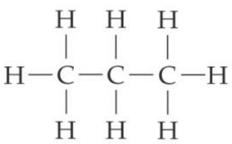
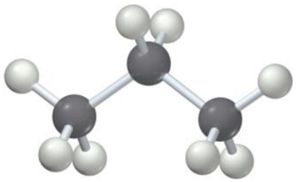
WORKED EXAMPLE 5.1 Drawing a Structural Formula

Propane, C_3H_8, has a structure in which the three carbon atoms are bonded in a row, each end carbon is bonded to three hydrogens, and the middle carbon is bonded to two hydrogens. Draw the structural formula, using lines between atoms to represent covalent bonds.

Solution

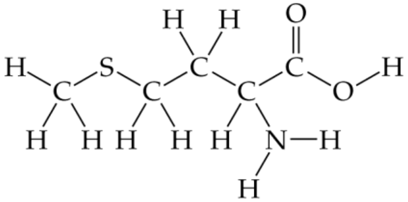


Propane



PROBLEM 5.1 Draw the structural formula of methylamine, CH_5N, a substance responsible for the odor of rotting fish. The carbon atom is bonded to the nitrogen atom and to three hydrogens. The nitrogen atom is bonded to the carbon and two hydrogens.

PROBLEM 5.2 Methionine, one of the 20 amino acid building blocks from which proteins are made, has the following structure. What is the chemical formula of methionine? In writing the formula, list the elements in alphabetical order.

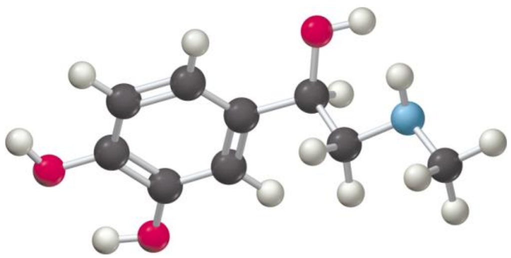


Methionine
(an amino acid)

WORKED EXAMPLE 5.1 Drawing a Structural Formula

Continued

KEY CONCEPT PROBLEM 5.3 Adrenaline, the so-called “fight or flight” hormone, can be represented by the following ball-and-stick model. What is the chemical formula of adrenaline (Gray = C, ivory = H, red = O, blue = N)



WORKED EXAMPLE 5.2 Naming Binary Molecular Compounds

Give systematic names for the following compounds:

(a) PCl_3 **(b)** N_2O_3

(c) P_4O_7 **(d)** BrF_3

Strategy

Look at a periodic table to see which element in each compound is cationlike (less electronegative) and which is anionlike (more electronegative). Then name the compound using the appropriate numerical prefix.

Solution

(a) Phosphorus trichloride **(b)** Dinitrogen trioxide

(c) Tetraphosphorus heptoxide **(d)** Bromine trifluoride

PROBLEM 5.7 Give systematic names for the following compounds:

(a) NCl_3 **(b)** P_4O_6

(c) S_2F_2 **(d)** SeO_2

PROBLEM 5.8 Write formulas for compounds with the following names:

(a) Disulfur dichloride

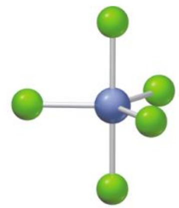
(b) Iodine monochloride

(c) Nitrogen triiodide

WORKED EXAMPLE 5.2 Naming Binary Molecular Compounds

Continued

KEY CONCEPT PROBLEM 5.9 Give systematic names for the following compounds:



Purple = P, green = Cl

(a)

Blue = N, red = O

(b)

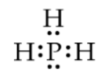
WORKED EXAMPLE 5.3 Drawing an Electron-Dot Structure

Draw an electron-dot structure for phosphine, PH_3.

Strategy

The number of covalent bonds formed by a main-group element depends on the element's group number. Phosphorus, a group 5A element, has five valence electrons and can achieve a valence-shell octet by forming three bonds and leaving one lone pair. Each hydrogen supplies one electron.

Solution



Phosphine

PROBLEM 5.10 Draw electron-dot structures for the following molecules:

(a) H_2S, a poisonous gas produced by rotten eggs

(b) $CHCl_3$, chloroform

PROBLEM 5.11 Draw an electron-dot structure for the hydronium ion, , and show how a coordinate covalent bond is formed by the reaction of H2O with H^+.

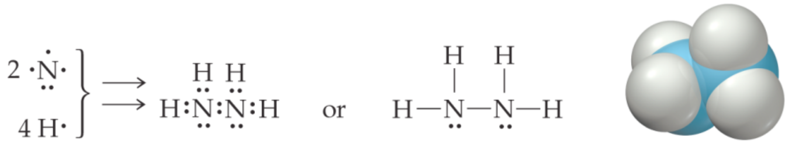
WORKED EXAMPLE 5.4 Drawing an Electron-Dot Structure

Draw an electron-dot structure for hydrazine, N_2H_4.

Strategy

Nitrogen, a group 5A element, has five valence electrons and forms three bonds. Join the two nitrogen atoms, and add two hydrogen atoms to each.

Solution



Hydrazine, N_2H_4

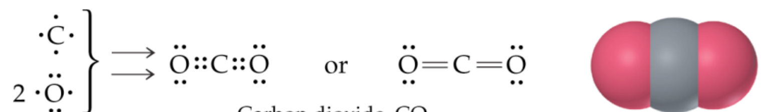
WORKED EXAMPLE 5.5 Drawing an Electron-Dot Structure

Draw an electron-dot structure for carbon dioxide, CO_2.

Strategy

Connect the atoms so that carbon forms four bonds and each oxygen forms two bonds. The only possible structure contains two carbon–oxygen double bonds.

Solution



Carbon dioxide, CO_2

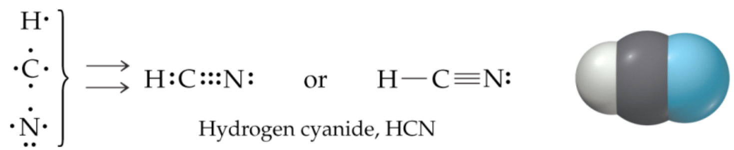
WORKED EXAMPLE 5.6 Drawing an Electron-dot Structure

Draw an electron-dot structure for the deadly gas hydrogen cyanide, HCN.

Strategy

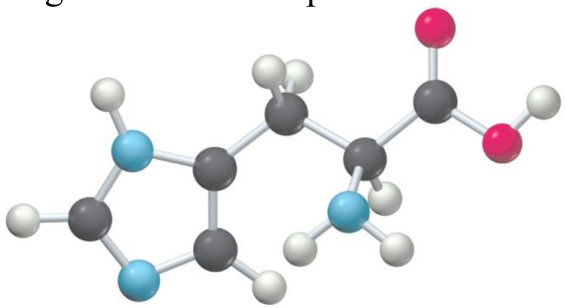
First, connect the carbon and nitrogen atoms. The only way the carbon can form four bonds and the nitrogen can form three bonds is if there is a carbon–nitrogen triple bond.

Solution



WORKED KEY CONCEPT EXAMPLE 5.7 Identifying Multiple Bonds in Molecules

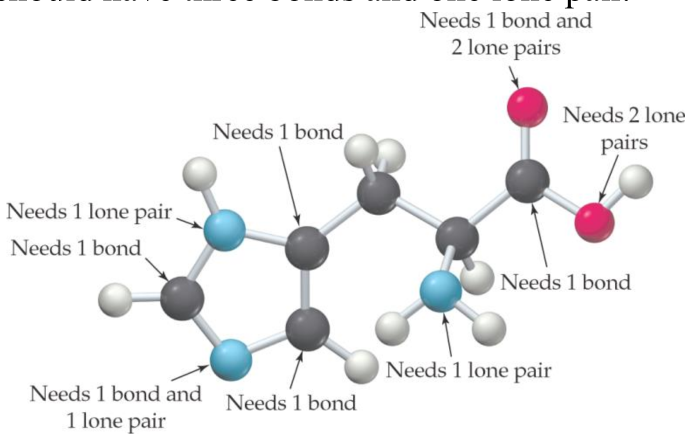
The following structure is a representation of histidine, an amino acid constituent of proteins. Only the connections between atoms are shown; multiple bonds are not indicated. Give the chemical formula of histidine, and complete the structure by showing where the multiple bonds and lone pairs are located (red = O, gray = C, blue = N, ivory = H).



Histidine

Strategy

Count the atoms of each element to find the formula. Then look at each atom in the structure to find what is needed for completion. Each carbon (gray) should have four bonds, each oxygen (red) should have two bonds and two lone pairs, and each nitrogen (blue) should have three bonds and one lone pair.

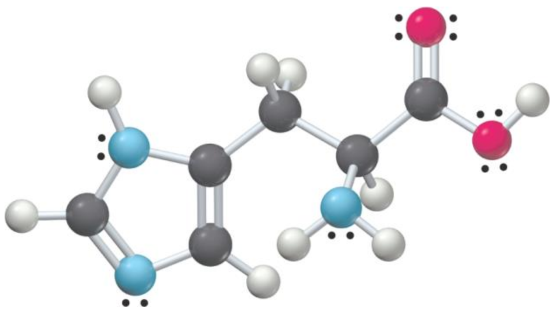


WORKED KEY CONCEPT EXAMPLE 5.7 Identifying Multiple Bonds in Molecules

Continued

Solution

Histidine has the formula $C_6H_9N_3O_2$.



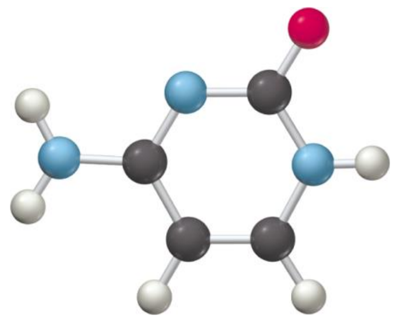
PROBLEM 5.12 Draw electron-dot structures for the following molecules:

(a) Propane, C_3H_8 **(b)** Hydrogen peroxide, H_2O_2
(c) Methylamine, CH_5N **(d)** Ethylene, C_2H_4
(e) Acetylene, C_2H_2 **(f)** Phosgene, Cl_2CO

PROBLEM 5.13 There are two molecules with the formula C_2H_6O. Draw electron-dot structures for both.

Continued

KEY CONCEPT PROBLEM 5.14 The following structure is a representation of cytosine, a constituent of the DNA found in all living cells. Only the connections between atoms are shown; multiple bonds are not indicated. Give the formula of cytosine, and complete the structure by showing where the multiple bonds and lone pairs are located (red = O, gray = C, blue = N, ivory = H).

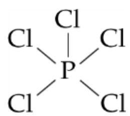


WORKED EXAMPLE 5.8 Drawing an Electron-Dot Structure

Draw an electron-dot structure for phosphorus pentachloride, PCl_5.

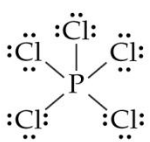
Strategy

Follow the steps outlined in the text. First, count the total number of valence electrons. Phosphorus has 5, and each chlorine has 7, for a total of 40. Next, decide on the connections between atoms, and draw lines to indicate the bonds. Because chlorine normally forms only one bond, it's likely in the case of PCl_5 that all five chlorines are bonded to a central phosphorus atom:

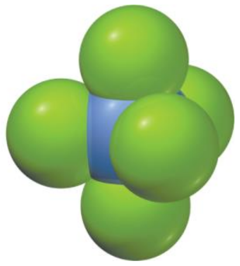


Ten of the 40 valence electrons are necessary for the five P — C1 bonds, leaving 30 to be distributed so that each chlorine has an octet. All 30 remaining valence electrons are used in this step.

Solution



Phosphorus pentachloride, PCl_5

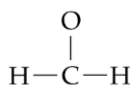


WORKED EXAMPLE 5.9 Drawing an Electron-Dot Structure

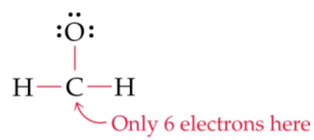
Draw an electron-dot structure for formaldehyde, CH_2O, a compound used in manufacturing the adhesives for making plywood and particle board.

Strategy

First, count the total number of valence electrons. Carbon has 4, each hydrogen has 1, and the oxygen has 6, for a total of 12. Next, decide on the probable connections between atoms, and draw a line to indicate each bond. In the case of formaldehyde, the less electronegative atom (carbon) is the central atom, and both hydrogens and the oxygen are bonded to carbon:

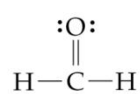


Six of the 12 valence electrons are used for bonds, leaving 6 for assignment to the terminal oxygen atom.



At this point, all the valence electrons are assigned, but the central carbon atom still does not have an octet. We therefore move two of the oxygen electrons from a lone pair into a bonding pair, generating a carbon–oxygen double bond and satisfying the octet rule for both oxygen and carbon.

Solution



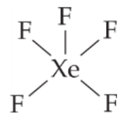
Formaldehyde, CH_2O

WORKED EXAMPLE 5.10 Drawing an Electron-Dot Structure

Draw an electron-dot structure for XeF_5^+, one of the very few noble-gas ions.

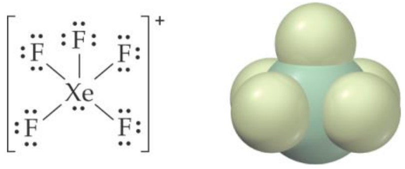
Strategy

Count the total number of valence electrons. Xenon has 8, each fluorine has 7, and 1 is subtracted to account for the positive charge, giving a total of 42. Then, decide on the probable connections between atoms, and draw a line for each bond. In the case of XeF_5^+, it's likely that the five fluorines are bonded to xenon, a fifth-row atom.



With 10 of the 42 valence electrons used in bonds, distribute as many of the remaining 32 electrons as necessary so that each of the terminal fluorine atoms has an octet. Two electrons still remain, so we assign them to xenon to give the final structure, which has a positive charge.

Solution



PROBLEM 5.15 Carbon monoxide, CO, is a deadly gas produced by incomplete combustion of fuels. Draw an electron-dot structure for CO.

WORKED EXAMPLE 5.10 Drawing an Electron-Dot Structure

Continued

PROBLEM 5.16 Draw an electron-dot structure for each of the following molecules:
(a) $AlCl_3$ **(b)** ICl_3 **(c)** $XeOF_4$ **(d)** HOBr

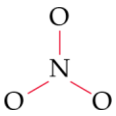
PROBLEM 5.17 Draw an electron-dot structure for each of the following ions:
(a) OH^- **(b)** H_3S^+ **(c)** HCO_3^- **(d)** ClO_4^-

WORKED EXAMPLE 5.11 Drawing Resonance Structures

The nitrate ion, NO_3^-, has three equivalent oxygen atoms, and its electronic structure is a resonance hybrid of three electron-dot structures. Draw them.

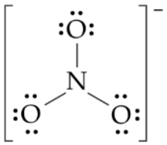
Strategy

Begin as you would for drawing any electron-dot structure. There are 24 valence electrons in the nitrate ion: 5 from nitrogen, 6 from each of 3 oxygens, and 1 for the negative charge. The three equivalent oxygens are all bonded to nitrogen, the less electronegative central atom:



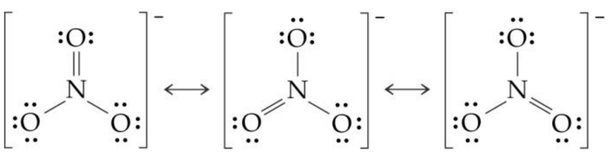
6 of 24 valence electrons assigned

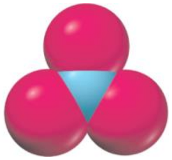
Distributing the remaining 18 valence electrons among the three terminal oxygen atoms completes the octet of each oxygen but leaves nitrogen with only 6 electrons.



To give nitrogen an octet, one of the oxygen atoms must use a lone pair to form an N — O double bond. But which one? There are three possibilities, and thus three electron-dot structures for the nitrate ion, which differ only in the placement of bonding and lone-pair electrons. The connections between atoms are the same in all three structures, and the atoms have the same positions in all structures.

Solution





WORKED EXAMPLE 5.11 Drawing Resonance Structures

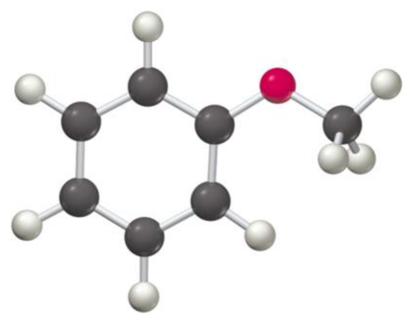
Continued

PROBLEM 5.18 Called "laughing gas," nitrous oxide (N_2O) is sometimes used by dentists as an anesthetic. Given the connections N—N—O, draw two resonance structures for N_2O.

PROBLEM 5.19 Draw as many resonance structures as possible for each of the following molecules or ions, giving all atoms (except H) octets:

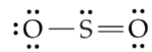
(a) SO_2 **(b)** CO_3^{2-} **(c)** HCO_2^- **(d)** BF_3

KEY CONCEPT PROBLEM 5.20 The following structure shows the connections between atoms for anisole, a compound used in perfumery. Draw two resonance structures for anisole, showing the positions of the multiple bonds in each (red = O, gray = C, ivory = H).



WORKED EXAMPLE 5.12 Calculating Formal Charges

Calculate the formal charge on each atom in the following electron-dot structure for SO_2:



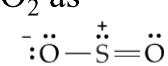
Strategy

Considering each atom separately, find the number of valence electrons on the atom (the periodic group number). Then subtract half the number of bonding electrons and all the nonbonding electrons.

Solution

For sulfur:	Isolated sulfur valence electrons	6
	Bound sulfur bonding electrons	6
	Bound sulfur nonbonding electrons	2
	Formal charge $= 6 - \frac{1}{2}(6) - 2 = +1$	
For singly bonded oxygen:	Isolated oxygen valence electrons	6
	Bound oxygen bonding electrons	2
	Bound oxygen nonbonding electrons	6
	Formal charge $= 6 - \frac{1}{2}(2) - 6 = -1$	
For doubly bonded oxygen:	Isolated oxygen valence electrons	6
	Bound oxygen bonding electrons	4
	Bound oxygen nonbonding electrons	4
	Formal charge $= 6 - \frac{1}{2}(4) - 4 = 0$	

The sulfur atom of SO_2 has a formal charge of +1, and the singly bonded oxygen atom has a formal charge of −1. We might therefore write the structure for SO_2 as

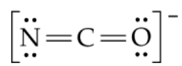


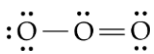
WORKED EXAMPLE 5.12 Calculating Formal Charges

Continued

PROBLEM 5.21 Calculate the formal charge on each atom in the three resonance structures for the nitrate ion in Worked Example 5.11.

PROBLEM 5.22 Calculate the formal charge on each atom in the following electron-dot structures:

(a) Cyanate ion: 

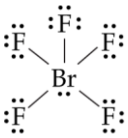
(b) Ozone: 

WORKED EXAMPLE 5.13 Using the VSEPR Model to Predict a Shape

Predict the shape of BrF_5.

Strategy

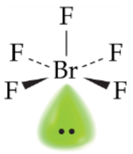
First, draw an electron-dot structure for BrF_5 to determine that the central bromine atom has six charge clouds (five bonds and one lone pair). Then predict how the six charge clouds are arranged.



Bromine pentafluoride

Solution

Six charge clouds implies an octahedral arrangement; five attached atoms and one lone pair give BrF_5 a square pyramidal shape:



PROBLEM 5.23 Predict the shapes of the following molecules or ions:

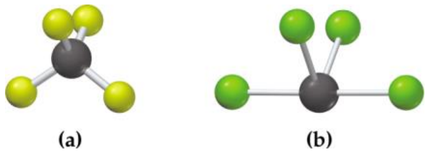
(a) O_3 **(b)** H_3O^+ **(c)** XeF_2 **(d)** PF_6^-
(e) $XeOF_4$ **(f)** AlH_4^- **(g)** BF_4^- **(h)** $SiCl_4$
(i) ICl_4^- **(j)** $AlCl_3$

PROBLEM 5.24 Acetic acid, CH3CO2H, is the main organic constituent of vinegar. Draw an electron-dot structure for acetic acid, and show its overall shape. (The two carbons are connected by a single bond, and both oxygens are connected to the same carbon.)

WORKED EXAMPLE 5.13 Using the VSEPR Model to Predict a Shape

Continued

KEY CONCEPT PROBLEM 5.25 What is the geometry around the central atom in each of the following molecular models?

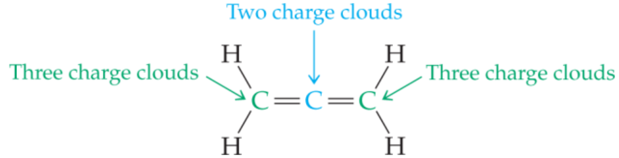


WORKED EXAMPLE 5.14 Predicting the Hybridization of an Atom

Describe the hybridization of the carbon atoms in allene, $H_2C{=}C{=}CH_2$, and make a rough sketch of the molecule showing its hybrid orbitals.

Strategy

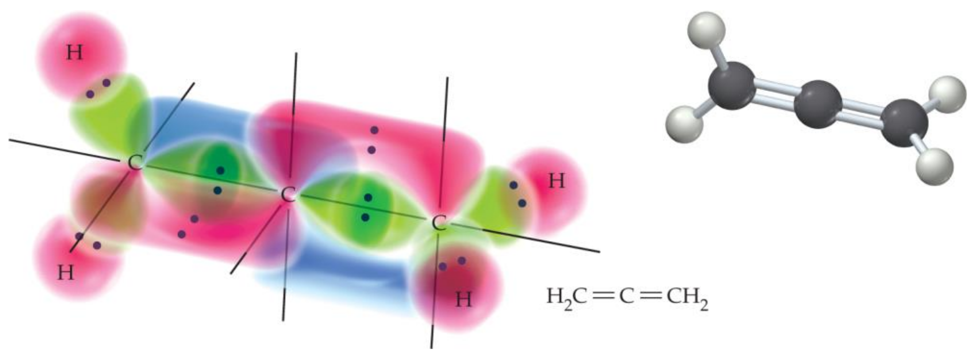
Draw an electron-dot structure to find the number of charge clouds on each atom.



Then predict the geometry around each atom using VSEPR theory.

Solution

Because the central carbon atom in allene has two charge clouds (two double bonds), it has a linear geometry and is *sp*-hybridized. Because the two terminal carbon atoms have three charge clouds each (one double bond and two C—H bonds), they have trigonal planar geometry and are sp^2-hybridized. The central carbon uses its *sp* orbitals to form two σ bonds at 180° angles and uses its two unhybridized *p* orbitals to form π bonds, one to each of the terminal carbons. Each terminal carbon atom uses an sp^2 orbital for σ bonding to carbon, a *p* orbital for π bonding, and its two remaining sp^2 orbitals for C—H bonds. Note that the mutually perpendicular arrangement of the two π bonds results in a similar perpendicular arrangement of the two CH_2 groups.



WORKED EXAMPLE 5.14 Predicting the Hybridization of an Atom

Continued

PROBLEM 5.29 Describe the hybridization of the carbon atoms in carbon dioxide, and make a rough sketch of the molecule showing its hybrid orbitals and bonds.

PROBLEM 5.30 Describe the hybridization of the carbon atom in the poisonous gas phosgene, Cl_2CO, and make a rough sketch of the molecule showing its hybrid orbitals and bonds.

KEY CONCEPT PROBLEM 5.31 Identify each of the following sets of hybrid orbitals:

(a)

(b)

(c)