Physics: Atomic Structure and Bonding part 2

EXPLAIN: Bonding and electrostatics

Atoms are rarely found on their own. In fact only the noble gases (group 18 elements He, Ne, Ar, Xe, and Rn) are found as single atoms. This is because they have full valence shells are do not need to react with other atoms to gain or lose electrons.

Other atoms react together to form complete valence shells. During the reaction, the atoms form bonds that hold the atoms together. These bonds are between atoms in the same molecule (or compound) so they are called intramolecular bonds.

Intramolecular bonds may be ionic (formed by ions), covalent (atoms sharing electrons), or metallic (metal atoms bound by mobile electrons).

Ionic bonds

To study an ionic bond, we will use the reaction of sodium metal and chlorine gas as an example. When a sodium atom reacts with a non-metal atom it forms a sodium ion (Na⁺). It has one less electron than its atomic number.

The sodium ion now has only 10 electrons. It has a complete valence shell and the same number of electrons as neon (Ne), but it behaves very differently because it has a positive charge.

Because it is positively charged, other electrically charged atoms (ions) of the opposite charge (negative) have a natural attraction to the sodium, e.g. the chloride ion formed when chlorine gains an electron. Together the sodium ion and chloride ion form sodium chloride (NaCl) table salt (below).

In its pure form, the element sodium is a silvery metal. Its atoms share their mobile electrons and are held together by metallic bonds. It is a very reactive metal.

Chlorine is a gaseous element with a yellow tinge. In its pure form, the atoms are found covalently bonded together in pairs. Chlorine is highly toxic and reactive.

Sodium chloride (table salt) is a highly stable, non-toxic crystal made of sodium and chloride ions held together by ionic bonds.

The positively charged sodium ion can combine with any ion with a negative charge. Together, ions of opposite charge balance out the charges created by the loss and gain of the electrons in the atom. Much like negatively charged electrons balance their positively charged proton counterparts, positively charged cations balance their negatively charged anion counterparts.

15. (a) Positive ions are attracted to _________________ ions.

(b) A cation with a charge of 2+ would need ___ anions with a charge of 1− or one anion with a charge of _____ to balance its total charge.

(c) A Mg²⁺ ion needs _____ Cl⁻ ions or _____ O²⁻ ion to balance its 2+ charge.

ANS:

16. (a) Predict what would happen if two lithium ions were near each other: ____________________________

(b) Predict what would happen if two fluoride ions were near each other: ________________________

ANS:
17. Predict what would happen if a lithium ion were near to a fluoride ion:

ANS:

18. Use electrostatics to explain the differences between the behavior of the ions in Q16 and Q17 above:

ANS:

19. A crystal of sodium chloride has a ratio of 1 Na⁺ ion to 1 Cl⁻ ion. What would the ratio of Al²⁺ to O²⁻ ions be in a crystal of aluminum oxide?

ANS:

20. Coulomb's law can be used to explain differences in the strength of ionic bonds. Consider the two ionic substances MgO and NaCl. The melting point of MgO is 2852°C whereas the melting point of NaCl is 801°C.

Use Coulomb's Law to explain why there is such a large difference between the melting points of NaCl and MgO:

ANS:

Covalent bonds

- Covalent bonds are formed when non-metal atoms share one or more pairs of electrons. Remember, non-metals want to gain valence electrons to reach a stable arrangement. If there are no metal atoms around to give them electrons, non-metal atoms share their valence electrons with other non-metal atoms.

- Since the atoms are using the same electrons they are held together in a neutral particle called a molecule, e.g., two oxygen atoms share electrons in an oxygen gas molecule. A molecule is a neutral particle of two or more atoms covalently bonded together.

- Molecules may contain atoms of the same element such as N₂, O₂, and Cl₂, or they may contain atoms of different elements like H₂O, NH₃, or C₆H₁₂O₆.

- Covalent bonds form when atoms have similar electronegativities (so electrons are shared, rather than gained or lost to form ions). The covalent bonds in an individual molecule are very strong compared to the bonds between those molecules in a substance, so covalent compounds tend to be gases, liquids, or low melting point solids. However, some covalently bonded substances (such as diamond and quartz) form covalent networks, which are very strong.

- The electrons in covalent bonds are not always shared evenly between atoms. Some atoms attract electrons more than others. This means that, in a molecule, electrons may spend more time around one atom than others. This results in polar covalent bonds.

- Molecules with polar covalent bonds can be non-polar overall if they have a symmetrical shape e.g., CO₂. Molecules that are not symmetrical will have a polarity, e.g., water (H₂O).

Non-polar molecule: Both oxygen atoms attract the electrons with the same force. Electrons are shared evenly. There is no polarity in the bond or the molecule.

Non-polar molecule. Oxygen attracts the electrons more than carbon, so each C=O bond is polar. However the molecule is symmetrical and so the molecule is non-polar overall.

Polar molecule: The oxygen atom attracts the electrons more than the hydrogen atom. Electrons are shared unequally resulting in a slightly negative (δ⁻) end and a slightly positive end (δ⁺) (a dipole).
21. Imagine two substances made of molecules of roughly the same size. One substance is polar and the other is non-polar. Use your knowledge of electrostatics and the information about covalent bonds above to predict which one would have the higher melting point. Explain your answer:

ANS:

22. Covalent bonds require a lot of energy to be broken. What is happening to the molecules in a molecular substance (such as propane, methanol, or water) when it melts or boils? What bonds or forces are being overcome?

ANS:

2.8 Investigation demo with microwave

23. (a) What was the effect of holding the rod close to the stream of water? __________________________________________ 

(b) What was the effect of holding the rod close to the stream of cyclohexane? __________________________________ 

(c) Now look at the structure of water and the structure of cyclohexane below. Use your knowledge of electrostatics to explain (a) and (b) above:

ANS:
Metallic bonds

Metallic bonds form between multiple metal atoms. Most metal atoms have only one or two valence electrons and these are not tightly bound to the atoms. In a piece of metal, these loosely held valence electrons do not belong to any single one of the atoms but are able to move freely through the structure from one atom to another.

Metals can be thought of as positive ions (all of the atom except the valence electrons) in a “sea” of loose (delocalized) valence electrons. The mutual attraction of each metal atom to the others’ valence electrons forms the metallic bond.

The metal ions line up in a regular repeating pattern (a crystal lattice) and their loose valence electrons move through this crystal acting as an electron glue. Each of the ions is strongly attracted to all of the loose electrons surrounding it so the whole metal holds together as a crystal.

While the attraction between the “electron glue” and the ions is strong, the attraction between the ions themselves has some “flexibility” (unlike the ionic bond between a sodium and chloride ion which is very rigid).

24. From the information above predict the following properties of metals:

(a) Electrical conductivity: __________________

(b) Conductivity of heat: __________________

(c) The ability of metal to be shaped (its “malleability” and its “ductility”): __________________

(d) The melting points of metals: __________________

ANS:
EXPLAIN: Intermolecular forces
- Molecules interact with each other via intermolecular forces. These are very weak compared to the intramolecular forces that bond the atoms within molecules together.
- Collectively intermolecular forces are called van der Waals forces. Two important van der Waals forces are hydrogen bonding and induced dipole-dipole forces.

Hydrogen bonds
- When hydrogen forms a covalent bond with either oxygen, nitrogen, or fluorine, those atoms attract the electrons much more than the hydrogen, producing a polar covalent bond. The dipole that forms allows other similar molecules to be attracted. Hydrogen bonds are the strongest intermolecular force.

Induced dipole-dipole forces
- Electrons are always in motion around an atom, even in atoms covalently bonded to other atoms. The motion is random and this results in instances where there are more electrons on one side of the molecule than another. This results in a slight polarity from one side of the molecule to the other (below).
- The instantaneous dipole can affect nearby molecules, so that they also form dipoles, resulting in temporary attractions between the molecules (below):
Van der Waals forces play an important role in sticking things together. The ability of geckos (above) to walk up seemingly smooth surfaces is due, in part, to van der Waals forces. The small effect is multiplied millions of time over by the microscopic hairs on the gecko’s feet.

Scientists have been inspired by the gecko’s feet to create dry glues that can be used multiple times or sticky pads that can be used to hold objects to a wall. In 2014, scientists at Stanford University created an adhesive device the size of a human hand and based on gecko’s feet, that allowed a 70 kg man to climb a vertical glass wall (right).

ANS: