

Objective 11a: Light and atomic structure: apply quantum numbers to write electron configuration of atoms, identify valence electrons, draw Lewis dot symbols.

Quiz Practice problems

Key ideas:

Particle-wave duality. A wave can behave like a particle (photoelectric effect); a particle can behave like a wave (electron diffraction). deBroglie equation: $\lambda = h/mv$

The idea that a particle can behave like a wave led to Quantum Theory of the atom – treat electrons like a wave (the math equation is called a wave function) – involves the probability of finding an electron in a specific region of space and the uncertainty principle.

A wave function for an electron in an atom is called an atomic orbital. Information (energy, location, etc.) about an electron in an atom is described with the four quantum numbers.

Skills: relate wavelength, mass, and velocity of a particle using deBroglie equation.

Understand meaning of each quantum number.

Relate atomic orbital, e.g., 1s, to the four quantum numbers.

Draw energy level diagram of atomic orbitals.

Write electron configuration for 1st 20 elements in periodic table.

Identify valence electrons.

Draw Lewis dot symbols for 1st 20 elements.

1. In 2004, researchers at Oak Ridge National Laboratory and Nion Company reported that they produced the highest resolution electron microscope in the world with an actual resolution limit of 0.6 Angstroms (Chemical and Engineering News, 9/20/04, p. 13).

a. Compare a light microscope to an electron microscope. What property of light is used in a light microscope? What property of an electron is used in an electron microscope?

b. What is the wavelength of an electron to give a resolution of 0.6 Angstroms? Note: resolution = 0.5 (observation wavelength)

c. Calculate the speed of an electron that corresponds to this wavelength. (Which equation should you use? Answer: speed is approximately $6E6$ m/sec = 6×10^6 m/sec)

Answers:

a. A light microscope uses the wave property of light.

An electron microscope uses the wave property of light.

b. resolution = 0.5 (observation wavelength)

$0.6E-10$ m = 0.5 (observation wavelength)

so observation wavelength = $1.2E-10$ m = wavelength of an electron

c. Use deBroglie equation: $\lambda = h/mv$

Rearrange and solve for v = $h/(m\lambda) = 6.63E-34$ J sec / $(9.11E-31$ kg) $(1.2E-10$ m) = $6.0E6$ m/sec = 6 million m/sec.

This speed is less than the speed of light = $3.0E8$ m/sec.

2. Quantum theory uses a wave function to describe how a particle behaves like a wave. The wave function of an electron in an atom is called an atomic orbital. An electron in an atom is described with four quantum numbers.

You've seen the atomic orbitals (AO) 1s, 2s, 2p, 3s, and 3p.

a. The 1 in 1s, 2 in 2s and 2p, and 3 in 3s and 3p refer to the principal quantum number (symbol = n) and tell us the relative energy of an electron.

Compare the 1s and 2s AO. As n increases, what happens to the energy?

b. The s in 1s and 2s and p in 2p and 3p refer to the angular momentum quantum number (symbol = ℓ). The ℓ quantum number tells us the shape of an AO, which tells us the probability of finding an electron in the region of space as described by the AO shape.

You know the shape of a s AO is spherical. Is the probability of finding an electron outside of the spherical region high or low?

c. You know there is only one type of s AO and three types of p AO's. This refers to the orientation in space of the AO. A s AO has only one orientation (only one orientation for a sphere). The p AO's have three orientations in space (p_x , p_y , and p_z). The magnetic quantum number (symbol = m_ℓ) tells us about this orientation in space. This m_ℓ quantum number depends on the ℓ quantum number.

For a s AO, $\ell = 0$ and $m_\ell = 0$. Only one value for m_ℓ , so only one orientation in space.

For a p AO, $\ell = 1$ and $m_\ell = 0, 1, \text{ and } -1$. Three values for m_ℓ , so three orientations in space.

(iii) For a d AO, $\ell = \underline{\hspace{1cm}}$ and $m_\ell = \underline{\hspace{1cm}}$. $\underline{\hspace{1cm}}$ values for m_ℓ , so $\underline{\hspace{1cm}}$ orientations in space.

Answers:

a. As n increases, energy increases.

b. The probability of finding an electron outside of the spherical region is low.

c. For a d AO, $\ell = 2$ and $m_\ell = 0, 1, -1, 2, \text{ and } -2$. Five values for m_ℓ , so five orientations in space.

3. a. In the structure of an atom, where is almost all of the mass of an atom? What occupies almost all of the volume of an atom?

b. The electron configuration of an atom tells us how electrons are distributed around the nucleus of an atom.

For example, nitrogen has 7 electrons and an electron configuration of $1s^2, 2s^2, 2p^3$.

You can either look up the electron configuration of an atom or apply the building up principle, Hund's rule, and the Pauli exclusion principle. We want to know about the valence electrons because these are the electrons that are responsible for bonding atoms to form compounds.

(i) How many valence electrons does nitrogen have? (Hint: see Group number in Periodic Table.)

(ii) See the electron configuration of carbon. Which electrons are the valence electrons? (Answer: $2s^2, 2p^3$)



c. Draw the Lewis dot symbol of nitrogen. (Answer: $\cdot \cdot$ Note the 3 unpaired electrons and lone pair of electrons match the valence electron configuration of nitrogen.)

d. Atoms are very stable (low energy) when their electron shell is completely filled with 8 electrons. How many electrons does nitrogen need to have a completely filled shell? (Answer: either gain 3 electrons or lose 5 electrons.)

e. Fill in the blanks in the table.

element	electron configuration	Group #	valence electrons	Lewis dot symbol	electrons gained or lost for completely filled shell
Na	$1s^2 2s^2 2p^6 3s^1$				
Cl	$1s^2 2s^2 2p^6 3s^2 3p^5$				
Ca					
O					

Answers:

a. almost all of the mass of an atom is in the nucleus. The electron cloud occupies almost all of the volume of an atom.

b. (i) N has 5 valence electrons. Group # = # of valence electrons.

(ii) N electron configuration is $1s^2, 2s^2, 2p^3$. The valence electrons are the outer shell electrons that are farthest away from the nucleus ==> $n = 2$ so the $2s^2, 2p^3$ electrons are the valence electrons.



c. Lewis dot symbol of nitrogen = $\cdot \cdot$

d. N needs to gain 3 electrons (5 valence electrons $+ 3 = 8$) or lose 5 electrons (5 valence electrons $- 5 = 0$) to have a completely filled shell.

e. Fill in the blanks in the table.

element	electron configuration	Group #	valence electrons	Lewis dot symbol	electrons gained or lost for completely filled shell
Na	$1s^2 2s^2 2p^6 3s^1$	1	1	Na \cdot	Lose 1
Cl	$1s^2 2s^2 2p^6 3s^2 3p^5$	7	7	$\cdot \overset{\cdot}{\underset{\cdot}{\text{Cl}}} \cdot$	Gain 1
Ca	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$	2	2	Ca:	Lose 2
O	$1s^2 2s^2 2p^4$	6	6	$\cdot \overset{\cdot}{\underset{\cdot}{\text{O}}} \cdot$	Gain 2

4. Reactivity of Metals has to do with ionization energy and the distance an electron is from the nucleus of an atom.

You place a piece of Mg metal in a beaker filled with water. You place a piece of Ca metal in a second beaker filled with water.

a. Which reaction occurs faster? In other words, which metal is more reactive? Give reasons.

b. For the reaction that occurs faster, write a molecular equation and net ionic equation.

c. Calculate ΔH of reaction for the reaction in part b. (Use your net ionic equation.)

d. If 2.5 g of the metal that reacts faster is added to 1 cup (240 ml) of water, calculate the final temperature of the water. Assume T_i of water = 25°C .

Answers:

a. These are single replacement reactions: $\text{Mg} + 2 \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Mg}(\text{OH})_2$ and $\text{Ca} + 2 \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Ca}(\text{OH})_2$
Ca is more reactive than Mg.

Ca (Period 4) is larger than Mg (Period 3).

The valence electrons in Ca ($4s^2$) are farther away from the nucleus than the valence electrons for Mg ($3s^2$).

This means the attractive force between electrons and protons is weaker in Ca than Mg.

So the valence electrons in Ca are easier to remove (lose) ==> this makes Ca more reactive.

b. $\text{Ca} + 2 \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Ca}(\text{OH})_2$

Ca(OH)₂ is insoluble in water

Net ionic equation: Ca (s) + 2 H₂O (l) → H₂ (g) + Ca(OH)₂ (s)

c. $\Delta H_{\text{rxn}} = \sum (n \Delta H_f \text{ (products)}) - \sum (n \Delta H_f \text{ for (reactants)})$

$$\begin{aligned}\Delta H_{\text{rxn}} &= [1 \Delta H_f (\text{H}_2 (\text{g})) + \Delta H_f (\text{Ca(OH)}_2 (\text{s}))] - [1 \Delta H_f (\text{Ca (s)}) + 2 \Delta H_f (\text{H}_2\text{O (g)})] \\ &= [(0) + (-986.6 \text{ kJ/mole})] - [1 (0) + 2 (-285.8 \text{ kJ/mole})] \\ &= -415 \text{ kJ/mole}\end{aligned}$$

d. heat gained by water = - heat lost by Ca + water reaction

$m \Delta T = - \text{moles of } \underline{\hspace{2cm}} \times \Delta H \text{ (in J/mole)}$

(240 g water)(4.18 J/g °C)(T_f - 25°C) = - (2.5 g Ca)(1 moles Ca/40 g Ca)(-415 kJ/mole)(1000 J/1 kJ)

Solve for T_f = 50.9°C

Add 2.5 g of Ca to 1 cup of water. Ca reacts with water and heats the water from 25°C to 50.9°C. Assume all of the Ca dissolves in the water.

Objective 11b: Draw Lewis structures, distinguish isomers

Quiz Practice problems

Key ideas:

Valence electrons are the electrons involved in bonding atoms together to form compounds.

of valence electrons = Group

General bonding rules for neutral molecules: C = 4 bonds, N = 3 bonds + 1 lone pair (l.p.), O = 2 bonds and 2 l.p., X (F, Cl, Br, I) = 1 bond and 3 l.p., H = 1 bond and 0 l.p.

For the following compounds,

(i) Draw the Lewis dot symbol of each atom.

(ii) Determine total number of valence electrons in the molecule.

(iii) Draw the Lewis structure of the molecule.

(iv) Identify and distinguish between isomers.

Isomers are two or more compounds that have the same chemical formula but different ways the atoms are connected (bonded) in a molecule.

Skills: Draw Lewis structure of molecules.

Draw Lewis structures of isomers of a compound.

1. The molecules below have single bonds:

a. Ammonia (you've smelled it) = NH₃. (Answer: 8 total valence electrons. N (3.0) is more electronegative than H (2.2). The N-H bond is a polar bond.)

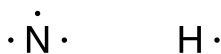
b. Natural gas (fuel used in stoves) = CH₄

Methanol (common organic solvent) = CH₃OH (Answer: 14 total valence electrons. C-O and C-H bonds are polar.)

Ethanol (common organic solvent, used in fuels) = CH₃CH₂OH or C₂H₆O.

Dimethyl ether (common organic solvent) = C₂H₆O. Dimethyl ether has the same chemical formula as ethanol but the way the atoms are bonded together is different. Two compounds that have the same chemical formula but different bonding are called **isomers**.

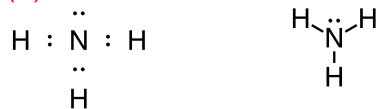
Answers:



a. (i) $\cdot \cdot$

(ii) N = 5 valence electrons, 3 H = 3 x (1 valence electrons) = 3. Total = 8 valence electrons.

(iii)



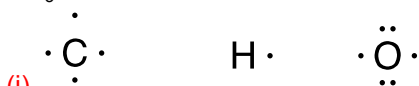
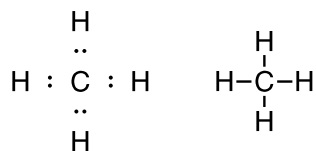
b. CH₄



(i)

(ii) N = 5 valence electrons, 3 H = 3 x (1 valence electrons) = 3. Total = 8 valence electrons.

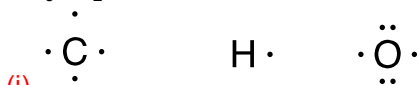
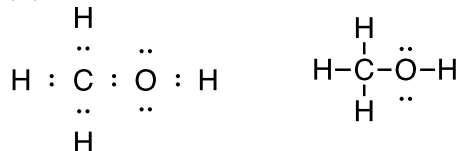
(iii)



(i)

(ii) C = 4 valence electrons, 4 H = 4 x (1 valence electrons) = 4, O = 6 valence electrons. Total = 14 valence electrons.

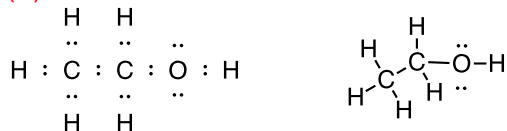
(iii)



(i)

(ii) 2 C = 2 x (4 valence electrons) = 8, 6 H = 6 x (1 valence electrons) = 6, O = 6 valence electrons. Total = 20 valence electrons.

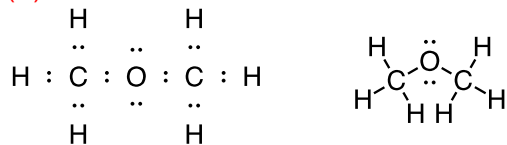
(iii)



(i)

(ii) 2 C = 2 x (4 valence electrons) = 8, 6 H = 6 x (1 valence electrons) = 6, O = 6 valence electrons. Total = 20 valence electrons.

(iii)



2. These compounds have at least one double bond.

Oxygen (we need this to survive) = O_2

Carbon dioxide (product of combustion reaction, global warming gas) = CO_2 (Answer: 16 total valence electrons.)

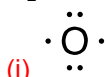
Ethylene (fuel, used to make many different organic compounds) = C_2H_4

Formic acid (the substance that ants emit when they bite you that causes the bite wound to sting) = HCOOH

Benzene (common organic solvent, carcinogen) = C_6H_6 (this compound is a six sided ring)

Answers:

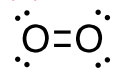
O_2



(i)

(ii) 2 O = 2 x 6 valence electrons. Total = 12 valence electrons.

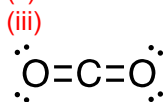
(iii)



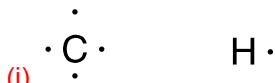
CO_2



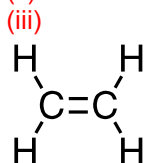
- (i)
 (ii) C = 4 valence electrons, 2 O = 2 x 6 valence electrons = 12. Total = 16 valence electrons.



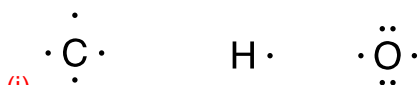
C₂H₄



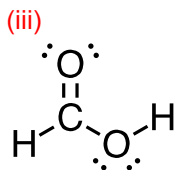
- (i)
 (ii) 2 C = 2 x (4 valence electrons) = 8, 4 H = 4 x (1 valence electrons) = 4. Total = 12 valence electrons.



HCOOH



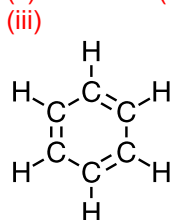
- (i)
 (ii) C = 4 valence electrons, 2 H = 2 x (1 valence electrons) = 2, 2 O = 2 x 6 valence electrons = 12. Total = 18 valence electrons.



C₆H₆



- (i)
 (ii) 6 C = 6 x (4 valence electrons) = 24, 6 H = 6 x (1 valence electrons) = 6. Total = 30 valence electrons.



3. These compounds have at least one triple bond.

Nitrogen (air is 80% of this gas) = N₂

Carbon monoxide (side product of combustion, toxic) = CO

Acetylene (fuel, used in torches) = C₂H₂

Answers:

N₂



- (i)
 (ii) 2 C = 2 x (5 valence electrons) = 10 Total valence electrons.

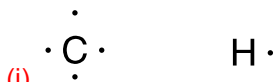


CO



(ii) C = 4 valence electrons, O = 6 valence electrons. Total = 10 valence electrons.

(iii)
:C≡O:



(ii) 2 C = 2 x (4 valence electrons) = 8, 2 H = 2 x (1 valence electrons) = 2. Total = 10 valence electrons.

(iii)
H-C≡C-H

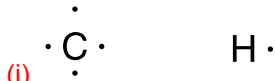
4. Bigger molecules have more atoms. More atoms means there can be different ways the atoms can bond together. Two or more compounds that have the same chemical formula but different connectivity (different ways the atoms are bonded to each other) are called isomers.

a. butane (used in camping stoves) = C₄H₁₀. There are two isomers. Draw the Lewis structures of each isomer.

b. hexane (component of gasoline) = C₆H₁₄. There are several isomers. Draw the Lewis structures of two isomers.

Answers:

a. C₄H₁₀

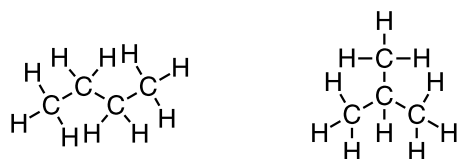


(ii) 4 C = 4 x (4 valence electrons) = 16, 10 H = 10 x (1 valence electrons) = 10. Total = 26 valence electrons.

(iii) Butane has two isomers. The way the atoms are bonded together is different. The properties of each isomer are different, too. The boiling point of the structure on the left is -1°C. The boiling point of the structure on the right is -12°C.

Compare the bonding in each isomer:

Left structure is called n-butane (n for normal).	Right structure is called iso-butane (this is the fuel used in camping stoves).
1 st C on left has 3 C-H bonds and 1 C-C bond	1 st C on left has 3 C-H bonds and 1 C-C bond
2 nd C from left has 2 C-H bonds and 2 C-C bonds	2 nd C from left has 1 C-H bond and 3 C-C bonds ==> DIFFERENT
2 nd C from right has 2 C-H bonds and 2 C-C bonds	top C has 3 C-H bonds and 1 C-C bond ==> DIFFERENT
1 st C on right has 3 C-H bonds and 1 C-C bond	1 st C on right has 3 C-H bonds and 1 C-C bond



b. C₆H₁₄



(ii) 6 C = 6 x (4 valence electrons) = 24, 14 H = 14 x (1 valence electrons) = 14. Total = 38 valence electrons.

(iii) Hexane, C₆H₁₄, has several isomers. Here are two isomers – compare the bonding in each structure to confirm the bonding is different.

