CH 221 Chapter Three Concept Guide

1. Radiation, Wavelength, and Frequency

Question

Is the frequency of the radiation used in a microwave oven higher or lower than that from an FM radio station broadcasting at 91.7 MHz (where 1 MHz = 10^6 s^{-1})?

Solution

Microwave radiation has a frequency on the order of 10^{10} Hz, compared to FM radio, which has a frequency on the order of 10^8 Hz. FM radio is, therefore, lower in frequency than microwaves.

2. The Relationship between Wavelength and Frequency

Question

What is the wavelength of orange light of frequency 4.85 x 10^{14} Hz?

Approach

We need to convert frequency to wavelength using the following relation:

$\lambda = c / \nu$

where λ is wavelength in meters, c is the speed of light, and ν is the frequency in s^{-1}.

Solution

$\lambda = c / \nu$

$\lambda = 3.00 \times 10^8$ m/s / 4.85×10^{14} s^{-1}

$\lambda = 6.19 \times 10^{-7}$ m = 619 nm

3. Planck's Law

Problem

Compare the energy of a mole of photons of green light (5.00 x 10^2 nm) with the energy of a mole of photons of microwave radiation having a frequency of 2.45 GHz (1 GHz = 10^9 s^{-1}). Which has greater energy? By what factor is one greater than the other?

Approach

First, we calculate the frequency of radiation of green light. Next, we calculate the energy of the green light and the energy of the microwave radiation. A ratio of energies will result in the factor by which one is greater than the other.

Solution

Step 1: Calculate the frequency of green light.

$\nu = c/\lambda = 3.00 \times 10^8$ m s^{-1} / 5.00×10^{-7} m = 6.00×10^{14} s^{-1}

Step 2: Calculate the energies of green light and microwave radiation.

E(green light) = $h\nu$ = (6.626×10^{-34} J s/photon)(6.00×10^{14} s^{-1}) = 3.98×10^{-19} J/photon

E(microwave radiation) = $h\nu$ = (6.626×10^{-34} J s/photon)(2.45×10^9 s^{-1}) = 1.62×10^{-24} J/photon

Green light has greater energy than microwave radiation.

Step 3: Use a ratio of energy values to calculate the factor by which the energy of green light is greater than that of microwave radiation.

E(green light) / E(microwave radiation)

= 3.98×10^{-19} J/photon / 1.62×10^{-24} J/photon = 2.45×10^5

Green light is almost a quarter of a million times more energetic than microwaves.

4. Matter as Waves

Question

Does a particle exhibiting wavelike behavior have a frequency as well as a wavelength?

Solution

All matter exhibits wavelike behavior. Recall that for all waves, $\lambda\nu = c$, where λ is the wavelength, ν is the frequency, and c is the speed of light. For waves, c is replaced by v, which is the velocity of the wave: $\lambda\nu = v$.

Thus, $\lambda = v/\nu$, and $v/\nu = h/mv$. Finally, $\nu = mv^2/h$.

5. Calculating Uncertainty in the Position of an Electron

Question

What is the smallest possible uncertainty in the position of an electron having a mass of 9.109×10^{-21} kg and a velocity of $3.0 \times 10^7 \pm 7.27 \times 10^5$ m/s? 1 Joule = 1 kg m^2/s^2.

Solution

The product of the uncertainty is momentum, $m\Delta v$, and the uncertainty in position, Δx, must be greater than h: $(m\Delta v)(\Delta x) > h$.

Therefore, $\Delta x > h/m\Delta v$.
$\Delta x > h/m\Delta v$
$\Delta x \sim (6.626 \times 10^{-34}\ \text{kg s m}^2/\text{s}^2) / (9.109 \times 10^{-21}\ \text{kg})(7.27 \times 10^5\ \text{m/s})$
$\Delta x \sim 10^{-19}$ m

6. Nodes

Question

The total number of nodes in an orbital is equal to the shell number, n, minus 1. These nodes are either nodal planes or nodal spheres. The number of nodal planes is equal to the value of l and the remainder are nodal spheres. What types of nodes exist in 3d orbitals and in 4d orbitals?

Approach

Find the total number of nodes from the shell number, the number of nodal planes for the value of l, and the number of nodal spheres by taking the difference.

Solution

A 3d orbital has $n = 3$, and a 4d orbital has $n = 4$, thus a 3d orbital has 2 nodes and a 4d orbital has 3 nodes. Both are d orbitals, therefore $l = 2$ and both 3d and 4d have 2 nodal planes. Finally, a 3d orbital has 2 nodes, of which 2 are nodal planes. This orbital has no nodal spheres. A 4d orbital, however, has 3 nodes, of which 2 are planes. A 4d orbital has 1 nodal sphere.

7. Quantum Numbers and Orbitals

Question

What values of the subshell quantum number correspond to the (a) d, (b) f, (c) s, (d) p, (e) g subshells?

Solution:

The first five subshells, $l = 0, 1, 2, 3, 4$, are identified by the letters s, p, d, f, and g.

(a) 2

(b) 3
(c) 0
(d) 1
(e) 4

8. Writing Electron Configurations

Question

What is the complete electron configuration of the zirconium atom?

Approach

With increasing atomic number, electrons occupy the subshells available in each main energy level in order, with few exceptions:

1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p.

Solution:

Forty electrons must be accommodated. The total electron configuration for Zr is:

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

This configuration may also be written as:

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

9. Writing Electron Configurations

Question

What is the complete electron configuration for the arsenic atom?

Approach

With increasing atomic number, electrons occupy the subshells available in each main energy level in order, with few exceptions:

1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p.

Solution:

Thirty-three electrons must be accommodated. The total electron configuration for As is:

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

This configuration may also be written as:

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

10. Writing Electron Configurations

Question

What is the noble gas notation for the electron configuration for the rubidium atom?

Approach

With increasing atomic number, electrons occupy the subshells available in each main energy level in specific order, with few exceptions:

1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p.

The noble gas notation substitutes the symbol of the noble gas for the corresponding noble gas core in the electron configuration.

Solution:

The noble gas just prior to Rb in the periodic table is Kr. The noble gas notation for the electron configuration for Rb is: $[Kr]5s^1$.

11. Writing Electron Configurations

Question

What is the complete electron configuration for the Br^- ? With which element in the periodic table is it isoelectric?

Approach
With increasing atomic number, electrons occupy the subshells available in each main energy level in specific order:

1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p.

Solution:
The anion Br^- is formed by the addition of 1 electron to the lowest energy orbital that has a vacancy. The electron configuration for Br^- is:

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

Cl^- is isoelectric with krypton.

12. Electron Configurations of Transition Metal Cations

We will look at iron, a transition metal, and two of its cations, and compare their electron configurations. We will compare what we would expect from main group behavior against the real behavior of the cations. We'll examine the real behavior closely to understand why it occurs, and then come to some conclusions about why the real behavior differs from our expectations.

We will be examining Fe, Fe^{2+}, and Fe^{3+}. The electron configuration of neutral Fe is $[Ar]4s^23d^6$.

Question: What will be the electron configurations of Fe^{2+} and of Fe^{3+}?

Expectation (based on main group behavior): If Fe loses electrons to form cations, we might expect the electrons removed to be those that were added last. We would expect:

Fe^{2+}: $[Ar]4s^23d^4$ Fe^{3+}: $[Ar]4s^23d^3$

Real Behavior:

Fe^{2+}: $[Ar]3d^6$ Fe^{3+}: $[Ar]3d^5$

Elaboration: Most transition metal atoms have electron configurations with two electrons in an s orbital, and some electrons in the d subshell of the shell below (with a lower value of n) that of the s orbital.

When transition metal atoms lose electrons to form ions, the first electrons lost are those in the s orbital. The electron configuration of Fe^{2+} is $[Ar]3d^6$. The 4s electrons have been lost, the 3d electrons remain. If a third electron is lost, forming Fe^{3+}, it will be removed from the 3d subshell, forming an ion with an electron configuration $[Ar]3d^5$.

Explanation: In an atom of Ca, the 4s subshell fills in preference to the 3d subshell and the atom is lower in energy with an $[Ar]4s^2$ electron configuration. Having a filled s subshell is favored for transition metal atoms as well, but this does not hold true for transition metal cations. In these cases, it is energetically favorable to have the d orbital subshell fill in preference to the s subshell. This implies that orbital subshells shift both in absolute energy as well as in energy relative to one another when ions form. This is the case.

Additional problems:
1) Give the electron configurations for O, S, and Se in spectroscopic notation. In what way are they similar?

2) Give the noble gas notation electron configuration for samarium, Sm, which is in the lanthanide series. What subshell remains only partially filled? Is a samarium atom expected to be diamagnetic or paramagnetic?

3) Give three atoms or ions that have an electron configuration of: $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^6$.

1. **Answer:**

   O: $1s^2 2s^2 2p^4$
   S: $1s^2 2s^2 2p^6 3s^2 3p^4$
   Se: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$

   They are similar in that they each have an outermost p subshell that contains four electrons. Each of the elements is located in group 4A of the periodic table. In general, elements that are found in the same periodic group have similar outermost electron configurations.

2. **Answer:**

   $[Xe]6s^2 4f^6$

   The 4f subshell is partially filled, as is expected for an f-block element. The 4f subshell has 6 electrons (the overall subshell, with seven orbitals, can hold 14 electrons). Sm has atoms among the most strongly paramagnetic of all the elements because its atoms have 6 unpaired electrons.

3. **Answer:** Notice that this electron configuration has an outermost 5p subshell that is filled. It therefore represents the noble gas element in period 5 of the periodic table. This is Xe.

   Atoms that can form anions with the same electron configuration will be found to the left of Xe in the periodic table. Therefore, I^- and Te^{2-} will each have this electron configuration. Atoms that can form cations with the same electron configuration will be the next two elements on the periodic table. Therefore, Cs^+ and Ba^{2+} will each have this electron configuration. These five species, Te^{2-}, I^-, Xe, Cs^+, and Ba^{2+} are all isoelectronic. They each have 54 electrons but, due to their differing number of protons, they have different charges.

13. Atomic Radii

Problem
Consulting the periodic table, decide whether the first atom in each of the following pairs is larger, smaller, or similar in atomic radius to the second atom:
(a) Si, Pb (b) Cs, Pb (c) Rh, Ir (d) Ti, V.

Approach
Atomic size increases moving down a group, and decreases moving left to right along a period.

Solution:
(a) Silicon is the second element in the carbon family, and lead is the fifth element. Silicon atoms should be smaller as size increases down a representative periodic group.
(b) Cesium and lead are in the same period, with lead further to the right in the period. Size decreases across the periods, and therefore cesium atoms should be larger than lead atoms.
(c) Rhodium and iridium are the second and third members of a d-transition metal group. Elements in the second and third transition series are very similar in size due to the lanthanide contraction, therefore, these atoms should be similar in size.
(d) Titanium and vanadium are adjacent elements in the same d-transition period. The decrease in size across the periods for transition elements is gradual. Atoms of these two elements should be similar in atomic radius.

14. Ionic Radii

Problem

Place the following species in order of increasing radius:

Cl Cl^- Cl^+

Approach

For species having the same number of protons, the more electrons, the larger the species.

Solution:

The positively charged chlorine atom is smaller than neutral chlorine; the former has one fewer electron than neutral chlorine. The negatively charge chlorine atom is the largest of all three; it has one additional electron than neutral chlorine.

$Cl^+ < Cl < Cl^-$

15. Ionic Radii

Problem

Arrange the following ions in order of increasing radius:

F^- Mg^{2+} Cl^- Be^{2+} S^{2-} Na^+

Approach

Ionic size increases moving down a group, and decreases moving left to right along a period. For isoelectric species, the greater the number of protons, the smaller the species.

Solution:

Mg^{2+}, Na^+, F^- all have the same number of electrons, thus they are similar in size. Mg^{2+}, however, has the largest number of protons, therefore it is the smallest of these three ions. Likewise, S^{2-} is larger than Cl^- because it has fewer protons. S^{2-} and Cl^- have an additional shell relative to Mg^{2+}, Na^+, and F^-, therefore S^{2-} and Cl^- are both larger than these three ions. Be^{2+} has one fewer shell, and is therefore smaller than Mg^{2+}, Na^+, and F^-.

$Be^{2+} < Mg^{2+} < Na^+ < F^- < Cl^- < S^{2-}$

16. Ion Charges

Question

What charge are the following ions expected to have?

(a) ionic barium (b) ionic oxygen (c) ionic potassium

Solution

(a) Barium is expected to form cations. Elements in periodic Group 2A form ions of +2 charge, therefore barium is expected to form Ba^{2+}.

(b) Oxygen is expected to form anions. It is in periodic Group 6A, and forms O^{2-}.

(c) Potassium is expected to form cations. Elements in periodic Group 1A form ions of +1 charge, therefore potassium will form K^+.

17. Ion Charge and Formula

Problem
Aluminum acts as a metal and oxygen acts as a nonmetal when they react. Predict the formula for aluminum oxide.

Approach
Aluminum loses 3 valence electrons to form Al^{3+}, whereas oxygen gains 2 valence electrons to form O^{2-}.

Solution:
When ionic compounds form from elements, the total charge on the cations must balance out the total negative charge on the anions. We will need two Al ions, which give a +6 charge, for every 3 oxygen ions, which give a -6 charge. The formula is: Al_2O_3.

18. Electrostatic Forces

Question
Which compound's ions are held together by stronger forces: LiBr or MgS?

Solution
The most significant difference between the two compounds is the charges on the individual ions. Li and Br have +1 and -1 charges, respectively. Mg and S have +2 and -2 charges, respectively. The higher charges on Mg and S (+2 and -2, in relation to +1 and -1 in LiBr) lead to stronger electrostatic forces.

19. Ionic Compounds

Problem
Give the number and identify the constituent ions in the following ionic compounds:
(a) NaF (b) $CaCl_2$ (c) $Cu(NO_3)_2$ (d) $NaCH_3CO_2$.

Solution
(a) 1 Na^+ and 1 F^- ion (b) 1 Ca^{2+} ion and 2 Cl^- ions
(c) 1 Cu^{2+} ion and 2 NO_3^- ions (d) 1 Na^+ and 1 $CH_3CO_2^-$ ion

20. Nomenclature

Problem
Give the formula for each of the following ionic compounds:
(a) ammonium nitrate (b) cobalt(II) sulfate (c) nickel(II) cyanide.

Solution
(a) NH_4NO_3 (b) $CoSO_4$ (c) $Ni(CN)_2$

21. Nomenclature

Problem
Name the following ionic compounds:
(a) Li_2CO_3 (b) $KHSO_3$ (c) CuCl and $CuCl_2$.

Solution
(a) Lithium carbonate (b) Potassium hydrogen sulfite
(c) Copper(I) chloride and copper(II) chloride

22. Nomenclature

Question

What are the names of each of these molecules?

(a) CO_2 (b) S_2F_{10} (c) BF_3

Solution

The symbol of the cation is always given first, followed by the anion symbol. The correct names for the above molecules are:

(a) carbon dioxide (b) disulfur decafluoride (c) boron trifluoride

23. Nomenclature

Problem

Give the name for each of the following compounds:

(a) PI_3 (b) SCl_2 (c) XeO_3

Solution

(a) Phosphorus triiodide (b) Sulfur dichloride (c) Xenon trioxide

24. Naming Hydrogen-containing Compounds

Question

What is the name of HBr?

Solution

Hydrogen monobromide or hydrobromic acid

25. Nomenclature

Problem

Give the formula for each of the following compounds:

(a) zinc(II) carbonate (b) sodium phosphate (c) aluminum chloride.

Solution

(a) $ZnCO_3$ (b) Na_3PO_4 (c) $AlCl_3$