2.1 What is the mass in grams of (a) a proton, (b) a neutron, and (c) an electron?
(a) mass of proton = $1.673 \times 10^{-24}$ g
(b) mass of neutron = $1.675 \times 10^{-24}$ g
(c) mass of electron = $9.109 \times 10^{-28}$ g

2.2 What is the electric charge in coulombs of (a) a proton, (b) a neutron, and (c) an electron?
(a) proton charge = $+1.602 \times 10^{-19}$ C
(b) neutron charge = 0 C
(c) electron charge = $-1.602 \times 10^{-19}$ C

2.3 Define (a) atomic number, (b) atomic mass unit, (c) Avogadro’s number, and (d) relative gram atomic mass.
(a) The atomic number is the number of protons contained in the nucleus of an atom.
(b) An atomic mass unit, $u$, is defined as exactly $1/12$ of the mass of the carbon atom which has a mass of 12 $u$.
(c) Avogadro’s number, $N_A$, is $6.02 \times 10^{23}$ atoms/mol.
(d) The relative gram atomic mass of an element is the mass in grams of $6.023 \times 10^{23}$ atoms of that element.

2.4 What is the mass in grams of one atom of gold?

$$x = \text{mass of 1 Au atom} = \frac{196.97 \text{ g/mol Au}}{6.02 \times 10^{23} \text{ atoms/mol}} \times (1 \text{ atom}) = 3.27 \times 10^{-22} \text{ g Au}$$

2.5 How many atoms are there in 1 g of gold?

$$x = \text{No. of atoms of Au} = \frac{6.02 \times 10^{23} \text{ atoms/mol}}{196.97 \text{ g/mol Au}} \times (1 \text{ g Au}) = 3.06 \times 10^{21} \text{ atoms Au}$$

2.6 A gold wire is 0.70 mm in diameter and 8.0 cm in length. How many atoms does it contain? The density of gold is 19.3 g/cm$^3$.

First determine the mass of gold based upon the wire volume and the density of gold.

$$m = \text{mass of Au} = \rho V \text{ where } \rho = 19.3 \text{ g/cm}^3$$

and
\[ V = \text{volume of wire} = (\text{area})(\text{length}) = \left( \frac{\pi d^2}{4} \right) L = \frac{\pi}{4} \left[ (0.7 \text{ mm}) \left( \frac{1 \text{ cm}}{10 \text{ mm}} \right) \right]^2 (8.0 \text{ cm}) = 0.0308 \text{ cm}^3 \]

Thus, \( m = (19.3 \text{ g/cm}^3 \text{ Au})(0.0308 \text{ cm}^3) = 0.5944 \text{ g Au} \)

The number of atoms is then calculated as,

\[ \text{No. of atoms Au} = \left( 0.5944 \text{ g Au} \right) \left[ \frac{6.02 \times 10^{23} \text{ atoms/mol}}{196.97 \text{ g/mol Au}} \right] = 1.82 \times 10^{21} \text{ atoms Au} \]

2.7 What is the mass in grams of one atom of molybdenum?

\[ x = \text{mass of 1 Mo atom} = \frac{95.94 \text{ g/mol Mo}}{6.02 \times 10^{23} \text{ atoms/mol}} \times (1 \text{ atom}) = 1.59 \times 10^{-22} \text{ g Mo} \]

2.8 How many atoms are there in 1 g of molybdenum?

\[ x = \text{No. of atoms of Mo} = \frac{6.02 \times 10^{23} \text{ atoms/mol}}{95.94 \text{ g/mol Mo}} \times (1 \text{ g Mo}) = 6.27 \times 10^{21} \text{ atoms Mo} \]

2.9 A solder contains 52 wt % tin and 48 wt % lead. What are the atomic percentages of Sn and Pb in this solder?

Using a basis of 100 g of solder, there are 52 g of Sn and 48 g of Pb. The number of gram-moles of tin and lead is therefore,

\[ \text{No. of gram-moles of Sn} = \frac{52 \text{ g}}{118.69 \text{ g/mol}} = 0.4381 \text{ mol} \]
\[ \text{No. of gram-moles of Pb} = \frac{48 \text{ g}}{207.19 \text{ g/mol}} = 0.2317 \text{ mol} \]

Total gram-moles = \text{0.6698 mol}

The atomic percentages may then be calculated as,

\[ \text{Atomic % Sn} = \left[ \frac{0.4381 \text{ mol}}{0.6698 \text{ mol}} \right] (100\%) = 65.4 \text{ at}\% \]
\[ \text{Atomic % Pb} = \left[ \frac{0.2317 \text{ mol}}{0.6698 \text{ mol}} \right] (100\%) = 34.6 \text{ at}\% \]

2.10 A monel alloy consists of 70 wt % Ni and 30 wt % Cu. What are the atomic percentages of Ni and Cu in this alloy?
Using a basis of 100 g of alloy, there are 70 g of Ni and 30 g of Cu. The number of gram-moles of each element is thus,

\[
\text{No. of gram-moles of Cu} = \frac{30 \text{ g}}{63.54 \text{ g/mol}} = 0.472 \text{ mol}
\]

\[
\text{No. of gram-moles of Ni} = \frac{70 \text{ g}}{58.71 \text{ g/mol}} = 1.192 \text{ mol}
\]

Total gram-moles = 1.664 mol

The atomic percentages may then be calculated as,

\[
\text{Atomic \% Cu} = \left( \frac{0.472 \text{ mol}}{1.664 \text{ mol}} \right) (100\%) = 28.4 \text{ at\%}
\]

\[
\text{Atomic \% Ni} = \left( \frac{1.192 \text{ mol}}{1.664 \text{ mol}} \right) (100\%) = 71.6 \text{ at\%}
\]

2.11 A cupronickel alloy consists of 80 wt \% Cu and 20 wt \% Ni. What are the atomic percentages of Cu and Ni in the alloy?

Using a basis of 100 g of alloy, there are 80 g of Cu and 20 g of Ni. The respective number of gram-moles is thus,

\[
\text{No. of gram-moles of Cu} = \frac{80 \text{ g}}{63.54 \text{ g/mol}} = 1.2590 \text{ mol}
\]

\[
\text{No. of gram-moles of Ni} = \frac{20 \text{ g}}{58.71 \text{ g/mol}} = 0.3407 \text{ mol}
\]

Total gram-moles = 1.5997 mol

The atomic percentages may then be calculated as,

\[
\text{Atomic \% Cu} = \left( \frac{1.2590 \text{ mol}}{1.5997 \text{ mol}} \right) (100\%) = 78.7 \text{ at\%}
\]

\[
\text{Atomic \% Ni} = \left( \frac{0.3407 \text{ mol}}{1.5997 \text{ mol}} \right) (100\%) = 21.3 \text{ at\%}
\]

2.12 What is the chemical formula of an intermetallic compound that consists of 49.18 wt \% Cu and 50.82 wt \% Au?

We need to determine \( \text{Cu}_x \text{Au}_y \) where \( x \) and \( y \) represent the gram-mole fractions of copper and gold, respectively. Therefore, first calculate the gram-mole fractions of these elements using a basis of 100 g of compound:
No. of gram-moles of Cu = \( \frac{49.18 \text{ g}}{63.54 \text{ g/mol}} = 0.774 \text{ mol} \)

No. of gram-moles of Au = \( \frac{50.82 \text{ g}}{196.97 \text{ g/mol}} = 0.258 \text{ mol} \)

Total gram-moles = 1.032 mol

\[
x = \text{Gram-mole fraction of Cu} = \frac{0.774 \text{ mol}}{1.032 \text{ mol}} = 0.75
\]

\[
y = \text{Gram-mole fraction of Au} = \frac{0.258 \text{ mol}}{1.032 \text{ mol}} = 0.25
\]

Thus we have Cu_{0.75}Au_{0.25} or, multiplying by 4, Cu_{3}Au.

2.13 What is the chemical formula of an intermetallic compound that consists of 15.68 wt % Mg and 84.32 wt % Al?

The chemical formula, Mg_{x}Al_{y}, may be determined based on the gram-mole fractions of magnesium and aluminum. Using a basis of 100 g of intermetallic compound,

\[
\text{No. of gram-moles of Mg} = \frac{15.68 \text{ g}}{24.31 \text{ g/mol}} = 0.645 \text{ mol}
\]

\[
\text{No. of gram-moles of Al} = \frac{84.32 \text{ g}}{26.98 \text{ g/mol}} = 3.125 \text{ mol}
\]

Total gram-moles = 3.770 mol

\[
x = \text{Gram-mole fraction of Mg} = \frac{0.645 \text{ mol}}{3.770 \text{ mol}} = 0.17
\]

\[
y = \text{Gram-mole fraction of Al} = \frac{3.125 \text{ mol}}{3.770 \text{ mol}} = 0.83
\]

Thus we have Mg_{0.17}Al_{0.83} or, multiplying by 6, Mg_{6}Al_{5}.

2.14 Define a photon.

A photon is a discrete amount or quantum of energy in the form of electromagnetic radiation.

2.15 Calculate the energy in joules and electron volts of the photon whose wavelength is 303.4 nm.

Using Plank’s equation with \( \nu = c/\lambda \),
\[ \Delta E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(303.4 \text{ nm})(10^{-9} \text{ m/nm})} = 6.56 \times 10^{-19} \text{ J} \]

\[ = (6.56 \times 10^{-19} \text{ J}) \left[ \frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}} \right] = 4.1 \text{ eV} \]

2.16 Calculate the energy in joules and electron volts of the photon whose wavelength is 226.4 nm.

\[ \Delta E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(226.4 \text{ nm})(10^{-9} \text{ m/nm})} = 8.79 \times 10^{-19} \text{ J} \]

\[ = (8.79 \times 10^{-19} \text{ J}) \left[ \frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}} \right] = 5.5 \text{ eV} \]

2.17 A hydrogen atom exists with its electron in the \( n = 4 \) state. The electron undergoes a transition to the \( n = 3 \) state. Calculate (a) the energy of the photon emitted, (b) its frequency, and (c) its wavelength in nanometers (nm).

(a) Photon energy emitted is:

\[ \Delta E = \Delta \left[ \frac{-13.6}{n^2} \right] = \left[ \frac{-13.6}{4^2} \right] - \left[ \frac{-13.6}{3^2} \right] = 0.66 \text{ eV} = 1.06 \times 10^{-19} \text{ J} \]

(b) Photon frequency is found as:

\[ \nu = \frac{\Delta E}{h} = \frac{1.06 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J} \cdot \text{s}} = 1.6 \times 10^{14} \text{ Hz} \]

(c) The wavelength is given as:

\[ \lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(1.06 \times 10^{-19} \text{ J})(10^{-9} \text{ m/nm})} = 1876 \text{ nm} \]

2.18 A hydrogen atom exists with its electron in the \( n = 6 \) state. The electron undergoes a transition to the \( n = 2 \) state. Calculate (a) the energy of the photon emitted, (b) its frequency, and (c) its wavelength in nanometers.

(a) Photon energy emitted is:

\[ \Delta E = \Delta \left[ \frac{-13.6}{n^2} \right] = \left[ \frac{-13.6}{6^2} \right] - \left[ \frac{-13.6}{2^2} \right] = 3.02 \text{ eV} = 4.84 \times 10^{-19} \text{ J} \]

(b) Photon frequency is found as:
\[ \nu = \frac{\Delta E}{h} = \frac{4.84 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J} \cdot \text{s}} = 7.3 \times 10^{14} \text{ Hz} \]

(c) The wavelength is given as:

\[ \lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(4.84 \times 10^{-19} \text{ J})(10^{-9} \text{ m/nm})} = 410 \text{ nm} \]

2.19 In a commercial x-ray generator, a stable metal such as copper (Cu) or tungsten (W) is exposed to an intense beam of high-energy electrons. These electrons cause ionization events in the metal atoms. When the metal atoms regain their ground state, they emit x-rays of characteristic energy and wavelength. For example, a “tungsten” atom struck by a high-energy electron may lose one of its K shell electrons. When this happens, another electron, probably from the tungsten L shell will “fall” into the vacant site in the K shell. If such a \( 2p \rightarrow 1s \) transition occurs in tungsten, a tungsten K\( \alpha \) x-ray is emitted. A tungsten K\( \alpha \) x-ray has a wavelength \( \lambda \) of 0.02138 nm. What is its energy? What is its frequency?

\[ E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(0.02138 \text{ nm})(10^{-9} \text{ m/nm})} = 9.30 \times 10^{-15} \text{ J} \]

\[ \nu = \frac{E}{h} = \frac{9.30 \times 10^{-15} \text{ J}}{6.63 \times 10^{-34} \text{ J} \cdot \text{s}} = 1.40 \times 10^{19} \text{ Hz} \]

2.20 Most modern scanning electron microscopes (SEM) are equipped with energy dispersive x-ray detectors for the purpose of chemical analysis of the specimens. This x-ray analysis is a natural extension of the capability of the SEM because the electrons that are used to form the image are also capable of creating characteristic x-rays in the sample. When the electron beam hits the specimen, x-rays specific to the elements in the specimen are created. These can be detected and used to deduce the composition of the specimen from the well-known wavelengths of the characteristic x-rays of the elements.

For example:

<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength of K( \alpha ) x-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>0.2291 nm</td>
</tr>
<tr>
<td>Mn</td>
<td>0.2103 nm</td>
</tr>
<tr>
<td>Fe</td>
<td>0.1937 nm</td>
</tr>
<tr>
<td>Co</td>
<td>0.1790 nm</td>
</tr>
<tr>
<td>Ni</td>
<td>0.1659 nm</td>
</tr>
<tr>
<td>Cu</td>
<td>0.1542 nm</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1436 nm</td>
</tr>
</tbody>
</table>
Suppose a metallic alloy is examined in an SEM and three different x-ray energies are detected. If the three energies are 7492, 5426, and 6417 eV, what elements are present in the sample? What would you call such an alloy? (Look ahead to Chap. 9 of the textbook.)

The elements may be identified by calculating their respective wavelengths.

\[ \lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(7492 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})} \]
\[ = 1.659 \times 10^{-10} \text{ m} = 0.1659 \text{ nm} \Rightarrow \text{Ni} \]

From the table provided, a wavelength of 0.1659 nm corresponds to nickel, Ni.

\[ \lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(5426 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})} \]
\[ = 2.291 \times 10^{-10} \text{ m} = 0.2291 \text{ nm} \Rightarrow \text{Cr} \]

From the table provided, a wavelength of 0.2291 nm corresponds to chromium, Cr.

\[ \lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{(6417 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})} \]
\[ = 1.937 \times 10^{-10} \text{ m} = 0.1937 \text{ nm} \Rightarrow \text{Fe} \]

From the table provided, a wavelength of 0.1937 nm corresponds to iron, Fe.

The elements present, nickel, chromium, and iron, are the primary constituents of the austenitic stainless steels.

2.21 Describe the Bohr model of the hydrogen atom. What are the major shortcomings of the Bohr model?

The Bohr model of the hydrogen atom envisions an electron revolving around a proton in a circular orbit having a radius of 0.05 nm. The electron is now believed to have noncircular or elliptical orbits around the hydrogen nucleus; these were not postulated in the original Bohr theory. The exact position of the hydrogen electron at any instant cannot be precisely determined because the electron is such a small particle. Scientists presently believe that the hydrogen electron can actually deviate to some extent in its distance from the nucleus. However, the highest probability of finding the electron in space about its nucleus is still believed to be at the Bohr radius of 0.05 nm.

2.22 What is the ionization energy in electron volts for a hydrogen atom in the ground state?

The ionization energy is given as, \( E = \frac{-13.6 \text{ eV}}{n^2} = \frac{-13.6 \text{ eV}}{1^2} = -13.6 \text{ eV} \)
2.23 Describe the four quantum numbers of an electron and give their allowed values.

1. The principal quantum number, \( n \), indicates an electron’s main energy levels, as well as, its location in space; a high probability exists for finding an electron within the \( n \) shell. This quantum number may have positive integer values of \( n = 1, 2, 3, 4 \ldots \)

2. The subsidiary quantum number, \( l \), specifies an electron’s subenergy levels and thus the subshell values where the electron is likely to be found. The allowed values are \( l = 0, 1, 2, 3, \ldots n - 1 \). The first four of these subenergy values have corresponding letter designations of \( l = s, p, d, f \) which represent electron orbitals.

3. The magnetic quantum number, \( m_l \), describes an atomic orbital’s spatial orientation and may have integral values of \(-l\) to \(+l\).

4. The electron spin quantum number, \( m_s \), provides for two electron spin directions, clockwise and counterclockwise, which are represented by the permissible values of \(+\frac{1}{2}\) and \(-\frac{1}{2}\).

2.24 Write the electron configurations of the following elements by using \( spdf \) notation:
(a) yttrium, (b) hafnium, (c) samarium, (d) rhenium.

(a) \( Y \) (Z = 39): \([Kr] 4d^{15}s^2\)  
(b) \( Hf \) (Z = 72): \([Xe] 4f^{14}5d^26s^2\)  
(c) \( Sm \) (Z = 62): \([Xe] 4f^66s^2\)  
(d) \( Re \) (Z = 75): \([Xe] 4f^{14}5d^56s^2\)

2.25 What is the outer electron configuration for all the noble gases except helium? \( s^2p^6 \)

2.26 Of the noble gases Ne, Ar, Kr, and Xe, which should be the most chemically reactive?

Xenon should be most reactive since its outermost electrons (5\(s^26p^6\)) are further away from the nucleus than the other noble gases, and thus easier to remove.

2.27 Define the term electronegativity.

Electronegativity is the degree to which an atom attracts electrons to itself.

2.28 Which five elements are the most electropositive according to the electronegativity scale?

The most electropositive elements are: Fr, Cs, Rb, K, Ra, and Ba. All of these have the lowest electronegativity value of 0.9.

2.29 Which five elements are the most electronegative according to the electronegativity scale?

The most electronegative elements, based on the electronegativity scale of 0 to 4.1, are: F (4.1); O (3.5); N (3.1); Cl (2.9); and Br (2.8).
2.30 Write the electron configuration of the following ions by using \( spdf \) notation:
(a) \( \text{Cr}^{2+}, \text{Cr}^{3+}, \text{Cr}^{6+} \); (b) \( \text{Mo}^{3+}, \text{Mo}^{4+}, \text{Mo}^{6+} \); (c) \( \text{Se}^{4+}, \text{Se}^{6+}, \text{Se}^{2-} \)

- (a) \( \text{Cr} \) [Ar] \( 3d^5 4s^1 \)
- (b) \( \text{Mo} \) [Kr] \( 4d^5 5s^1 \)
- (c) \( \text{Se} \) [Ar] \( 3d^{10} 4s^2 4p^4 \)

(a) \( \text{Cr}^{2+} \) [Ar] \( 3d^4 \)
(b) \( \text{Mo}^{3+} \) [Kr] \( 4d^3 \)
(c) \( \text{Se}^{4+} \) [Ar] \( 3d^{10} 4s^2 \)

2.31 Briefly describe the following types of primary bonding: (a) ionic, (b) covalent, and (c) metallic.

(a) Ionic bonding arises from the electrostatic attraction between oppositely charged ions. In the process of ion formation, an electron or a number of electrons may be transferred from a highly electropositive element to a highly electronegative one. The ionic bond in solids is nondirectional.

(b) Covalent bonding is a primary type of bonding which arises from the reduction in energy associated with the overlapping of half-filled orbitals of two atoms. In this bond, there is an electron exchange interaction. The covalent bond is a directional type of bond.

(c) Metallic bonding is a primary type of bonding involving the interaction of the valence electron or electrons of one atom with many surrounding atoms. This interaction leads to a reduction in energy of the system considered. The valence bonding electrons of these bonds are sometimes regarded as an “electron gas” bonding the positive ion cores (atoms less their valence electrons) of atoms. The metallic bond is nondirectional.

2.32 Briefly describe the following types of secondary bonding: (a) fluctuating dipole, and (b) permanent dipole.

(a) Fluctuating dipole bonding is a secondary type of bonding between atoms which contain electric dipoles. These electric dipoles, formed due to the asymmetrical electron charge distribution within the atoms, change in both direction and magnitude with time. This type of bond is electrostatic in nature, very weak and nondirectional.

(b) Permanent dipole bonding is also a secondary type of bonding between molecules possessing permanent electric dipoles. The bonds, formed by the electrostatic attraction of the dipoles, are directional in nature.

2.33 In general, why does bonding between atoms occur?

Bonding between atoms generally occurs because the atoms’ energies are lowered through the bonding process.

2.34 Describe the ionic bonding process between a pair of Na and Cl atoms. Which electrons
are involved in the bonding process?

The ionic bonding process between a pair of Na and Cl atoms involves a transfer of the outer 3s\(^1\) electron of the Na atom to the 3p vacancy in the Cl atom. Thus, the Na ion formed has the Ne electron configuration while the Cl ion has the Kr electron configuration.

2.35 After ionization, why is the sodium ion smaller than the sodium atom?

After ionization to the Na\(^+\), the Na atom becomes smaller because the electron-to-proton ratio of the Na atom is decreased when the Na\(^+\) ion forms. Also, the outer third shell no longer exists once the 3s\(^1\) electron is lost by the Na atom.

2.36 After ionization, why is the chloride ion larger than the chlorine atom?

After ionization, the Cl\(^-\) ion is larger because the electron-to-proton ratio of the chlorine atom is decreased by the ionization process.

2.37 Calculate the attractive force between a pair of K\(^+\) and Br\(^-\) ions that just touch each other. Assume the ionic radius of the K\(^+\) ion to be 0.133 nm and that of the Br\(^-\) ion to be 0.196 nm.

The attractive force between the ion pair is found by applying Coulomb’s law,

\[
F_{\text{attractive}} = \frac{-Z_1 Z_2 e^2}{4 \pi \varepsilon_o a_o^2}
\]

Where \( Z_1 = +1 \) for K\(^+\), \( Z_2 = -1 \) for Br\(^-\), and
\[
a_o = r_{K^+} + r_{Br^-} = 0.133 \text{ nm} + 0.196 \text{ nm} = 0.329 \text{ nm} = 3.29 \times 10^{-10} \text{ m}
\]

Substituting,

\[
F_{\text{attractive}} = \frac{- (+1)(-1)(1.60 \times 10^{-19} \text{ C})^2}{4 \pi (8.85 \times 10^{-12} \text{ C}^2 / \text{ N} \cdot \text{ m}^2)(3.29 \times 10^{-10} \text{ m})^2} = 2.13 \times 10^{-9} \text{ N}
\]

2.38 Calculate the attractive force between a pair of Ba\(^{2+}\) and S\(^{2-}\) ions that just touch each other. Assume the ionic radius of the Ba\(^{2+}\) ion to be 0.143 nm and that of the S\(^{2-}\) ion to be 0.174 nm.

The attractive force between the ion pair is found by applying Coulomb’s law,

\[
F_{\text{attractive}} = \frac{-Z_1 Z_2 e^2}{4 \pi \varepsilon_o a_o^2}
\]

Where \( Z_1 = +2 \) for Ba\(^{2+}\), \( Z_2 = -2 \) for S\(^{2-}\), and
\[ a_o = r_{Ba^{2+}} + r_{S^{2-}} = 0.143 \text{ nm} + 0.174 \text{ nm} = 0.317 \text{ nm} = 3.17 \times 10^{-10} \text{ m} \]

Substituting,
\[ F_{\text{attractive}} = \frac{-(-2)(-2)(1.60 \times 10^{-19} \text{ C})^2}{4\pi(8.85 \times 10^{-12} \text{ C}^2 / \text{ N} \cdot \text{m}^2)(3.17 \times 10^{-10} \text{ m})^2} = 9.16 \times 10^{-9} \text{ N} \]

2.39 Calculate the net potential energy for a K\(^+\)Br\(^-\) pair by using the \( b \) constant calculated from Problem 2.37. Assume \( n = 9.5 \).

The repulsive energy constant \( b \) is:
\[ b = \frac{\frac{-F_{\text{Repulsive}} a_o^{n+1}}{n}}{\frac{-F_{\text{Attractive}} a_o^{n+1}}{n}} = \frac{-(-2.13 \times 10^{-9} \text{ N})(3.29 \times 10^{-10} \text{ m})^{10.5}}{9.5} \]
\[ = 6.042 \times 10^{-110} \text{ N} \cdot \text{m}^{10} \]

Thus the net potential energy between the ions is,
\[ E_{K^+Br^-} = \frac{+Z_1 Z_2 e^2}{4\pi \varepsilon_o a_o} + \frac{b}{a_o^n} = \frac{+(+1)(-1)(1.60 \times 10^{-19} \text{ C})^2}{4\pi(8.85 \times 10^{-12} \text{ C}^2 / \text{N} \cdot \text{m}^2)(3.29 \times 10^{-10} \text{ m})} + \frac{6.042 \times 10^{-110} \text{ N} \cdot \text{m}^{10}}{(3.29 \times 10^{-10} \text{ m})^{9.5}} \]
\[ = (-6.997 \times 10^{-19} \text{ J}) + (7.38 \times 10^{-20} \text{ J}) = -6.26 \times 10^{-19} \text{ J} \]

2.40 Calculate the net potential energy for a Ba\(^{2+}\)S\(^{2-}\) ion pair by using the \( b \) constant calculated from Problem 2.38. Assume \( n = 10.5 \).

The repulsive energy constant \( b \) is:
\[ b = \frac{\frac{-F_{\text{Repulsive}} a_o^{n+1}}{n}}{\frac{-F_{\text{Attractive}} a_o^{n+1}}{n}} = \frac{-(-9.16 \times 10^{-9} \text{ N})(3.17 \times 10^{-10} \text{ m})^{11.5}}{10.5} \]
\[ = 5.045 \times 10^{-119} \text{ N} \cdot \text{m}^{10} \]

Thus the net potential energy between the ions is,
\[ E_{Ba^{2+}S^{2-}} = \frac{+Z_1 Z_2 e^2}{4\pi \varepsilon_o a_o} + \frac{b}{a_o^n} = \frac{+(+2)(-2)(1.60 \times 10^{-19} \text{ C})^2}{4\pi(8.85 \times 10^{-12} \text{ C}^2 / \text{N} \cdot \text{m}^2)(3.17 \times 10^{-10} \text{ m})} + \frac{5.045 \times 10^{-119} \text{ N} \cdot \text{m}^{10}}{(3.17 \times 10^{-10} \text{ m})^{10.5}} \]
\[ = (-2.905 \times 10^{-18} \text{ J}) + (2.765 \times 10^{-19} \text{ J}) = -2.63 \times 10^{-18} \text{ J} \]

2.41 If the attractive force between a pair of Cs\(^+\) and I\(^-\) ions is \( 2.83 \times 10^{-9} \text{ N} \) and the ionic
radius of the Cs\(^+\) ion is 0.165 nm, calculate the ionic radius of the I\(^-\) ion in nanometers.

From Coulomb’s law,

\[
a_o = \sqrt{\frac{-Z_1 Z_2 e^2}{4 \pi \varepsilon_o F_{\text{Attractive}}}} = \sqrt{\frac{-(+1)(-1)(1.60 \times 10^{-19} \text{ C})^2}{4 \pi (8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2))(2.83 \times 10^{-9} \text{ N})}}
\]

\[= 2.852 \times 10^{-10} \text{ m} = 0.2852 \text{ nm}\]

The ionic radius of iodine is thus,

\[r_{I^-} = a_o - r_{Cs^+} = 0.285 \text{ nm} - 0.165 \text{ nm} = 0.120 \text{ nm}\]

2.42 If the attractive force between a pair of Sr\(^{2+}\) and O\(^{2-}\) ions is \(1.29 \times 10^{-8} \text{ N}\) and the ionic radius of the O\(^{2-}\) ion is 0.132 nm, calculate the ionic radius of the Sr\(^{2+}\) ion in nanometers.

From Coulomb’s law,

\[
a_o = \sqrt{\frac{-Z_1 Z_2 e^2}{4 \pi \varepsilon_o F_{\text{Attractive}}}} = \sqrt{\frac{-(+2)(-2)(1.60 \times 10^{-19} \text{ C})^2}{4 \pi (8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2))(1.29 \times 10^{-8} \text{ N})}}
\]

\[= 2.672 \times 10^{-10} \text{ m} = 0.2672 \text{ nm}\]

The ionic radius of iodine is thus,

\[r_{Sr^{2+}} = a_o - r_{O^{2-}} = 0.267 \text{ nm} - 0.132 \text{ nm} = 0.135 \text{ nm}\]

2.43 Describe the two major factors that must be taken into account in the packing of ions in an ionic crystal.

1. The structure of ionic solids is partly determined by the radii of the cations and anions of the ionic solid. Only certain ranges of cation-to-anion radius ratios are allowed by packing considerations.

2. Electrical neutrality must be maintained. Thus, if the cations and anions have different valences, the number of anions surrounding a particular cation will be restricted.

2.44 Describe the covalent bonding process between a pair of hydrogen atoms. What is the driving energy for the formation of a diatomic molecule?

The covalent bonding in the hydrogen molecule involves the interaction and overlapping of the 1s orbitals of the hydrogen atoms. The covalent bond forms between the two hydrogen atoms because their energies are lowered by the bonding process.

2.45 Describe the covalent bonding electron arrangement in the following diatomic molecules: (a) fluorine, (b) oxygen, (c) nitrogen.

(a) In fluorine molecules, a single covalent bond is formed between the \(p\) orbitals of two
fluorine atoms.

(b) In oxygen molecules, a double covalent bond is formed between the $p$ orbitals of two oxygen atoms.

(c) In nitrogen molecules, a triple covalent bond is formed between the $p$ orbitals of two nitrogen atoms.

2.46 Describe the hybridization process for the formation of four equivalent $sp^3$ hybrid orbitals in carbon during covalent bonding. Use orbital diagrams.

In the hybridization process, four equal $sp^3$ hybrid orbitals are formed in the carbon atom. This is accomplished through the promotion of one of the $2s$ orbitals to a $2p$ level.

2.47 List the number of atoms bonded to a C atom that exhibits $sp^3$, $sp^2$, and $sp$ hybridization. For each, give the geometrical arrangement of the atoms in the molecule.

- $sp^3$ hybridization: Four atoms are bonded to a central carbon atom in a tetrahedral arrangement. An example is methane, CH$_4$.
- $sp^2$ hybridization: Three atoms are bonded to a carbon atom in a planar arrangement. An example is ethylene, CH$_2$:CH$_2$.
- $sp$ hybridization: Two atoms are bonded to a carbon atom in a linear arrangement. An example is acetylene, CH:CH.

2.48 Why is diamond such a hard material?

Diamond is extremely hard because its carbon atoms are covalently bonded by single $sp^3$ hybrid bonds in a three dimensional arrangement.

2.49 Describe the metallic bonding process among an aggregate of copper atoms.
Copper has a crystal structure of closely packed atoms; each atom is surrounded by twelve others. This compact structure is due, in part, to the fact that each atom has only one valence electron. Consequently, there is a low density electron charge cloud available for bonding.

2.50 How can the high electrical and thermal conductivities of metals be explained by the "electron gas" model of metallic bonding? Ductility?

The high electrical and thermal conductivities of metals are explained by the mobility of their outer valence electrons in the presence of an electrical potential or thermal gradient. The ductility of metals is explained by the bonding "electron gas" which enables atoms to pass over each other during deformation, without severing their bonds.

2.51 The melting point of the metal potassium is 63.5°C, while that of titanium is 1660°C. What explanation can be given for this great difference in melting temperatures?

The significantly higher melting point of titanium, as compared to potassium, is in part attributed to the hybridized covalent bonding between the 3d and 4s orbitals of titanium.

2.52 Is there a correlation between the electron configurations of the element potassium (Z = 19) through copper (Z = 29) and their melting points? (See Tables 2.8 and 2.9.)

A possible correlation between the melting points and the electron configurations of the elements from scandium (Z = 21) to copper (Z = 29) is that unpaired 3d electrons cause covalent hybridized bonds, and hence give higher melting points to these transition metals.

2.53 Using the covalent-metallitivity values of Table 2.9, calculate values for the percent metallic and covalent bonding in the structural metal titanium.

Assuming purely covalent and metallic bonding in the titanium,

\[
\begin{align*}
% \text{ covalent bonding} & = \frac{1.91}{4.00} \times 100\% = 47.75\% \\
% \text{ metallic bonding} & = 100\% - 47.75\% = 52.25\%
\end{align*}
\]

2.54 Using the covalent-metallitivity values of Table 2.9, calculate values for the percent metallic and covalent bonding in the metal tungsten.

Assuming purely covalent and metallic bonding in the tungsten,

\[
\begin{align*}
% \text{ covalent bonding} & = \frac{3.86}{4.00} \times 100\% = 96.50\% \\
% \text{ metallic bonding} & = 100\% - 96.50\% = 3.50\%
\end{align*}
\]
2.55 Define an electric dipole moment.

An electric dipole moment is defined as the product of the absolute charge of one of the dipoles (positive or negative) multiplied by the separation distance between the positive and negative dipole charges.

2.56 Describe fluctuating dipole bonding among the atoms of the noble gas neon. Of a choice between the noble gases krypton and xenon, which noble gas would be expected to have the strongest dipole bonding and why?

A fluctuating electric dipole exists in the atoms of noble gases, such as neon, because there is, at any instant, an asymmetrical distribution of electrical charge among their electrons. The noble gas xenon would be expected to have a stronger fluctuating dipole moment than krypton since it has an additional electron shell; the krypton atom has four electron shells while the xenon atom has five. The electrons of this fifth shell, being further away from the xenon nucleus, and are able to fluctuate more and thus create greater asymmetry of charge.

2.57 Describe permanent dipole bonding among polar covalent molecules.

Polar covalent molecules with permanent dipoles bond together because of the electrostatic attraction of their positive and negative charge centers.

2.58 Carbon tetrachloride (CCl₄) has a zero dipole moment. What does this tell us about the C—Cl bonding arrangement in this molecule?

Since the molecule CCl₄ has a zero dipole moment, the C—Cl bonding arrangement must be symmetrical about the carbon nucleus.

2.59 Describe the hydrogen bond. Among what elements is this bond restricted?

The hydrogen bond is a permanent dipole bond restricted to a hydrogen atom and highly electronegative atoms such as O, N, F and Cl. This secondary bond is relatively strong due to the small size of the hydrogen atom.

2.60 Describe hydrogen bonding among water molecules.

Hydrogen bonding occurs between water molecules because of the electrostatic attraction between the negatively charged oxygen regions of the water molecules and the positively charged hydrogen regions.

2.61 Methane (CH₄) has a much lower boiling temperature than does water (H₂O). Explain why this is true in terms of the bonding between molecules in each of these two substances.
The methane molecules are bonded together by weak –C–H dipoles. The water molecules are bonded together by the much stronger –O–H hydrogen bonded dipoles.

2.62 Sketch a tetrahedron and make a small model of one from cardboard and tape with a 2-inch side. Do the same for an octahedron.

The models should resemble these 3-D sketches:

The methane molecules are bonded together by weak –C–H dipoles. The water molecules are bonded together by the much stronger –O–H hydrogen bonded dipoles.

2.63 What is Pauling’s equation for determining the percentage ionic character in a mixed ionic-covalently bonded compound?

Pauling’s equation relating the percent ionic character of an ionic-covalent bond to the electronegativities of the bonding atoms is:

\[
% \text{ Ionic Character} = \left[1-e^{-0.25(x_A-x_B)^2}\right][100%]
\]

where \(x_A\) is the electronegativity of the more electropositive element and \(x_B\) is the electronegativity of the more electronegative element.

2.64 Compare the percentage ionic character in the semiconducting compound CdTe and InP.

Applying Pauling’s equation to CdTe and InP compounds,

For CdTe (2 – 6), \( \% \text{ Ionic character} = (1 - e^{-0.25(1.5-2.0)^2})(100\%) = 6.1\% \)

For InP (3 – 5), \( \% \text{ Ionic character} = (1 - e^{-0.25(1.5-2.1)^2})(100\%) = 8.6\% \)

While a 2 – 6 compound typically has a higher ionic character than a 3 – 5, the relatively high electronegativity of phosphorous causes InP to be more ionic in nature.

2.65 Compare the percentage ionic character in the semiconducting compound InSb and ZnTe.

Applying Pauling’s equation to InSb and ZnTe compounds,

For InSb (2 – 6), \( \% \text{ Ionic character} = (1 - e^{-0.25(1.5-1.8)^2})(100\%) = 2.2\% \)

For ZnTe (3 – 5), \( \% \text{ Ionic character} = (1 - e^{-0.25(1.7-2.0)^2})(100\%) = 2.2\% \)

While a 2 – 6 compound typically has a higher ionic character than a 3 – 5, in this case, the compounds have identical ionic character.
2.66 For each of the following compounds, state whether the bonding is essentially metallic, covalent, ionic, van der Waals, or hydrogen: (a) Ni, (b) ZrO₂, (c) graphite, (d) solid Kr, (e) Si, (f) BN, (g) SiC, (h) Fe₂O₃, (i) MgO, (j) W, (k) H₂O within the molecules, (l) H₂O between the molecules.

If ionic and covalent bonding are involved in the bonding of any of the compounds listed, calculate the percentage ionic character in the compound.

(a) Ni: Nickel bonding is primarily metallic.

(b) ZrO₂: From Pauling’s equation, the Zr–O bond is 73.4% ionic and 26.6% covalent, where \( x_A \) and \( x_B \) are the electronegativities of zirconium and oxygen, respectively.

(c) Graphite: The bonding is covalent within the layers and secondary between the layers.

(d) Solid Kr: The bonding represents van der Waals due to fluctuating dipoles.

(e) Si: Silicon bonding is covalent.

(f) BN: The B–N bond, from Pauling’s equation (2-10), is 26.1% ionic and 73.9% covalent.

(g) SiC: From Eq. (2-10), the Si–C bond is 11% ionic and 89% covalent.

(h) Fe₂O₃: From Eq. (2-10), the Fe–O bond is 55.5% ionic and 44.5% covalent.

(i) MgO: From Eq. (2-10), the Mg–O bond is 70.2% ionic and 29.8% covalent.

(j) W: Tungsten bonding primarily consists of metallic bonding with some covalent character.

(k) H₂O within the molecules: The H–O bond is 38.7% ionic and 61.3% covalent.

(l) H₂O between the molecules: Hydrogen bonding exists between H₂O molecules.