in a group and from right to left in a period, so the lowest value belongs to the element lying at the bottom left of the periodic table. Among the first group elements given in the chapter, caesium has the least ionization energy, 377 kJ mol^{-1} . Electronegativity, on the other hand, increases from left to right in a period and decreases down a group, so the highest value belongs to the element at the top right-hand corner: fluorine, whose electronegativity on the Pauling scale is 4.0, the highest of all the elements.

3. Constructed Response Questions

1. Suppose a new element is discovered. Where would you like to accommodate this element in the periodic table?

Ans: The new element would be placed according to its atomic number and its electronic configuration, because the modern periodic table is an arrangement of elements in the ascending order of atomic number. First we would find out its atomic number and write the electronic configuration of its atom. The number of shells occupied gives the period, since each period represents the completion of a shell. The number of electrons in the outermost shell gives the group — one outermost electron means group 1, two means group 2, ns^2np^5 means group 17, and so on. The subshell which is being filled tells us the block: s, p, d or f. The element would then be placed in that period and group, where it should show properties similar to the other members of its group.

2. What is the first element of the periodic table? Will it lose an electron or gain it?

Ans: The first element of the periodic table is hydrogen, whose atomic number is 1. It has only one electron, which is present in its outermost (1st) shell. Like the other elements of group 1 it has a strong tendency to lose this single electron and form a positive ion, H^+ , which is simply a proton — this is exactly what happens when an acid dissociates in water. Hydrogen is, however, a special case: its shell is complete with two electrons, so it can also gain one electron to complete its duplet and form the hydride ion, H^- . Its usual behaviour, though, is to lose the electron.

3. Atomic radii of boron and aluminium are 88 pm and 125 pm respectively. Which element is expected to lose electron or electrons easily?

Ans: Aluminium will lose its electrons more easily. Ionization energy is directly related to atomic size: the smaller the radius of an atom, the stronger the attraction between the nucleus and the outer electrons and the higher the ionization energy. Aluminium, with a radius of 125 pm, is a much bigger atom than boron with 88 pm, so its outermost electrons lie farther from the nucleus and are also shielded by more inner electrons. They are therefore held loosely and can be removed with less energy. This also means aluminium is more metallic and more electropositive than boron — which is why metallic character increases as we move down a group.

4. How would you find the atomic radius of an atom?

Ans: The electron cloud of an atom has no definite limit, so the size of an isolated atom cannot be defined exactly. What can be measured is the radius of an atom when it is bonded to an identical atom. The atomic radius is therefore defined as half the distance between the nuclei of two identical bonded atoms, and it is expressed in picometres ($1\text{ pm} = 10^{-12}\text{ m}$). For example, the distance between the nuclei of two bonded carbon atoms is 154 pm, so half of this distance, 77 pm, is the radius of the carbon atom. This is also called the covalent radius of the atom.

5. Why is it not possible for an oxygen atom to accept three electrons to form an O^{3-} ion like nitrogen which can accept electrons to form N^{3-} ?

Ans: The number of electrons an atom can accept is fixed by how many it needs to complete its octet. Nitrogen belongs to group 15 and has the configuration ns^2np^3 , that is five electrons in its outermost shell; it therefore needs exactly three more electrons to reach eight and can form N^{3-} . Oxygen belongs to group 16 and has the configuration ns^2np^4 , that is six electrons in its outermost shell; it needs only two electrons to complete its octet and forms O^{2-} . A third electron would have no vacant place left in that shell and would have to enter a new shell much farther from the nucleus, against the repulsion of the two negative charges already present on the ion. This would need energy instead of releasing it, so the O^{3-} ion is not formed.