7. The VSEPR notation for the molecule is AX_4. The arrangement of the electron pairs about the germanium atom is tetrahedral, and the shape of the molecule is also tedrahedral. The Ge—H bond is essentially non-polar ($\Delta EN = 0.19$). The molecule is symmetrical, so the polarities of the four bonds cancel each other. Therefore, the molecule is non-polar.

8. The electronegativity differences of the four halides decrease in this order: Cs—F ($\Delta EN = 3.19$) > Cs—Cl ($\Delta EN = 2.37$) > Cs—Br ($\Delta EN = 2.17$) > Cs—I ($\Delta EN = 1.87$). The decrease in ΔEN implies a decrease in the attractive force between the cation and the anion, because the effective charge on the ions decreases. The size of the halide ions varies and $I^- > Br^- > Cl^- > F^-$. Since the electrostatic force of attraction varies inversely as the square of the distance between the charges, the electrostatic force between a cation and an anion decreases for larger ions. As a result, the force of attraction between the Cs^+ ion and the halide ion decreases in the following order: CsF > CsCl > CsBr > CsI. To melt an ionic solid, the bond between the cation and the anion needs to be broken. Therefore, the melting points of the halides, from highest to lowest, are in this order: CsF > CsCl > CsBr > CsI.

9. A canoe often comes into contact with rocks when, for example, going aground at a portage or running rapids. The material for making a canoe has to be strong enough to resist possible punctures as a result of this contact. As well, a canoe has to be light enough to be carried. A material that has the strength of steel and the weight of feathers is ideal. KEVLAR® is used to make canoes because it is produced from very light fibres, which can withstand the impact of a bullet without shredding. KEVLAR® spreads any impact over a wide area, so that no part of the canoe punctures or breaks.

10. Diamond is a network solid. Each carbon atom of diamond is joined to four other carbon atoms in the shape of a tetrahedron, so each diamond is a single molecule.
    (a) An electrical insulator is a poor conductor of electricity. It is used to suppress the flow of electricity. Diamond does not conduct electricity because all its electrons are tied up in the covalent bonds between carbon atoms. Thus, diamond would make an excellent insulator. Diamond is not flexible, however, so it cannot be wrapped around wires. Currently, industrial diamonds are very small and are only used for abrasives.
    (b) To create an optical fibre, the core of the fibre must have a very high refractive index. The refractive index of glass fibre is 1.512. The refractive index of diamond is 2.417. This optical property of diamond would make it an ideal core fibre. However, no technology has yet been developed to grow or machine diamond into long thin threads. Thus, diamond is not yet a suitable material for making cables for fibre optics.

Chapter 4 Review Answers

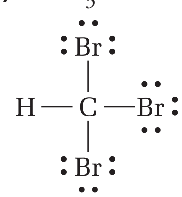
Student Textbook pages 209-211

Answers to Knowledge/ Understanding Questions

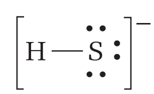
1. An octet in the valence level of atoms is a stable arrangement—an arrangement that corresponds to a minimum total energy for the system. For example, the noble gases are chemically unreactive, and each atom of a noble gas element (other than He) has eight valence electrons.

2. All the halogen hydrides are polar. They experience dispersion forces as well as dipole-dipole forces. The dispersion forces are greatest in HI and smallest in HF, because the HI molecule is the largest and contains the most electrons. ΔEN is greatest in HF and smallest in HI, so the dipole-dipole forces are greatest in HF and smallest in HI. However, ΔEN is small for the halogens, so the difference in the strength of the dipole-dipole forces is not as significant as the difference in the strength of the dispersion forces. Therefore, the boiling point should increase from HF to HI. In HF, though, the relative sizes of the hydrogen atom and fluorine atom allows hydrogen bonding to occur in this molecule. Hydrogen bonding does not occur in the other hydrogen halides. As a result, HF has the strongest intermolecular forces and its boiling point is higher than the boiling points of the other hydrogen halides.

3. **(a)** $CHBr_3$



(b) HS^-



4. An induced dipole exists when a non-polar molecule comes close to an ion or a polar molecule. As soon as the ion or polar molecule moves away, the induced dipole disappears. A permanent dipole is produced by the difference in the electronegativities of the atoms within a molecule. The dipole does not disappear, and its existence is independent of the presence of other molecules.

5. The intermolecular forces of non-polar molecules are dispersion forces. The strength of these forces depends on the number of electrons and the shape and size of the molecule. Oil is a mixture of large organic molecules, which have many car-

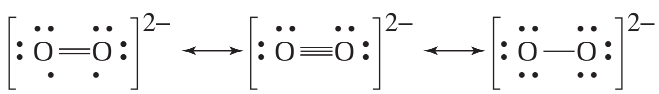
bon atoms and a large number of electrons. As a result, the dispersion forces between the molecules are very strong, even stronger than the hydrogen bonding in water. Therefore, cooking oil has a higher boiling point than water.

6. **(a)** dispersion forces and dipole-dipole forces
(b) ionic bond
(c) metallic bond
(d) dispersion forces

7. Cesium is a metallic solid, and sulfur is a molecular solid. The other two elements are gases. Thus, cesium has the highest boiling point, and sulfur has the next highest boiling point. Krypton has more electrons (36) in its atom than oxygen gas (32). The dispersion forces of krypton are greater than the dispersion forces of O_2. Thus, the order of decreasing boiling points is cesium > sulfur > krypton > oxygen. This order agrees with the measured boiling points: Cs (944 K), S (717.8 K), Kr (119.9 K), and O_2 (90.2 K).

8. H_2O and NH_3 have the same number of electrons in their molecules. ΔEN is greater for O—H (1.24) than for N—H (0.84). Therefore, the O—H bond is more polar and forms stronger hydrogen bonds. Thus, hydrogen bonding is stronger in water than in ammonia.

9. O_2^{2-}



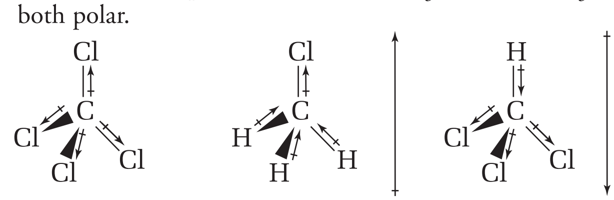
10. The term “crystal” describes something macroscopic—something we can see. The unit cell of a crystal is microscopic. It cannot be seen with the unaided eye or even with a microscope. X-ray diffraction is used to make a model of the crystal, from which the unit cell can be determined. The unit cell is the structure that, if repeated many times, makes up the crystal.

11. If an ionic crystal is broken, each of the broken pieces is still made up of repeating unit cells of the original crystal. Thus, on a microscopic scale, each broken piece has the same shape as the original crystal. Glass is an amorphous solid. If glass is shattered, the silicate tetrahedra do not arrange themselves identically in the broken pieces.

12. Viscosity is the ability of a liquid to resist flow. In flowing, the molecules must move past one another. A liquid with low viscosity thus experiences weaker intermolecular forces between liquid molecules. Surface tension arises due to an imbalance of forces between molecules at the surface of the liquid and the forces between the liquid molecules in the interior. Regardless of the strength of the intermolecular forces, this net force always exists at the surface of the liquid. Therefore, a liquid with low viscosity can have a high surface tension.

13. SiO_2 is a network solid, so it has the highest boiling point. K is a metallic solid. The boiling point of K is therefore relatively lower. C_3H_8 and C_2H_5OH are covalent solids, which have lower boiling points than SiO_2 and K. C_2H_5OH is polar, and it may have hydrogen bonding in its solid form. C_3H_8 is non-polar and will not form hydrogen bonds. C_2H_5OH probably has a higher boiling point than C_3H_8. Thus, the order of increasing boiling points is $C_3H < C_2H_5OH < K < SiO_2$. Actual boiling point data support this prediction: C_2H_5OH (351 K), SiO_2 (2503 K), C_3H_8 (231 K), K (1039 K).

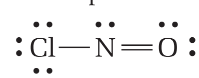
14. The molecular shapes of CCl_4, CH_3Cl, and $CHCl_3$ are all tetrahedral. CCl_4 is non-polar, and CH_3Cl and $CHCl_3$ are both polar.



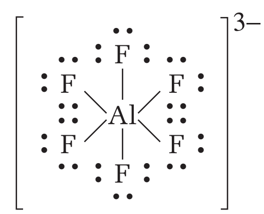
CH_3Cl and $CHCl_3$ would have dipole-dipole forces between molecules in liquid samples.

15. Dipole-dipole attractions are intermolecular forces between two polar molecules. An ionic bond is the attraction between two ions: one positively charged and the other negatively charged. Ionic bonds are usually thought of as intramolecular forces. In an ionic crystal, however, it is impossible to differentiate between the intermolecular and intramolecular forces.

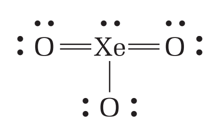
16. **(a)** The shape of the NOCl molecule is bent.



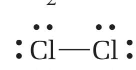
(b) The shape of the AlF_6^{3-} ion is octahedral.



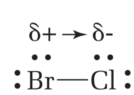
(c) The shape of the XeO_3 molecule is trigonal pyramidal.



17. **(a)** Cl_2



(b) BrCl

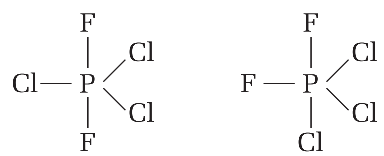


18. Substances that have the following VSEPR notations have the same name for the molecular shape and the electron group arrangement: AX_2 (linear), AX_3 (trigonal planar), AX_4 (tetrahedral), AX_5 (trigonal bipyramidal), and AX_6 (octahedral). In other words, a molecule that does not have any lone pairs of electrons has the same name for its molecular shape and electron group arrangement.

19. If the polar bonds in a molecule are arranged around the central atom in such a way that the dipoles can cancel each other, then the molecule is non-polar. Non-polar molecules with polar covalent bonds include binary (two-element) molecules with no electron lone pairs. These molecules have the VSEPR notation AX_n, where n = 2, 3, 4, 5, and 6. Linear molecules that have the VSEPR notation AX_2E_3 (XeF_2, for example) and square planar molecules that have the VSEPR notation AX_4E_2 (XeF_4, for example) are also non-polar.

Answers to Inquiry Questions

20.



non-polar polar

When the two fluorine atoms are bonded to the central atom along the vertical axis of the trigonal bipyramidal arrangement, the dipoles cancel and the molecule is non-polar. When one fluorine atom and one chlorine atom are bonded to the central atom along the vertical axis, however, the molecule is polar.

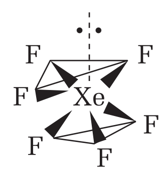
21. At temperatures above 4°C, water cools. The molecules move closer together, so the density of the water increases. This increase in density continues until the temperature of the water is 4°C, when the open hexagonal structure (due to hydrogen bonding) stops further contraction in the volume of the water. When the water cools further, below 4°C, the water molecules form more of the open hexagons that are found in ice. The volume begins to increase, so the density begins to decrease.

22. The electronegativity difference between the elements in a compound determines the type of bonding present. ΔEN of NaCl is 2.23, and the compound is ionic. ΔEN of $CaCl_2$ is 2.16. The compound is also ionic, but it has less ionic character than NaCl. ΔEN of $AlCl_3$ is 1.55, and the compound is polar covalent. Al^{3+} and Cl^- ions do not form the lattice structure that is characteristic of ionic solids. The electrostatic force of attraction is greatest in NaCl, so NaCl requires the most energy to melt (to break its ionic lattice). Therefore, NaCl has the highest melting point. Since $AlCl_3$ is more of a covalent compound, the melting point of $AlCl_3$ is the lowest.

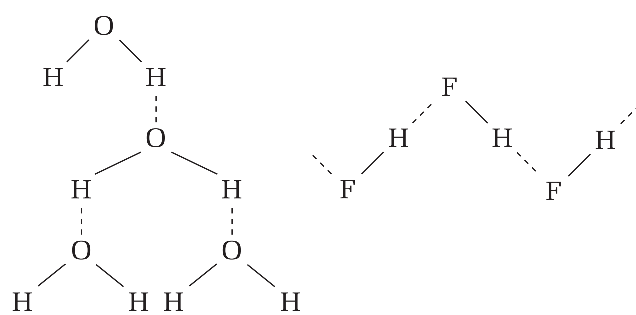
23. (a) The decomposition of Au_2S_3 occurs at a lower temperature than the decomposition of Au_2S. Thus, Au_2S has greater ionic character. That is, more energy is required to break the ionic lattice of Au_2S.

(b) The decomposition of the sulfide is the reverse of the formation reaction. Since the decomposition temperature of Au_2S is higher than the decomposition temperature of Au_2S_3, Au_2S is thermally a more stable compound than Au_2S_3. Since stability is related to lattice energy, the lattice energy of Au_2S is greater than the lattice energy of Au_2S_3.

24. The ground state electron configuration of Xe is [Kr] $4d^{10}$ $5s^2$ $5p^6$. If six fluorine atoms are bonded to Xe, the resulting molecule will have the VSEPR notation AX_6E. In total, there will be one non-bonding pair and six bonding pairs of electrons surrounding the central atom. Thus, the shape is not octahedral. This molecule has the xenon atom in the centre, with a lone pair of electrons directly above it. The six fluorine atoms are arranged at the three points of each of two triangles above and below the xenon atom.



25. From the electronegativity values, the H—F bond (ΔEN = 1.78) is more polar than the O—H bond (ΔEN = 1.24). This suggests that hydrogen fluoride may have a higher boiling point than water. However, hydrogen bonding is much stronger in water than in hydrogen fluoride. The bent shape of the water molecule allows for two O—H bonds to form hydrogen bonds. Each water molecule can be linked to three other molecules, but each hydrogen fluoride molecule can be linked to only two other molecules. As a result, water should have a higher boiling point. From Figure 4.16 on page 193 of the student textbook, the boiling point of water is 373 K and the boiling point of hydrogen fluoride is 293 K.



Answers to Communication Questions

26. The ground state electron configuration of S is [Ne]$3s^2$ $3p^4$. To form four bonds, as in SF_4, one electron of S has to be excited to a $3d$ orbital to give [Ne]$3s^2$ $3p^3$ $3d^1$. As a result, the electron arrangement around the central S atom involves four bonding pairs and one non-bonding pair of electrons. The VSEPR notation for this molecule is AX_4E. The electron group arrangement is trigonal bipyramidal, and the shape of the molecule is seesaw. The molecule is slightly polar.

The ground state electron configuration of Si is [Ne]$3s^2$ $3p^2$. To form four bonds, as in SiF_4, one electron of Si has to be excited to a $3p$ orbital to give [Ne]$3s^1$ $3p^3$. As a result, the electron arrangement around the central Si atom involves four bonding pairs of electrons. The VSEPR notation for this molecule is AX_4. The electron group arrangement is tetrahedral, and the shape of the molecule is also tetrahedral. The molecule is non-polar due to the symmetry of the four identical Si—F bonds around the central atom.

27. The electronegativity difference between Na and I is 1.73. NaI is an ionic solid. Therefore, the forces of attraction that must be overcome to melt this solid are the electrostatic attractions due to ionic bonding. The electronegativity difference between H and I is 0.46. HI is a covalent solid that is only slightly polar. The intermolecular forces in HI are dispersion forces and dipole-dipole forces. To melt solid HI, these forces of attraction have to be overcome.

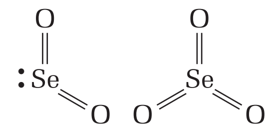
28. (a) Diamond is a crystalline solid that does not melt. It sublimes at a temperature around 4000 K. It is one of the hardest substances known. 2,2-dimethylpropane is a liquid at room temperature. Its melting point is 257 K, and its boiling point is 283 K.

(b) The C—C bonds in both diamond and 2,2-dimethylpropane are the same. The bond energy is 348 kJ/mol, and the bond length is 154 pm. In both substances, a carbon atom is bonded to four other carbon atoms in the shape of a tetrahedron. In diamond, however, each carbon atom is bonded to four other carbon atoms in a huge network. In 2,2-dimethylpropane, each outer carbon is bonded to one carbon atom and three hydrogen atoms. Thus, 2,2-dimethylpropane exists as discrete molecules. The diamond molecule is the diamond itself. The entire crystal is a molecule because every carbon atom in the crystal is linked to four other carbon atoms within the network.

(c) The C—C bonds in diamond are networked. To cleave, to smash, or to scratch a diamond, you have to break thousands of C—C bonds. This makes diamond a very hard solid. For 2,2-dimethylpropane, the forces that hold the molecules in a solid are dispersion forces. Thus, the solid is much softer and melts at a much lower temperature.

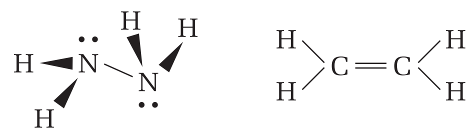
29. Carbon dioxide is a linear, non-polar covalent molecule. The only intermolecular forces that act between the molecules are dispersion forces. These forces are very weak because the carbon dioxide molecule has only 22 electrons and is quite small. Therefore, carbon dioxide exists as free molecules (a gas) at room temperature. In contrast, each silicon atom is strongly bonded to four oxygen atoms in the form of a tetrahedron, and each oxygen atom is bonded to two silicon atoms to form a network. To melt silica, a lot of energy is needed to break the bonds in the network. Therefore, silica has a very high melting point (1873K), and it exists as a solid at room temperature.

30.



The electronegativity difference between selenium and oxygen is 0.89. Thus, each Se=O bond is polar. The shape of a SeO_2 molecule is bent, and a net dipole results. Therefore, the molecule is polar. In SeO_3, the selenium atom forms three double bonds with three oxygen atoms. The shape of the molecule is trigonal planar. Although the Se=O bonds are polar, the symmetry of the molecule causes the dipoles of the Se=O bonds to cancel one another. Therefore, the SeO_3 molecule is non-polar.

31.



Ethene is a planar molecule with a double bond between the two carbon atoms. In this arrangement, the slight polarities of the C—H bond cancel each other. Therefore, ethene is a non-polar molecule. The intermolecular forces in ethene are dispersion forces only. Hydrazine (18 electrons) has stronger dispersion forces than ethene (14 electrons). The N—H bond is also more polar than the C—H bond. A hydrazine molecule consists of two trigonal pyramidal structures linked through the nitrogen atoms. In this arrangement, the polarities of the N—H bonds do not cancel, and the molecule is polar. As well as dipole-dipole forces and dispersion forces, hydrogen bonding occurs between the hydrogen atoms of one molecule and the nitrogen atoms of another molecule. Thus, the intermolecular forces in liquid hydrazine are considerably larger than the intermolecular forces in ethene. As a result, the boiling point of hydrazine should be higher than the boiling point of ethene.

Answers to Making Connections Questions

32. There are no correct or typical answers to questions like this. However, students should include the following ideas and provide reasons for their opinion.

Risks associated with inert substances:

- Materials that are very inert present problems with disposal. A common example is foam cups, which do not decompose and therefore end up in landfill sites. Imagine what would happen if every 12-year-old bought a KEVLAR® jacket for protection. Three years later, the landfill sites would be filled with KEVLAR® jackets that the children outgrew.

Benefits associated with inert substances:

- KEVLAR® gloves and vests protect workers in hazardous situations.
- Foam cups are inexpensive and convenient for keeping drinks warm or cold.

Benefits versus risks:

- The benefits of KEVLAR® products outweigh the risks, since the quantity in use remains quite small.
- The benefits of foam cups do not outweigh the risks, since people can use re-usable cups instead.

33. Here are some examples of how intermolecular forces influence the weather:

- If you are standing at the top of a ski hill and snow just begins to fall, you may feel that the temperature is rising. As water sublimes to form snowflakes, hydrogen bonds (intermolecular forces) are formed. The making of bonds produces energy, so you feel that the air temperature is higher.
- On a very hot summer day, if you get out of a swimming pool and lay on a hot concrete patio beside the pool, you may find yourself shivering in the heat. As the water on your body evaporates, the hydrogen bonds in the water need energy to break. The energy is absorbed from your body, so your skin feels cool.
- On a cold winter morning, you may notice frost on the classroom windows. During the previous night, the glass window became very cold. As water vapour passed over the window, it cooled and the water molecules were brought closer together. The hydrogen bonds then formed to give small crystals of ice. The frost "painting" on the window was formed by water vapour subliming to the solid.

Unit 2 Project

Materials Convention

Student Textbook pages 212–213

Tips

- Have students work in groups of three or four on this project. In each group, include students with different abilities. Consider assigning a leader for each group if you want students to develop leadership skills.
- Students should start working on their unit project when you start teaching the unit. Students' presentations should be done before the unit test.
- When discussing the rubric for assessing the work, ensure that criteria related to Knowledge/Understanding, Inquiry, Communication, and Making Connections are included, as well as co-operative learning skills.
- If you use this or any other unit project as an assignment for the whole class, consider displaying the finished project in a public place within the school area, so that other students and visitors can see it.
- Some types of materials that students may wish to study are semiconductor materials, plastic and polymeric materials, biomaterials, metals and alloys, glasses, ceramics and composites, and structural and building materials. Students can use these names as keywords to start their search on the Internet.

Assessment and Evaluation

Rubric for the Unit 2 Project: Materials Convention is available. See Assessment Rubrics on the *Teacher's Resource* CD-ROM.