Analysis

(d) According to the evidence collected, solid 1 is network covalent, 2 is ionic, 3 is metallic, and 4 is molecular.

Evaluation

(e) Most of the evidence was sufficient to classify the majority of the solids. The classification of the network covalent solid fits with the properties of network covalent solids but was done mainly by elimination once the others were classified. This classification is very uncertain and it is possible that solid 1 may be a low-solubility ionic solid. The classification of solids 2, 3, and 4 seems relatively certain.

Other properties such as hardness and melting points would help to make the classification more certain.

CHAPTER 4 SUMMARY

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Force or bond	Central particle	Surrounding particles
covalent	electron pair	nuclei
covalent network	electron pair	nuclei
dipole–dipole	charge site	opposite charge sites
hydrogen	proton	electron pairs
ionic	ion	oppositely charged ions
London	nuclei	nearby valence electrons
metallic	nuclei	mobile valence electrons (electron sea)

Substance	Hardness	Melting point	Electrical conductivity		
			Solid	Liquid	Solution
molecular	low	low	negligible	negligible	negligible
ionic	medium to high	high	negligible	high	high
covalent network	high	very high	negligible	negligible	n/a
metallic	medium	medium to high	high	high	n/a

CHAPTER 4 SELF-QUIZ

(Page 281)

1. False: The shape of molecules of the rocket fuel hydrazine, $N_2H_{4(l)}$, is predicted by VSEPR theory to be pyramidal around each nitrogen.
2. True
3. False: A central atom with two bonded atoms and two unshared electron pairs has a V-shaped arrangement of its electron pairs.
4. False: Ionic substances are ionic solids, with ionic bonding.
5. False: Hydrogen bonding is possible whenever the molecule contains hydrogen atoms bonded to N, O, or F atoms.
6. False: A molecule with a pyramidal shape and polar bonds will be polar.
7. True
8. True
9. False: The end of a soap molecule that attracts and dissolves oily dirt must be nonpolar.
10. True
11. (b)
12. (b)

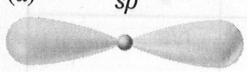
13. (d)
14. (a)
15. (c)
16. (c)
17. (c)
18. (a)
19. (b)
20. (d)

CHAPTER 4 REVIEW

(Page 282)

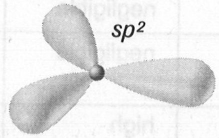
Understanding Concepts

1. (a) ·Ca· (2) (b) :Cl· (1) (c) ·P· (3) (d) ·Si· (4) (e) :S· (2)
2. For a covalent bond to form between two approaching atoms, both atoms must have a valence orbital occupied by a single electron (or one atom must have a vacant valence orbital and the other must have a lone pair of electrons) and the orbitals must be able to overlap in space.
3. (a) three lone pairs
   (b) one lone pair
   (c) two lone pairs
   (d) no lone pairs
   (e) one lone pair
4. (a) :F· (b) ·P· (c) K· (d) :Se· (e) ·Sr·
5. The electron configuration that gives an atom maximum stability is one with eight electrons in the shell with the highest principal quantum number (the "valence" shell).
6. (a) $1s^2\ 2s^2\ 2p^6$
   (b) A carbide-12 ion has 6 protons and 6 neutrons in the nucleus, with 2 electrons in the first shell (inner layer), and 8 more electrons in the second shell (outer layer).
7. (a) *sp*



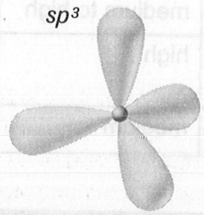
linear

(b) sp^2



trigonal planar

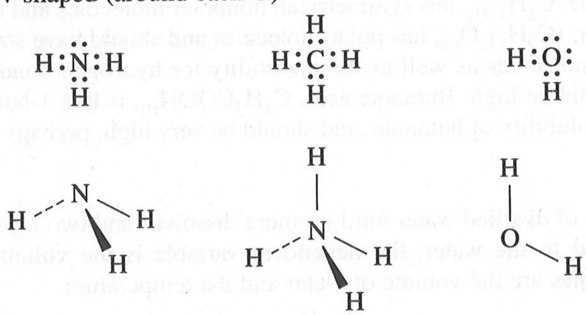
(c) sp^3



tetrahedral

8. (a) sp^3
   (b) sp^2
   (c) sp
   (d) sp^3
9. A sigma bond involves overlap of orbitals directly, or end to end, between the atomic nuclei. A pi bond involves side-by-side overlap of the two lobes of *p* orbitals above and below a line between the atomic nuclei.
10. (a) 2 sigma bonds
    (b) 3 sigma bonds and 2 pi bonds
    (c) 5 sigma bonds and 1 pi bond
    (d) 7 sigma bonds
11. The B atom has sp^2 hybridization initially, and the N atom has sp^3 hybridization (with an unshared pair of elecrons in the fourth hybrid orbital). After reaction, both central atoms must be sp^3 hybridized (they are each bonded to four other atoms). This occurs because the N supplies both electrons for the B-N sigma bond.

12. (a) Valence shell refers to the energy level of electrons with the highest principal quantum number.
    (b) Bonding pair refers to a pair of electrons shared between atoms in a valence orbital.
    (c) Lone pair refers to a pair of electrons in a valence orbital that are not shared with another atom.
    (d) Electron pair repulsion assumes that valence orbitals occupied by a pair of electrons are "full" and will repel any other full valence orbital.
13. To predict the shape of a molecule using the VSEPR model, you
    first, draw a Lewis diagram for the molecule, and
    second, count the lone pairs and bond pairs around the central atom(s), and
    finally, predict the shape around the central atom(s) from the electron pair numbers.
14. (a) linear
    (b) trigonal planar
    (c) tetrahedral
    (d) tetrahedral
    (e) linear
    (f) V-shaped
    (g) tetrahedral
    (h) V-shaped (around each O)
15. (a)



pyramidal　　　tetrahedral　　　V-shape

    (b) In methane, the bond angles are the normal tetrahedral angle. In ammonia, repulsion from the lone pair compresses the bond angles a bit, and in water, stronger repulsion from two lone pairs compresses the bond angle even more.
16. (a) :Ö::C::Ö:
    (b) A carbon dioxide molecule is linear, with a bond angle of 180°.
    (c) Carbon dioxide has two double bonds, each of which is strongly polar. The two bond polarities are exactly opposite and so the resultant is zero, and the molecule is nonpolar.
17. (a) An N–Cl bond is not noticeably polar, with an electronegativity difference of 0.0; whereas a C–Cl bond is polar, with an electronegativity difference of 0.5.
    (b) A molecule of $NCl_{3(l)}$ should be nonpolar because the bonds are nonpolar. A molecule of $CCl_{4(l)}$ should be nonpolar because it is symmetrical, so the bond dipoles balance, cancelling any molecular polarity.
18. (a) BeH_2 is a nonpolar molecule because it is linear and symmetrical, so its bond dipoles balance each other. H_2S is a polar molecule because it is V-shaped and not symmetrical, so its bond dipoles combine to produce a nonzero resultant dipole.
    (b) BH_3 is trigonal planar, while NH_3 is pyramidal in shape, because NH_3 has a lone pair of electrons repelling the three bond pairs.
    (c) LiH has a melting point of 688°C because solid LiH has an ionic crystal structure, with ions held together by relatively strong ionic bonding. HF has a melting point of –83°C because solid HF has a molecular crystal structure, with molecules held together by much weaker intermolecular forces.
19. The larger molecules have stronger London force intermolecular bonding because the molecules have a greater number of electrons per molecule. Therefore, the larger the molecule in this series, the higher the boiling point.
20. $CH_{4(g)}$ (–164°C), has London force; $NH_{3(g)}$ (–33°C), has London force, dipole–dipole force, and hydrogen bonding; and $BF_{3(g)}$ (–100°C), has London force. Ammonia has the strongest intermolecular bonds because of the hydrogen bonding; boron trifluoride has London force from a 32-electron molecule; and methane has weaker London force from a 10-electron molecule.

21. (a) Nickel has a much higher melting point than sodium chloride because the metallic bonding holding nickel atoms together is stronger than the ionic bonding holding sodium and chloride ions together.
(b) Solid nickel will conduct well, because the atoms' valence electrons are free to move. Solid sodium chloride will not conduct because the charges (ions) are not free to move.
(c) Solid nickel will not dissolve, because the atoms attract each other much more than water molecules can attract them. Solid sodium chloride will dissolve because the charges (ions) are strongly attracted by polar water molecules.

22. (a) Hexane has London force.
(b) 1-butanol has London force, dipole–dipole force, and hydrogen bonding.
(c) Ethylamine has London force, dipole–dipole force, and hydrogen bonding.
(d) Chloroethane has London force and dipole–dipole force.
(e) Calcium carbonate has ionic bonds.
(f) Diamond has convalent bonds.

Applying Inquiry Skills

23. (a) **Prediction**

According to intermolecular forces concepts, the order from lowest to highest solubility in water is pentane, diethyl ether, 1-butanol, and butanoic acid. Pentane, $C_5H_{12(l)}$, has symmetrical, nonpolar molecules and therefore should have little solubility in water. Diethyl ether, $(C_2H_5)_2O_{(l)}$, has polar molecules and should have some solubility in water. 1-butanol, $C_4H_9OH_{(l)}$, has polar molecules as well as the possibility for hydrogen bonding with water molecules. The solubility of 1-butanol should be high. Butanoic acid, $C_3H_7COOH_{(l)}$, is like 1-butanol but has more hydrogen bonding sites available. The solubility of butanoic acid should be very high, perhaps miscible with water.

(b) **Experimental Design**

Slowly add each of the liquids to a small quantity of distilled water until no more dissolves and two layers form. The independent variable is the substance added to the water, the dependent variable is the volume of the substance that dissolves, and the controlled variables are the volume of water and the temperature.

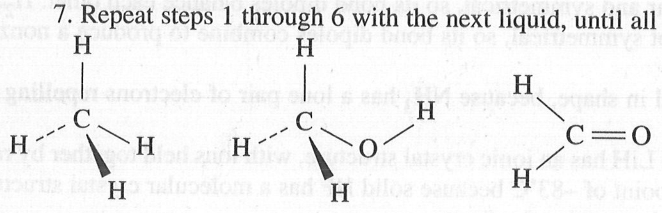
(c) **Materials**

lab apron
eye protection
medium-sized test tube with stopper
5 10-mL graduated cylinders
5 droppers or disposable pipets
waste container for organic mixtures
bottle of distilled water
samples of pentane, 1-butanol, diethyl ether, butanoic acid

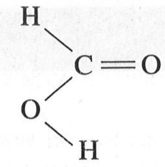
(d) **Procedure**

1. Measure 10.0 mL of water with a graduated cylinder and place it into the test tube.
2. Measure 10.0 mL of pentane in another graduated cylinder.
3. Start adding little of the pentane to the water, and stopper and invert between each addition.
4. Stop adding pentane when a second layer is noticed in the test tube. Note the volume of pentane added.
5. Dispose of mixture into the labelled waste container.
6. Clean and dry the test tube.
7. Repeat steps 1 through 6 with the next liquid, until all liquids have been tested.

24.



tetrahedral (methane) | tetrahedral and V-shape (methanol) | trigonal planar (methanal)



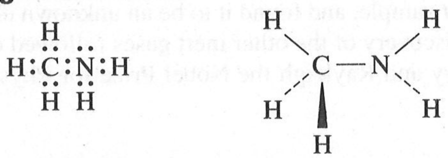
trigonal planar
and V-shape
(methanoic acid)

linear
(carbon dioxide)

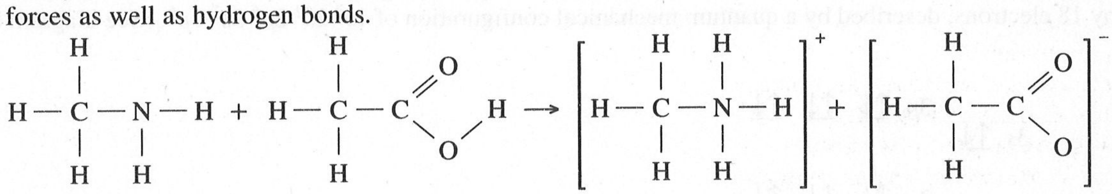
25. (a) Metallic solids are composed of atoms with mobile valence electrons—they may be thought of as an arrangement of close-packed positive ions held together by strong mutual attraction for electrons that permeate the structure. Network solids are composed of atoms held together by very strong (directional) covalent bonds.
(b) Network solids are composed of atoms held together by very strong (directional) covalent bonds. Molecular solids are composed of molecules held together by relatively weak intermolecular forces.
(c) Molecular solids are composed of molecules held together by relatively weak intermolecular forces. Ionic solids are composed of positive and negative ions held together by relatively strong (nondirectional) ionic bonds.

Making Connections

26. (a)



(b) The shape around the carbon atom is tetrahedral, and the shape around the nitrogen atom is pyramidal.
(c) Methylamine has a much higher boiling point because methylamine molecules have additional dipole–dipole forces as well as hydrogen bonds.
(d)

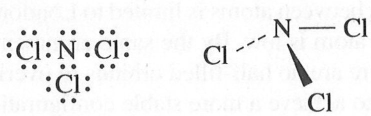


(e) Vinegar and lemon juice reduce the odour of fish because they are acidic, and react to neutralize the basic amines that cause "fishy" odours.

27. The material used for the skin of stealth aircraft is a carbon fibre composite material. It has fibres of carbon embedded in a matrix—the same basic type of structure as fibreglass composites, but very much stronger. The material can also be structured as a "honeycomb" to give a very high strength-to-weight ratio for solid pieces. The material is suited for radar "stealthing" because it can be made to absorb microwaves, greatly reducing any detectable reflection.

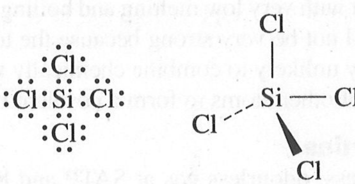
Extension

28. (a)



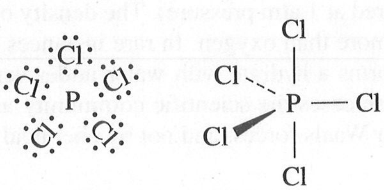
nonpolar

(b)



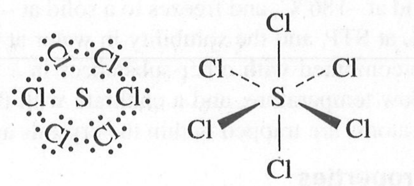
nonpolar

(c)



nonpolar

(d)



nonpolar

UNIT 2 PERFORMANCE TASK: A STUDY OF AN ELEMENT

(Page 284)

A STUDY OF ARGON

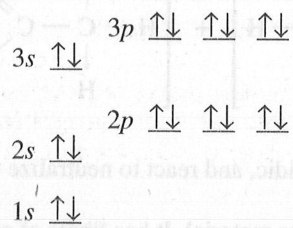
History

The English scientist, Henry Cavendish, was shy and reclusive to the point of phobia, and, consequently, never took examinations for his degree at Cambridge, which would have involved personal contact with the examiners. Nonetheless, his contributions to science guarantee his place in history. He is most famous for the physics experiment in which he determined the value of G, the universal gravitational constant; but in 1785, he performed chemical experiments with air which eventually led to the discovery of argon. When he chemically combined all of the oxygen and nitrogen in a sample of dry air, he found that a small bubble of gas, about 1% of the total volume, remained no matter what he did to get it to react. He speculated at the time that air contains an unknown gas that is resistant to chemical reaction. This was correct—he had discovered a new element.

The Cavendish experiment was ignored for more than a century until it was repeated by Sir William Ramsay in 1892 in an attempt to solve a problem publicized by Lord Rayleigh. Rayleigh had found that nitrogen obtained from air had a slightly higher density than did nitrogen obtained from its compounds. Ramsay and Rayleigh used a spectroscope to analyze the bright-line spectrum emitted by the unreacted gas from an air sample, and found it to be an unknown element. They named the new element argon, from the Greek word for "inert." Discovery of the other inert gases followed quickly from this research. In 1904, Ramsay won the Nobel Prize for Chemistry and Rayleigh the Nobel Prize for Physics, for their discovery and determination of the properties of argon.

Structure and Bonding

An atom of argon is theoretically described as having atomic number 18, meaning a nuclear structure made up of 18 protons, and, most commonly, 22 neutrons. About 0.34% of argon atom nuclei have 20 neutrons, and about 0.07% have 18 neutrons. There are at least 12 other unstable (radioactive) isotopes of argon known to exist. The atomic volume is occupied by 18 electrons, described by a quantum mechanical configuration of $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$. (See diagram below.)



Ground-state electron configuration for an argon atom, Ar

The octet of electrons of the highest energy level results in a particularly stable (low) energy configuration. Notice that all orbitals contain a pair of electrons and that there are no half-filled orbitals. Theoretically then, argon should exist as a monatomic element with very low melting and boiling points because the attraction between atoms is limited to London forces. These forces should not be very strong because the total number of electrons per atom is low. By the same argument, argon should be extremely unlikely to combine chemically with other atoms because there are no half-filled orbitals to overlap with half-filled orbitals of other atoms to form a covalent bond or to transfer electrons to achieve a more stable configuration.

Physical Properties

Argon is a colourless, odourless gas at SATP and has a molar mass of 39.95 g/mol. The gas condenses to a colourless, odourless liquid at –186°C, and freezes to a solid at –189°C (both values measured at 1 atm pressure). The density of argon gas is 1.78 g/L at STP, and the solubility in water at 0°C is 56 mL/L, slightly more than oxygen. In rare instances, argon is found to be combined with other substances in a fixed-mass ratio. Argon forms a hydrate with water under very high pressure and low temperature, and a clathrate with ß-hydroquinone, but in these cases the scientific community assumes that the argon atoms are trapped within the crystals and held in place by van der Waals forces, and not by chemical bonds.

Chemical Properties

Argon has no known chemical compounds, which agrees very well with the prediction from the theoretical atomic structure. This evidence strongly supports the quantum mechanical and bonding theories. I am not sure why one or more valence elec-