Chapter 7

Solutions to Supplementary *Check for Understanding* Problems

Electromagnetic Radiation

1. How are the different types of electromagnetic radiation similar? How do they differ?

Solution

All electromagnetic radiation has the same velocity in a vacuum (speed of light), the wavelength of electromagnetic radiation is inversely proportional to its frequency and all forms are composed of photons which have an energy described by $E_{photon} = h\nu = hc/\lambda$.

Different types of electromagnetic radiation differ in frequency, wavelength and photon energy.

2. Which of the following colors of visible light has the longest wavelength?

   A. blue

   B. yellow

   C. orange

   D. violet

   E. green

Answer: C

Solution

Visible light consists of a continuous rainbow of colors red - orange - yellow - green - blue - violet spanning wavelengths from about 400 nm (violet) to 750 nm (red). Orange is choice with the longest wavelength.

3. Which of the following wavelengths of electromagnetic radiation has the highest frequency?

   A. 425 nm

   B. 200 μm

   C. 1.8×10^{-5} mm

   D. 5 cm

Answer: C

Solution

Since the frequency of electromagnetic radiation is inversely proportional to wavelength ($\nu = c/\lambda$), the highest frequency will be associated with the shortest wavelength. Compare wavelengths by converting all of the choices to a common unit of measure (the meter is the most convenient unit).

A. $425 \cancel{\text{nm}} \times \dfrac{10^{-9}\text{ m}}{1 \cancel{\text{nm}}} = 4.25 \times 10^{-7}\text{ m}$

B. $200 \cancel{\mu\text{m}} \times \dfrac{10^{-6}\text{ m}}{1 \cancel{\mu\text{m}}} = 2 \times 10^{-4}\text{ m}$

C. $1.8 \times 10^{-5} \cancel{\text{mm}} \times \dfrac{10^{-3}\text{ m}}{1 \cancel{\text{mm}}} = 1.8 \times 10^{-8}\text{ m}$ ← shortest

D. $5 \cancel{\text{cm}} \times \dfrac{10^{-2}\text{ m}}{1 \cancel{\text{cm}}} = 5 \times 10^{-2}\text{ m}$

Bohr Atom

1. What experimental evidence do scientists have that the electron energy levels of an atom are quantized?

Solution

The emission of only specific wavelengths of light (line spectrum) by vaporized atoms suggests that the electrons in atoms can undergo only certain energy changes. This is possible if they have only discrete energies (their energy levels are quantized).

2. What does it mean to say that an atom is in an "excited state".

Solution

This means that at least one electron in the atom does not have its lowest possible energy.

3. How is the average distance of an electron from the nucleus related to its energy?

Solution

As the energy of an electron increases its average distance form the nucleus tends to increase. Electrons that are on the average further from the nucleus are less strongly attracted to the nucleus. This decreased electrostatic attraction results in a higher potential energy for the electron.

4. What is meant by the ground state of an atom?

Solution

The ground state of an atom is the state in which all of the electrons in the atom occupy the lowest possible energy levels.

Quantum Mechanical Model

1. What is meant by an *orbital*? What is the general shape of an *s* orbital and a *p* orbital?

Solution

An *orbital* is a representation of the space around the nucleus occupied by an electron. An *s* orbital has a spherical shape with the nucleus in the center. A *p* orbital has two lobes that extend out from the nucleus along the *x*, *y* or *z* axis.

2. Does a hydrogen atom have a 3*s* orbital? Explain.

Solution

Yes. Although the hydrogen atom has only one electron, it possesses a complete set of available orbitals. When a hydrogen atom absorbs energy its electron can be promoted to a higher energy orbital.

3. For the designation $4d^5$, what is the significance of 4, *d* and 5?

Solution

The 4 indicates the principal energy level occupied by the electron(s). The *d* indicates the sublevel orbital occupied by the electron(s). The 5 indicates the number of electrons in that particular sublevel.

4. Which of the following electron orbital designations is (are) not correct?

a) $1p$ b) $2d$ c) $3f$ d) $4s$ e) $4d$

Answers: a, b, and c

Solutions

For $n = 1$, there is only a single sublevel ($1s$) so (a) is incorrect. For $n = 2$ there are two sublevels ($2s$ and $2p$) so (b) is incorrect. For $n = 3$ there are three sublevels ($3s$, $3p$ and $3d$) so (c) is incorrect. For $n = 4$ there are four sublevels ($4s$, $4p$, $4d$ and $4f$) so (d) and (e) are correct.

5. How does the number of sublevels change as n for the principal energy level increases?

Solution

As the principal energy level (n) increases the number of sublevels increases. The number of sublevels equals the value of n.

Electron Configurations

1. Which element corresponds to each of the following electron configurations?

a) $1s^22s^22p^63s^23p^64s^1$

b) $1s^22s^22p^63s^23p^64s^23d^{10}$

c) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^2$

Answers: a) K b) Zn c) Sn

Solutions

The number of electrons present in the atom equals the atomic number of the element and is equal to the sum of the superscripts in the electron configuration for the atom. For (a) the sum is 19 so the element has an atomic number of 19 and is potassium (K). For (b) the sum is 30 so the element is zinc (Zn). For (c) the sum is 50 so the element is tin (Sn).

2. Write the electron configuration for each of the following elements.

a) Sr b) V c) Kr d) In

Answers:

a) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^2$

b) $1s^22s^22p^63s^23p^64s^23d^3$

c) $1s^22s^22p^63s^23p^64s^23d^{10}4p^6$

d) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^1$

Solutions

What we know: number of electrons in each atom; order of filling the electron energy levels

Desired answer: ground state electron configuration for each atom

a) From the periodic table you can find the atomic number for strontium (Z=38). This represents the number of electrons that must be accounted for in the electron configuration. From the periodic table in Figure 7.11, the electron energy levels fill in the order 1*s*, 2*s*, 2*p*, 3*s*, 3*p*, 4*s*, 3*d*, 4*p*, 5*s*, 4*d*... Start filling the orbitals until all 38 electrons are accounted for; remember each orbital can have a maximum of two electrons. The correct electron configuration is $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^2$.

b) From the periodic table you can find the atomic number for vanadium (Z=23). This represents the number of electrons that must be accounted for in the electron configuration. From the periodic table in Figure 7.11, the electron energy levels fill in the order 1*s*, 2*s*, 2*p*, 3*s*, 3*p*, 4*s*, 3*d*, 4*p*, 5*s*, 4*d*... Start filling the orbitals until all 23 electrons are accounted for; remember each orbital can have a maximum of two electrons. The correct electron configuration is $1s^22s^22p^63s^23p^64s^23d^3$.

c) From the periodic table you can find the atomic number for krypton (Z=36). This represents the number of electrons that must be accounted for in the electron configuration. From the periodic table in Figure 7.11, the electron energy levels fill in the order 1*s*, 2*s*, 2*p*, 3*s*, 3*p*, 4*s*, 3*d*, 4*p*, 5*s*, 4*d*... Start filling the orbitals until all 36 electrons are accounted for; remember each orbital can have a maximum of two electrons. The correct electron configuration is $1s^22s^22p^63s^23p^64s^23d^{10}4p^6$.

d) From the periodic table you can find the atomic number for indium (Z=49). This represents the number of electrons that must be accounted for in the electron configuration. From the periodic table in Figure 7.11, the electron energy levels fill in the order 1*s*, 2*s*, 2*p*, 3*s*, 3*p*, 4*s*, 3*d*, 4*p*, 5*s*, 4*d*... Start filling the orbitals until all 49 electrons are accounted for; remember each orbital can have a maximum of two electrons. The correct electron configuration is $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^1$.

3. Which electrons in an atom are the valence electrons? Why are these electrons especially important to the chemical properties of an element?

Solution

The valence electrons are those in the highest occupied principal energy level (highest *n*). These electrons are, on the average, farthest from the nucleus and least strongly attracted to the nucleus. This makes them more likely to be shared with other atoms or lost in chemical reactions.

4. How many 3*d* electrons are found in each of the following elements?

a) Co   b) Ca   c) Cd

Answers: a) 7   b) 0   c) 10

Solutions

One could write the electron configuration for each atom type, however, it is easier to simply note the element's location in the periodic table with respect to the filling of the 3*d* orbitals (see Figures 3.5 and 7.11) and determine how many 3*d* electrons are present from this.

a) Cobalt is located in period 4 in the 8B group of elements. This is where the 3*d* orbitals are being filled (starting with Sc). Since cobalt is the seventh transition element in this period one can expect that it has seven 3*d* electrons.

b) Calcium is located in Group 2A in period 4. This is before the 3*d* orbitals are being filled so it does not have any 3*d* electrons.

c) Cadmium is a transition element in period 5. This is after all of the 3*d* orbitals have been filled so cadmium has ten 3*d* electrons.

5. How many valence electrons does each of the following atoms possess?

a) Al   b) Fe   c) Pb

Answers: a) 3   b) 2   c) 4

Solutions

a) Since aluminum (Al) is from Group 3A is has three valence electrons.

b) Since iron (Fe) is a B group element, you must determine its electron configuration to decide on how many valence electrons there are. Iron has 26 electrons. Start with hydrogen and work across from left to right and down the periodic table until you get to Fe. In the process you will put electrons into the following sequence of orbitals.

$$1s2s2p3s3p4s3d$$

Now fill each sublevel until you accommodate all 26 electrons. This results in the following electron configuration for iron.

$$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$$

The highest occupied electron energy level is $n = 4$, thus there are 2 valence electrons in an iron atom.

c) Since lead (Pb) is from Group 4A is has four valence electrons.

6. What is unique about the noble gases in terms of their electron configurations?

<u>Solution</u>

If you examine the electron configurations of the noble gases (except for helium) you will notice that there are eight valence electrons (this is expected since the noble gases are in Group 8A) and that these valence electrons completely fill the *s* and *p* orbitals in the valence shell.

He $1s^2$

Ne $1s^2 2s^2 2p^6$

Ar $1s^2 2s^2 2p^6 3s^2 3p^6$

Kr $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$

Xe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6$

Rn $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6$

7. What sublevel is being filled in the:

   a) Group 3A to Group 8A elements in period 3?

   b) period 5 transition elements?

   c) lanthanides?

Answers: a) 3*p* b) 4*d* c) 4*f*

Solutions

Note the sublevel filling pattern in the periodic table shown in Figure 7.11.

Electron Configurations and Chemical Properties

1. How are the electron arrangements for elements in a given A group of the periodic table related? What is the consequence of this?

Solution

Elements in the same A group have the same number of valence electrons. The chemical properties of an element depend on its valence electrons because these electrons, as a result of being the easiest ones to lose or share, are the ones that are involved in chemical bonding. Consequently, elements in the same A group have similar chemical properties.

2. What is meant by the effective nuclear charge (Z_{eff})?

Solution

The effective nuclear charge is the portion of the actual nuclear charge experienced by an electron. It is usually less than the actual nuclear charge because most electrons are shielded from the nucleus by other electrons.

3. Are the 1*s* electrons more strongly attracted to the nucleus in a helium atom or in an argon atom? Explain.

Answer: argon nucleus

Solution

The 1*s* electrons are the lowest energy electrons in any atom and are the electrons most strongly attracted to the nucleus because they are not shielded effectively by higher energy electrons. Thus, $Z_{eff} = Z$. For argon Z = 18 and for helium Z = 4. Consequently, the 1*s* electrons in an argon atom have a much higher Z_{eff} and are more strongly attracted to the nucleus.

4. Which element, silicon or arsenic, has chemical properties more like that of phosphorus? Explain.

Answer: arsenic

Solution

Arsenic is in the same Group 5A as phosphorus and thus has the same number of valence electrons (5) as phosphorus. This similarity results in chemical properties that are more alike than is found between silicon (a Group 4A element with four valence electrons) and phosphorus.

5. Hydrogen and lithium atoms each have a single valence electron. Explain why it takes less energy to remove the valence electron in a lithium atom than it does to remove the valence electron from a hydrogen atom.

Solution

The valence electron in a hydrogen atom is in a 1*s* orbital while the valence electron in a lithium atom is in a 2*s* orbital. Since $Z_{eff} = 1$ for both valence electrons one expects the 2*s* electron to be on the average further away from the nucleus and less tightly bound thus requiring less energy to remove it.