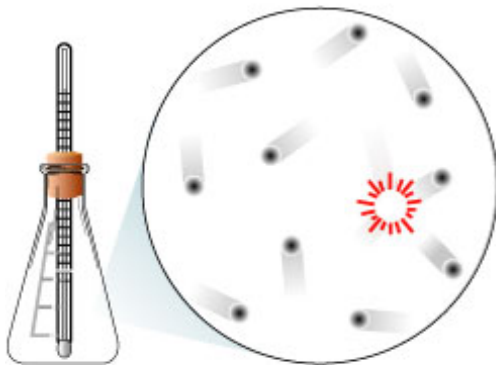
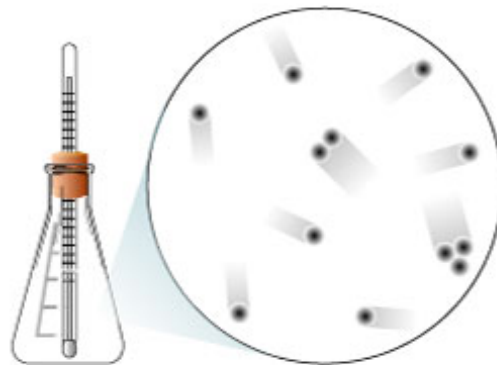


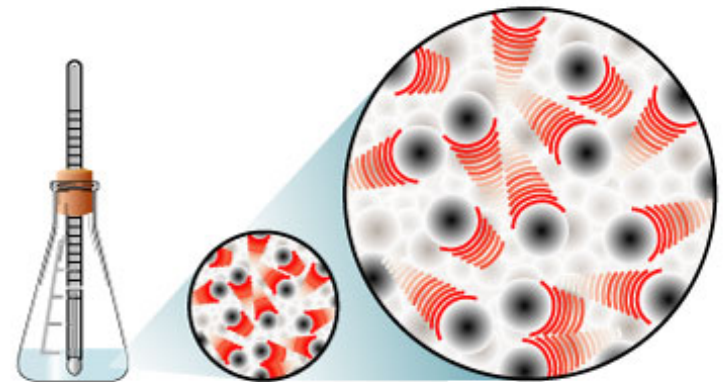
# Condensation (Gas to Liquid)



At a high temperature, there are no significant attractions between the particles.



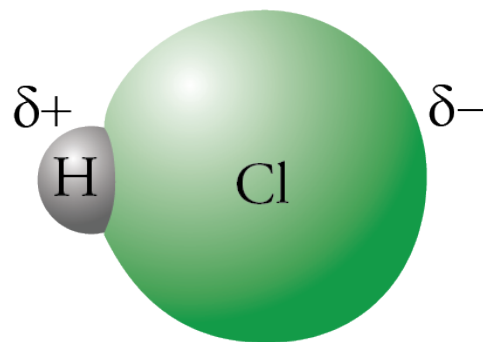
As the temperature is lowered, attractions between particles lead to the formation of very small clusters that remain in the gas phase.



As the temperature is lowered further, the particles move slowly enough to form clusters so large that they drop to the bottom of the container and combine to form a liquid.

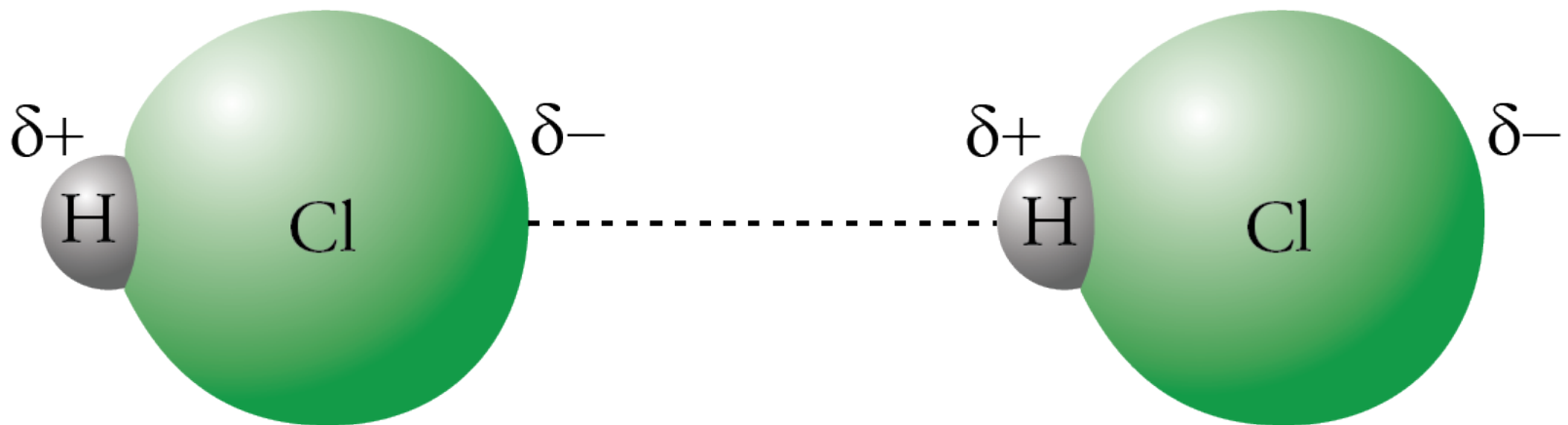
# Hydrogen Chloride Molecule

- The hydrogen atom and the chlorine atom in an HCl molecule are held together by a polar covalent bond. Because chlorine atoms attract electrons more strongly than hydrogen atoms, some of the hydrogen atom's electron cloud is pulled toward the chlorine atom, making the hydrogen atom partially positive and the chlorine atom partially negative.
- We call this separation of positive and negative charges a **dipole**.



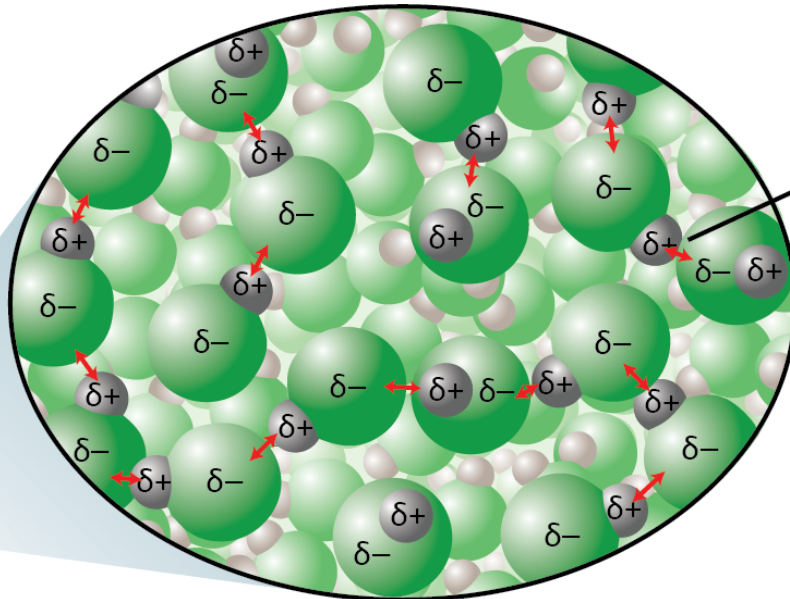
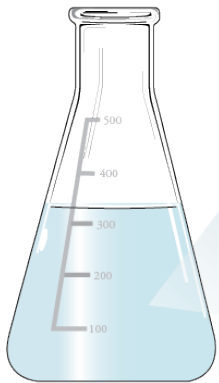
# Dipole-Dipole Attractions

- The partial negative end of one HCl molecule is attracted to the partial positive end of another HCl molecule.
- This attraction is called a **dipole-dipole attraction**.



# Dipole-Dipole Attractions in a Liquid

- When hydrogen chloride is cooled and/or compressed enough to convert it into a liquid, dipole-dipole attractions hold the HCl molecules together.
- It is dipole-dipole attractions that would be broken and reformed as HCl molecules move throughout the liquid, and it is dipole-dipole attractions that are broken when liquid HCl is converted into a gas.



The polar molecules are held together by dipole-dipole attractions, which are broken and re-formed as the molecules travel throughout the liquid.

# Polar Molecules

- Polar molecules have a separation of charge with one end of the molecule more positive and one end more negative.
- For a molecule to be polar, it must have
  - at least one polar covalent bond
  - and an asymmetrical (unbalanced) distribution of the polar bonds.

# Nonpolar Molecules

- A nonpolar molecule has no separation of charge, either because
  - it has no polar bonds,
  - or it has a symmetrical distribution of its polar bonds.

# Electronegativity



- **Electronegativity** is a measure of the electron attracting ability of atoms in chemical bonds.
  - Based on experimental evidence, the atoms of each element are assigned a number that represents its electron attracting ability.
  - The higher the number is, the stronger the atom's attraction for electrons.





# Electronegativity

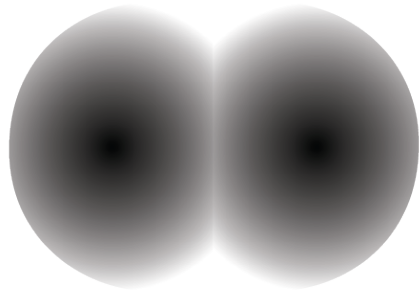


- Electronegativity values can be used to predict
  - whether a chemical bond is nonpolar covalent, polar covalent, or ionic.
  - which atom in a polar covalent bond is partial negative and which is partial positive.
  - which atom in an ionic bond forms the cation and which forms the anion.
  - and which of two covalent bonds are more polar.

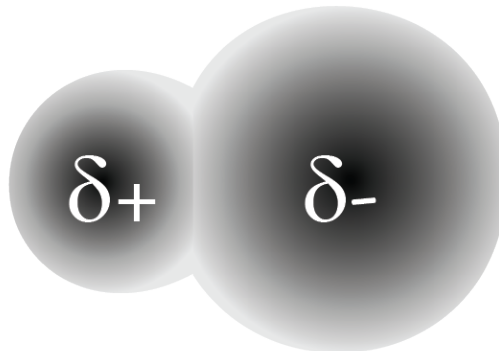
# Bond Types

## Covalent bond

(nonmetal-nonmetal always covalent)



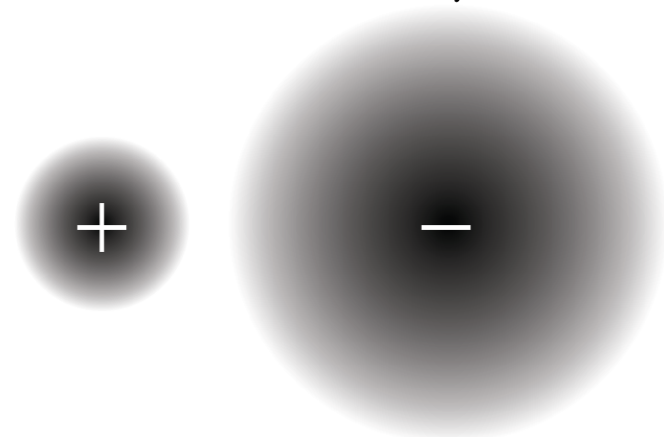
Nonpolar covalent bond  
 $\Delta EN < 0.4$



Polar covalent bond  
 $\Delta EN 0.4-1.7$

## Ionic bond

(metal-nonmetal usually ionic)



$\Delta EN > 1.7$



Which atom in a polar covalent bond is partially negative and which is partially positive?

higher electronegativity



greater attraction for electrons



partial negative charge

lower electronegativity



lesser attraction for electrons



partial positive charge

# Which of two bonds is more polar?

- The greater the difference in electronegativity ( $\Delta EN$ ) is, the larger the partial negative and partial positive charges on the atoms and the more polar the bond.
  - $\Delta EN$  for C-O is 0.89
  - $\Delta EN$  for C-N is 0.49
  - The C-O bond has larger the partial negative and partial positive charges and is more polar.

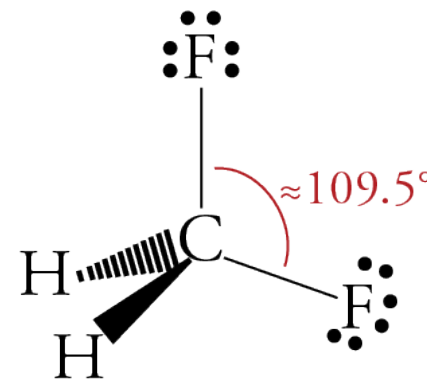
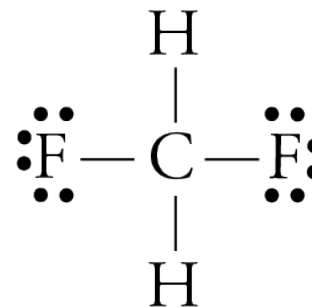
# Predicting Molecular Polarity

- Three questions will help you predict whether substances are composed of polar or nonpolar molecules.
  - *Is the substance molecular?* (all nonmetallic atoms and no ammonium)
  - *If the substance is molecular, do the molecules contain polar covalent bonds?* (You can see the bonds from the Lewis structure, and you predict polarity from electronegativities.)
  - *If the molecules contain polar covalent bonds, are these bonds asymmetrically arranged?* (This may involve sketching the molecular geometry.)

# Predicting Molecular Polarity – Example 1

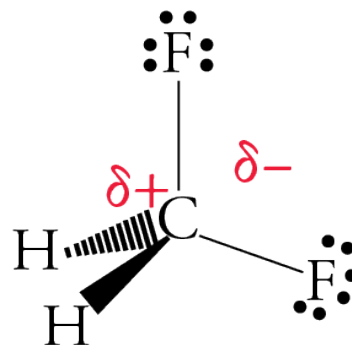
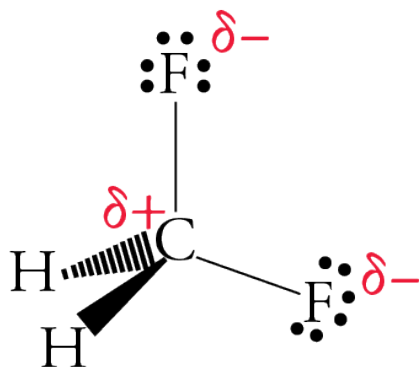
## Difluoromethane, $\text{CH}_2\text{F}_2$

- All nonmetals and no ammonium – molecular
- You need a Lewis structure to see bonds.
- The carbon-fluorine bonds are polar.
- You need a geometric sketch to predict the symmetry.
- Asymmetrical - polar



# Ways to Predict Symmetry

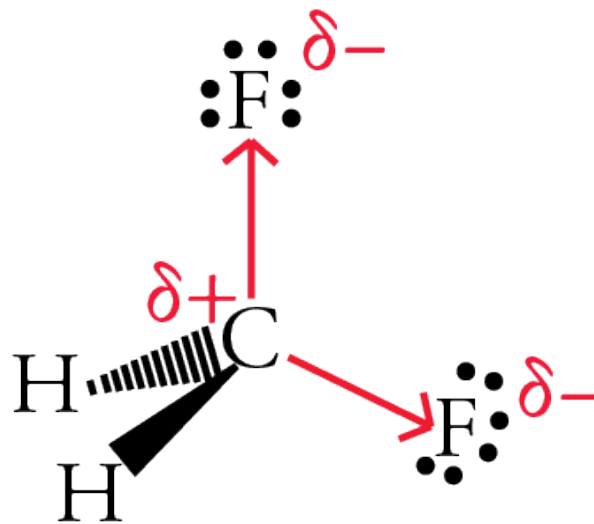
- Is the center of the partial negative charge in a different place than the center of the positive charge?
  - If yes, polar
  - If no, nonpolar





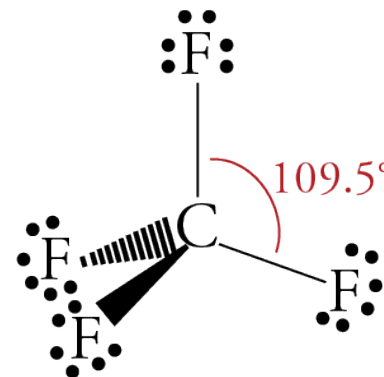
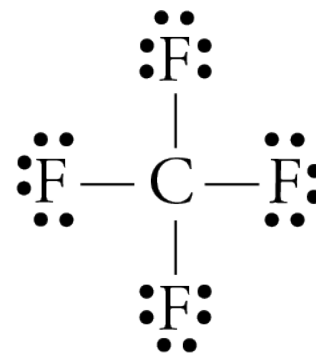
# Ways to Predict Symmetry

- If we describe the movement of electrons in the polar bonds with arrows, and if we think of the arrows as forces, would the molecule move?
  - If yes, polar
  - If no, nonpolar



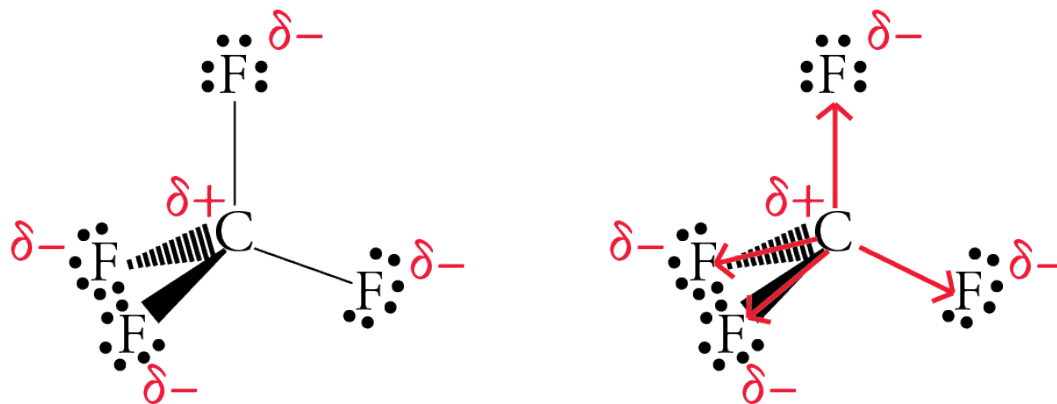
# Predicting Molecular Polarity – Example 2

- **Tetrafluoromethane,  $\text{CF}_4$**
- All nonmetals and no ammonium – molecular
- You need a Lewis structure to see bonds.
- The carbon-fluorine bonds are polar.
- You need a geometric sketch to predict the symmetry.
- Symmetrical – nonpolar



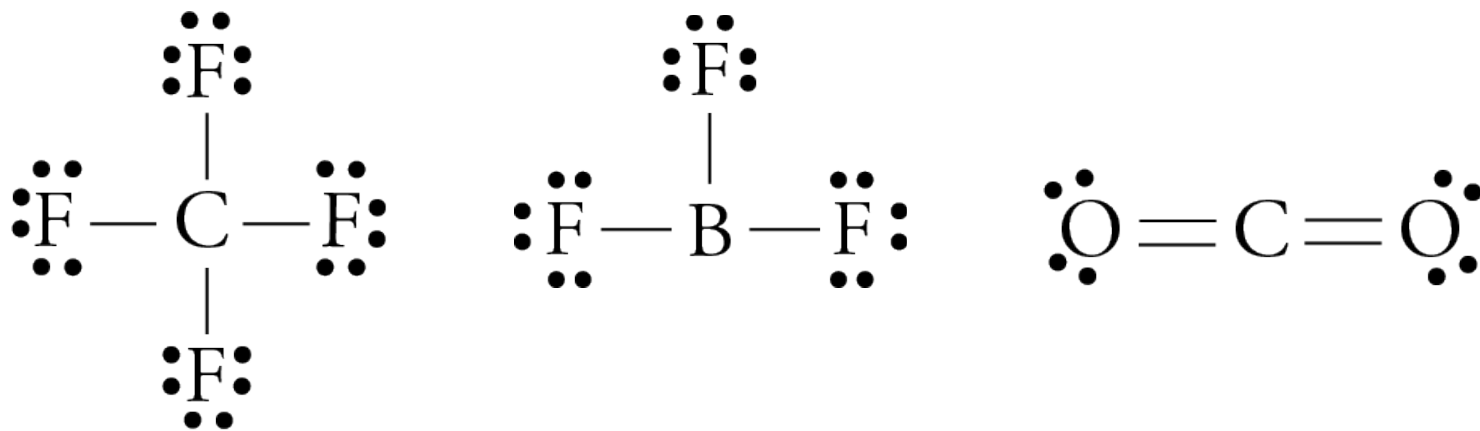
# Ways to Predict Symmetry

- The center of the partial plus and partial minus are both at the carbon.
- If the arrows showing the shift of electrons were forces, the molecule would not move.
- So the molecule has a symmetrical distribution of polar bonds and is nonpolar.



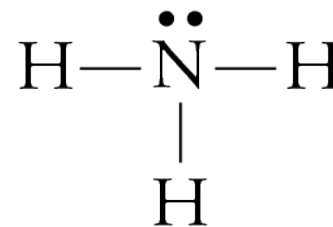
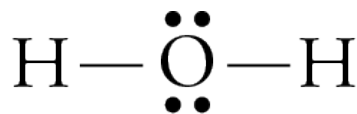
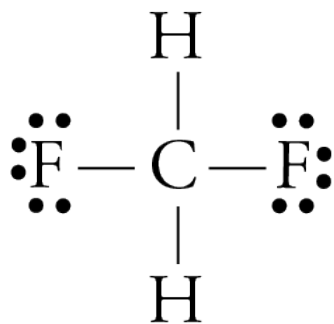
# Shortcuts

- If all of the groups around the central atom are identical, e.g. all bond groups to atoms of the same element and no lone pairs on the central atom, the molecule is nonpolar.



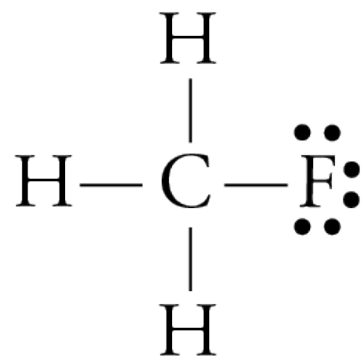
# Shortcuts

- If a molecule has at least one polar bond, and if the groups around the central atom are not identical, e.g. bonds to atoms of different elements or a mixture of bonds and lone pairs, it is *almost* certainly polar.



# Shortcuts

- If there is only one polar bond, the molecule is polar.



# Examples of Polar and Nonpolar Molecules



- Polar
  - $\text{H}_2\text{O}$ ,  $\text{NH}_3$
  - Acids ( $\text{HNO}_3$ ,  $\text{H}_2\text{SO}_4$ , and  $\text{HC}_2\text{H}_3\text{O}_2$ )
  - Hydrogen halides:  $\text{HF}$ ,  $\text{HCl}$ ,  $\text{HBr}$ , and  $\text{HI}$
  - Alcohols:  $\text{CH}_3\text{OH}$ ,  $\text{C}_2\text{H}_5\text{OH}$
- Nonpolar
  - Elements composed of molecules:  $\text{H}_2$ ,  $\text{N}_2$ ,  $\text{O}_2$ ,  $\text{F}_2$ ,  $\text{Cl}_2$ ,  $\text{Br}_2$ ,  $\text{I}_2$ ,  $\text{P}_4$ ,  $\text{S}_8$ ,  $\text{Se}_8$
  - $\text{CO}_2$
  - Hydrocarbons,  $\text{C}_a\text{H}_b$

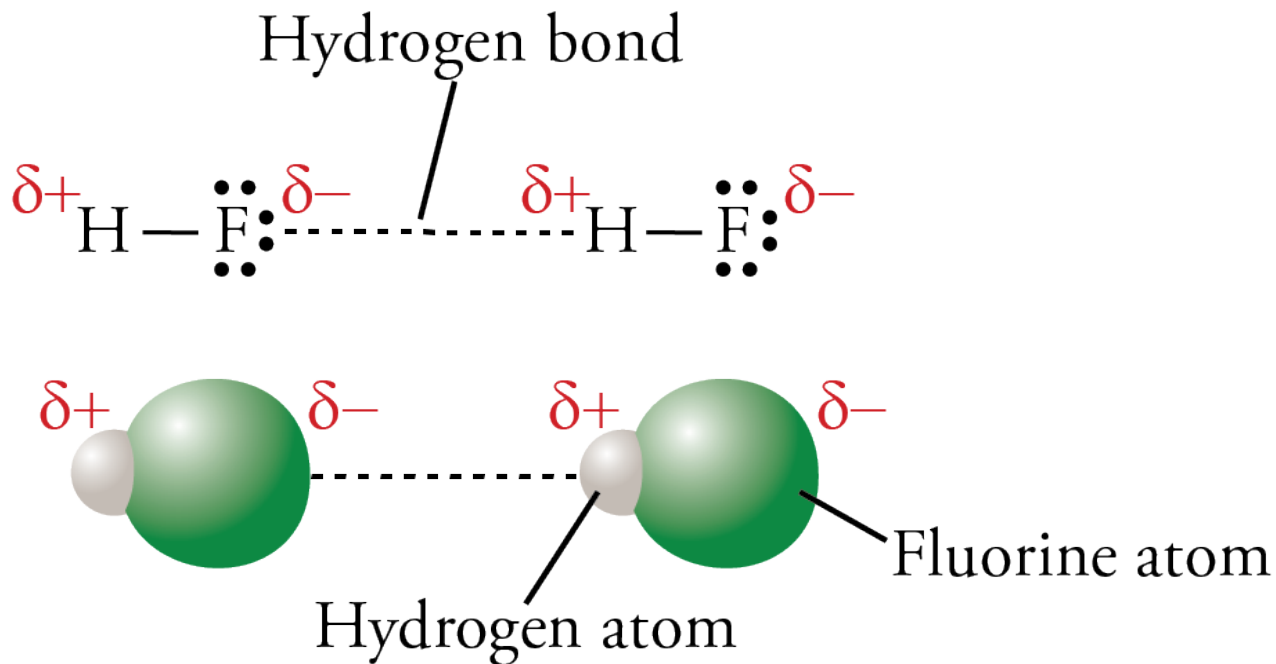
# Hydrogen Bonds

- **Hydrogen bonds** are attractions between a nitrogen, oxygen, or fluorine atom of one molecule and a hydrogen atom attached to a nitrogen, oxygen, or fluorine atom of another molecule.
- Hydrogen bonds are generally stronger than normal dipole-dipole attractions.



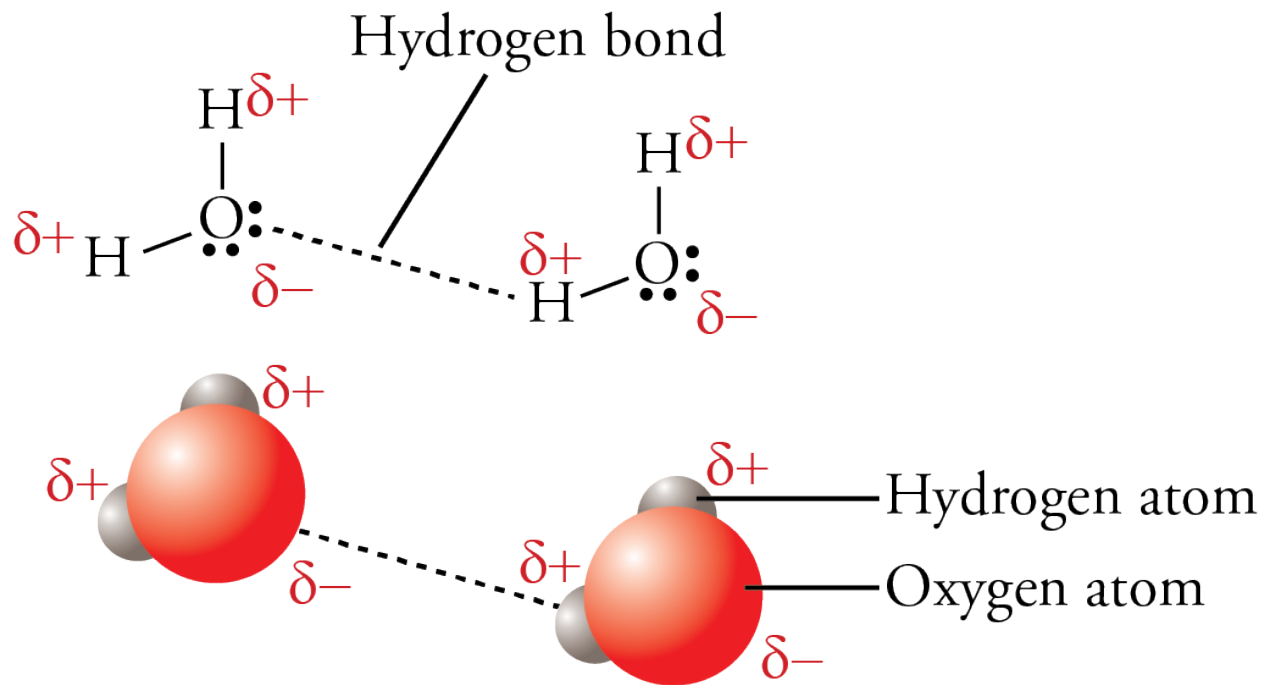
# Hydrogen Bonds in HF

In HF, the hydrogen bond is between the partial positive H of one HF molecule and the partial negative F of another HF molecule.



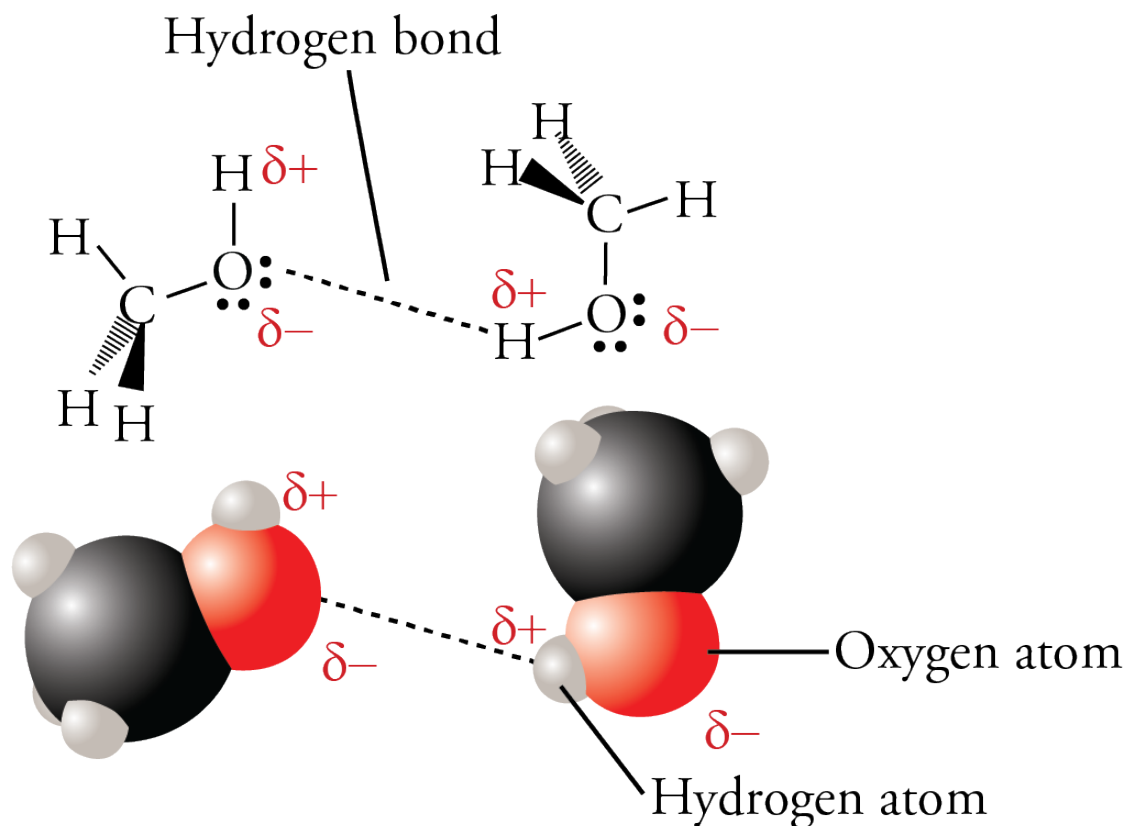
# Hydrogen Bonds in Water

In  $\text{H}_2\text{O}$ , the hydrogen bond is between a partial positive H of one  $\text{H}_2\text{O}$  molecule and the partial negative O of another  $\text{H}_2\text{O}$  molecule.



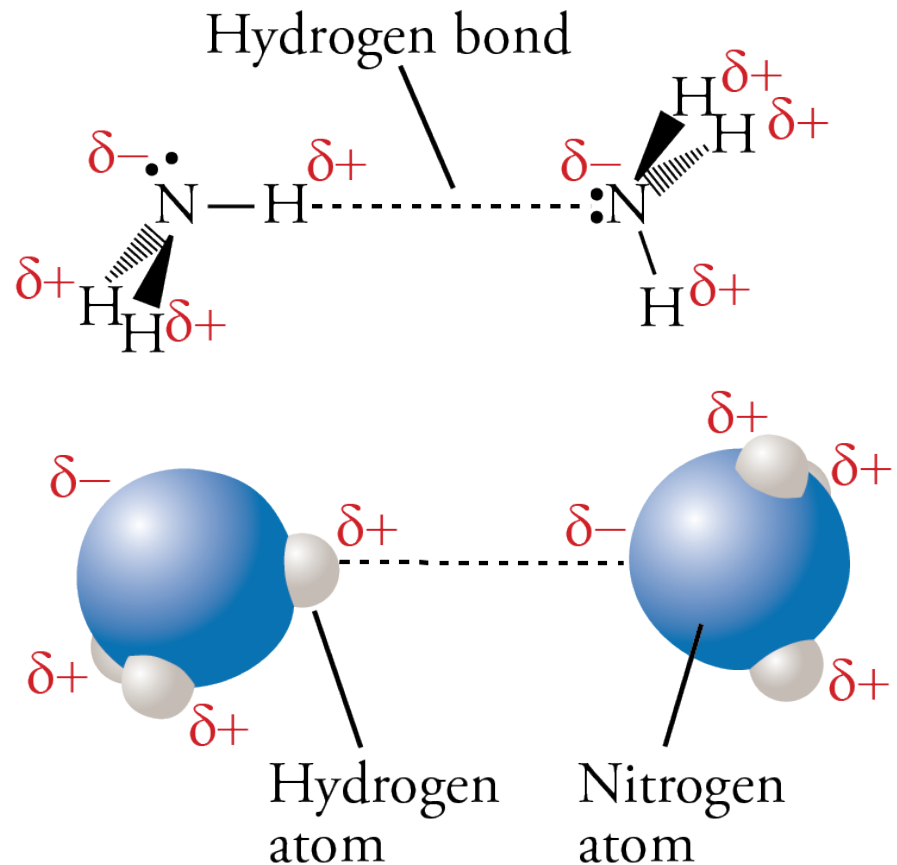
# Hydrogen Bonds in Methanol

In  $\text{CH}_3\text{OH}$ , the hydrogen bond is between the partial positive H of one  $\text{CH}_3\text{OH}$  molecule and the partial negative O of another  $\text{CH}_3\text{OH}$  molecule.



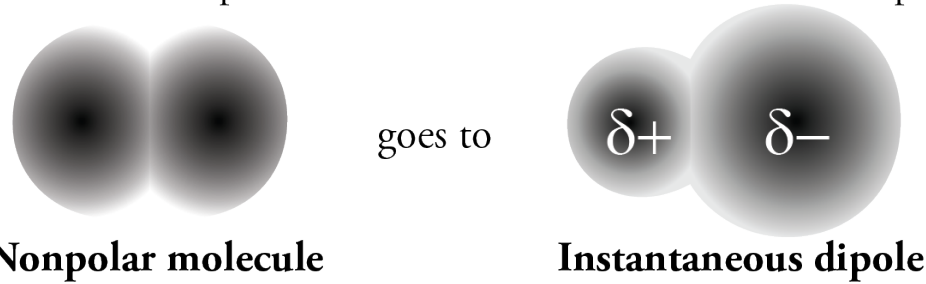
# Hydrogen Bonds in Ammonia

In  $\text{NH}_3$ , the hydrogen bond is between a partial positive H of one  $\text{NH}_3$  molecule and the partial negative N of another  $\text{NH}_3$  molecule.

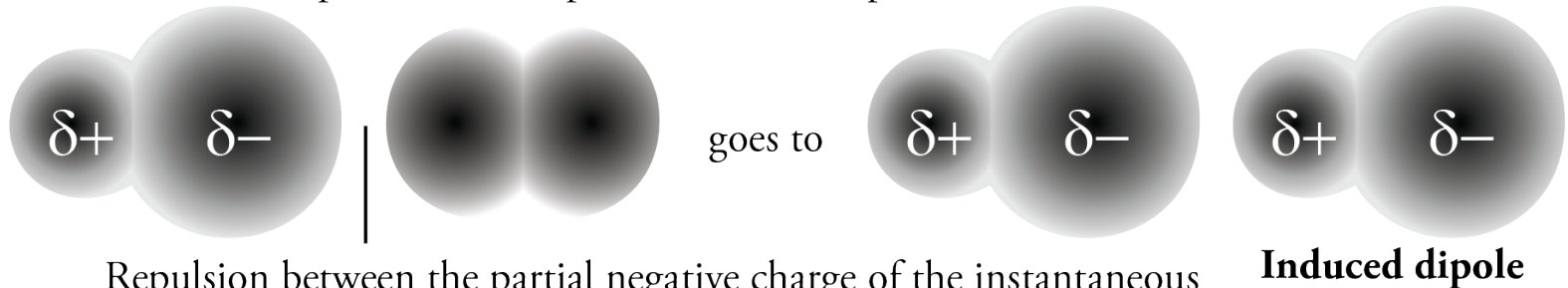


1. Chance or collisions cause nonpolar molecules to form instantaneous dipoles.

# London Forces

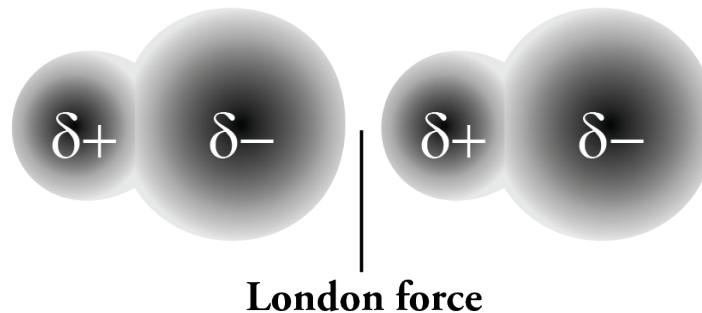


2. Instantaneous dipoles induce dipoles in other nonpolar molecules.

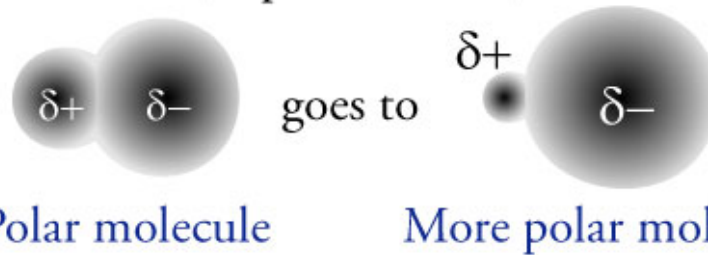


Repulsion between the partial negative charge of the instantaneous dipole and the negative charge of the electrons in the nonpolar molecule pushes the electrons in the nonpolar molecule to the right, forming an induced dipole.

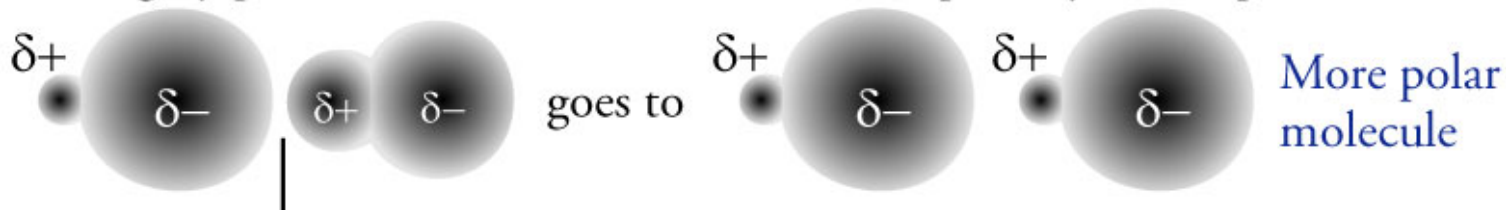
3. Induced dipoles can induce dipoles in other nonpolar molecules, resulting in many molecules with partial charges. London forces are the attractions between the partial positive and partial negative charges in these instantaneous and induced dipoles.



1. Chance or collisions cause polar molecules to become more polar.

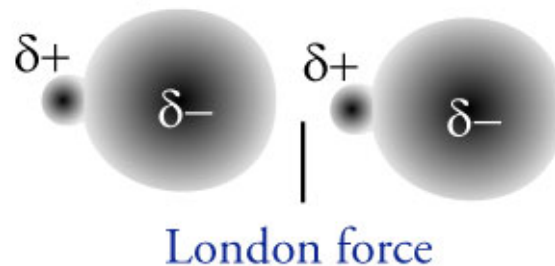


2. More highly polar molecules induce increases in polarity in less polar molecules.



Repulsion between the partial negative charge of the more polar molecule and the negative charge of the electrons in the less polar molecule pushes the electrons in the less polar molecule to the right, leading to an induced increase in polarity.

3. The more polar molecules can induce increases in polarity in other less polar molecules, resulting in many molecules with larger partial charges. London forces are the attractions between the partial positive and partial negative charges in these instantaneously increased dipoles and induced increases in dipoles.



# London Forces in Polar Molecules

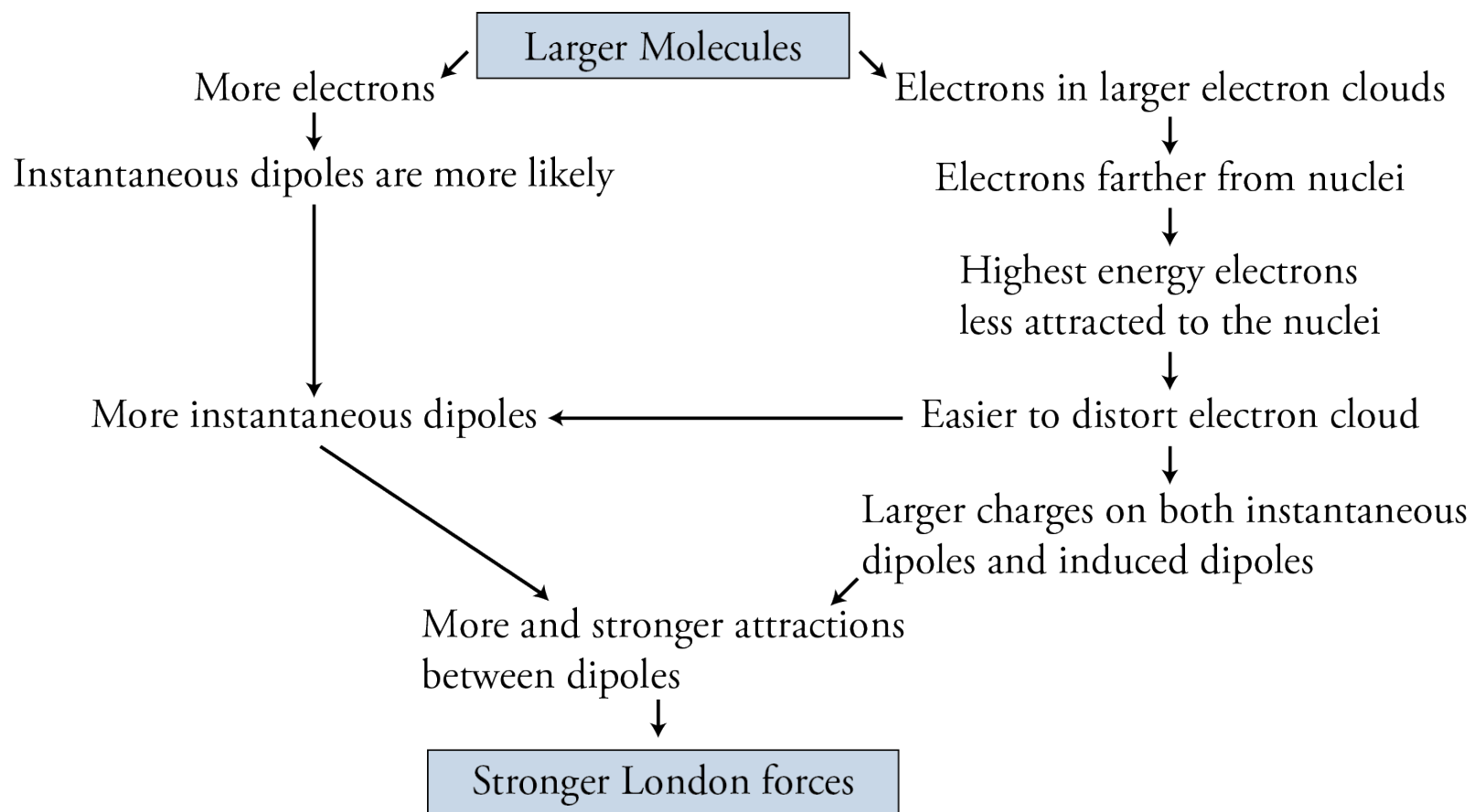
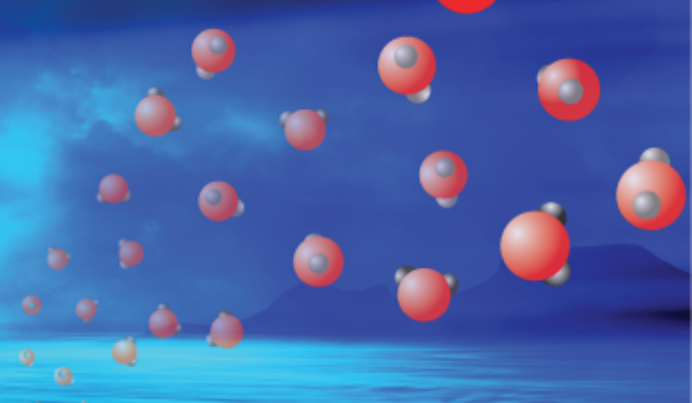
# Halogens and Attractions

- Fluorine and chlorine are gases
- Bromine is a liquid.
- Iodine is a solid.

Increasing size of molecules leads to increasing strengths of London forces.

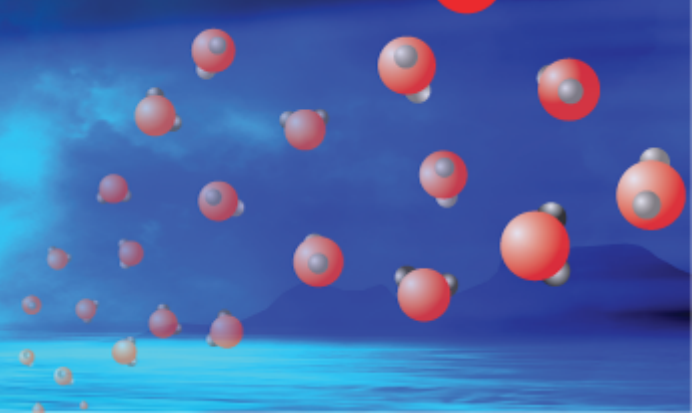
Gas	9 F 18.9984
Gas	17 Cl 35.4527
Liquid	35 Br 79.904
Solid	53 I 126.9045

# Why Larger Molecules Have Stronger London Forces





# Types of Particles and Attractions - Elements



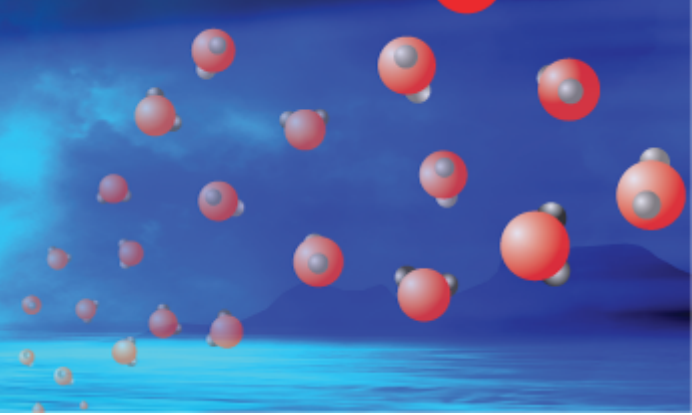
Type of element	Particles to visualize	Examples	Type of Attraction
Metals	cations in a sea of electrons	gold, Au	metallic bonds
Noble gases	atoms	xenon, Xe	London forces
Carbon (diamond)	atoms	C(dia)	covalent bonds
Other nonmetallic elements	molecules	H <sub>2</sub> , N <sub>2</sub> , O <sub>2</sub> , F <sub>2</sub> , Cl <sub>2</sub> , Br <sub>2</sub> , I <sub>2</sub> , S <sub>8</sub> , Se <sub>8</sub> , P <sub>4</sub>	London forces

# Types of Attractions – Carbon



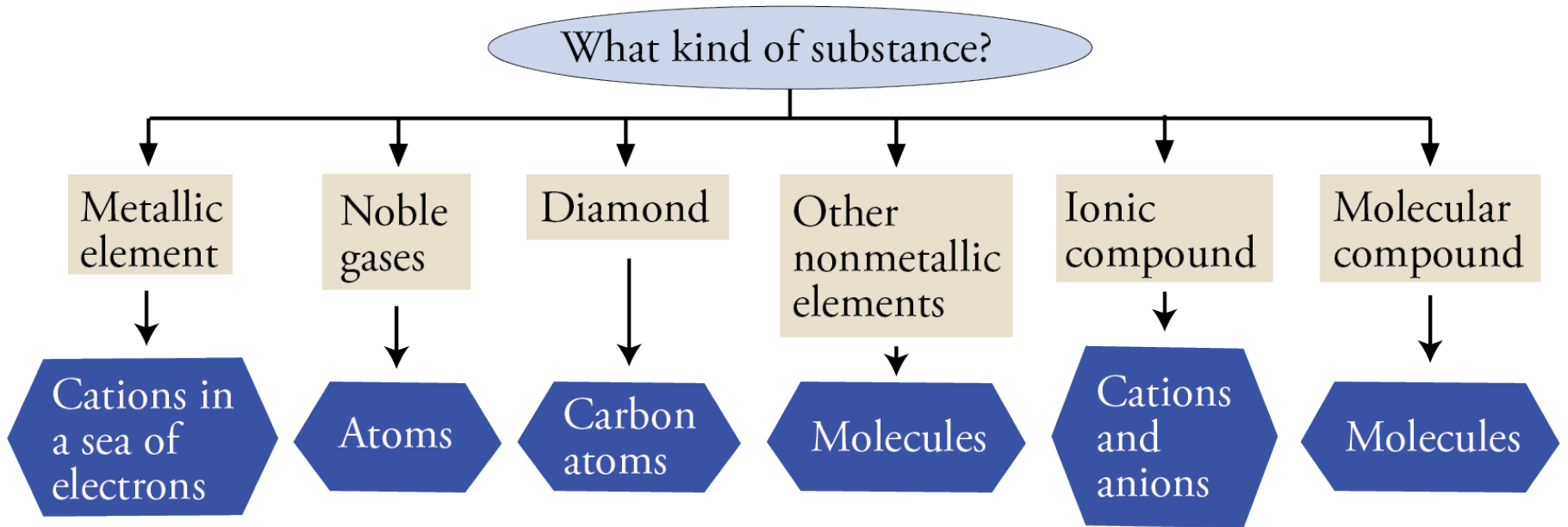
- **Diamond** - Carbons atoms held together by covalent bonds, forming huge 3-dimensional molecules.
- **Graphite** - Carbons atoms held together by covalent bonds, forming huge 2-dimensional molecules held together by London forces.
- **Fullerenes** - Carbons atoms held together by covalent bonds, forming 3-dimensional molecules held together by London forces.

# Types of Particles and Attractions - Compounds

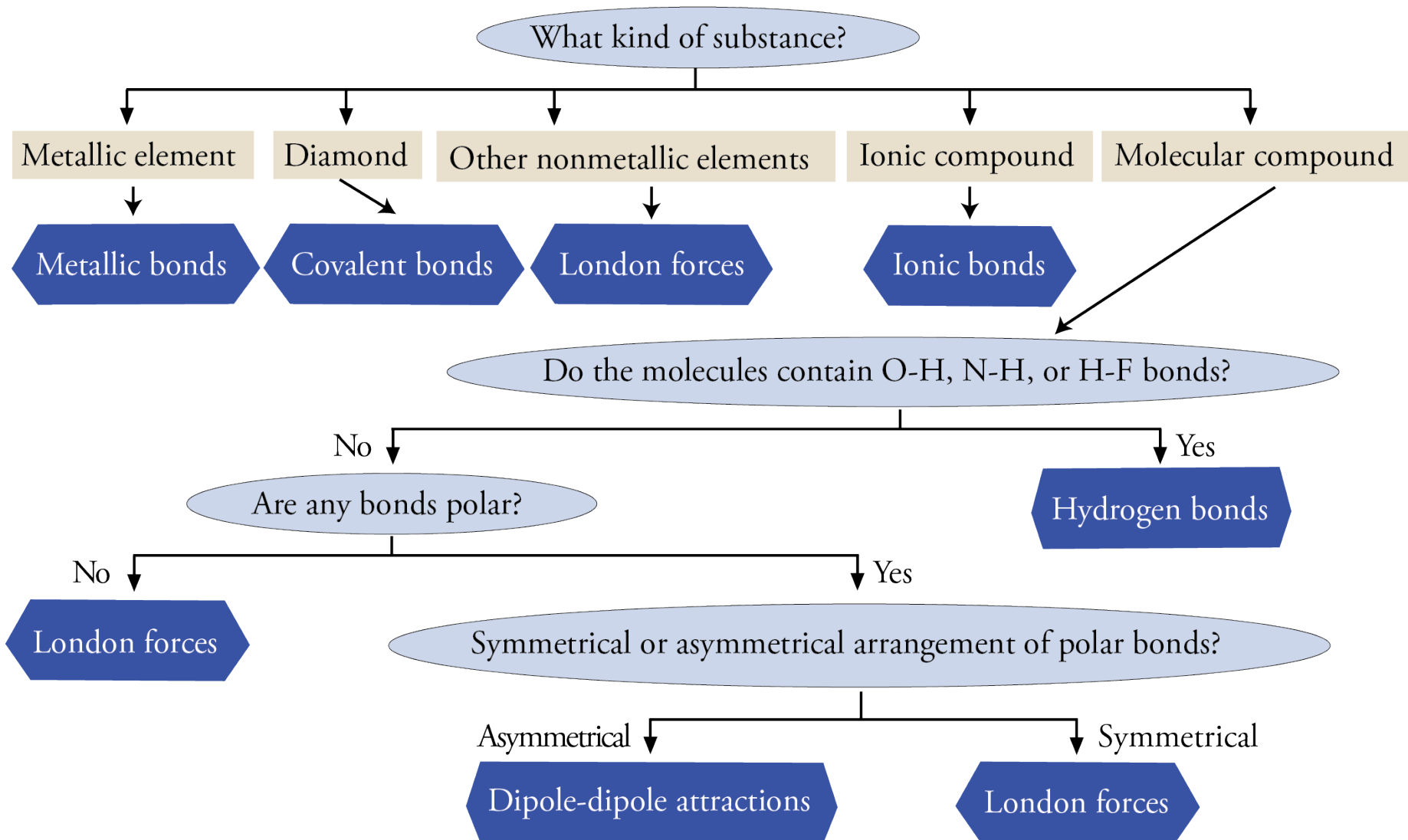


Type of compound	Particles to visualize	Examples	Type of Attraction
Ionic	cations and anions	NaCl	ionic bonds
Nonpolar molecular	molecules	hydrocarbons	London forces
Polar molecular w/out H-F, O-H, or N-H	molecules	HCl	dipole-dipole
Polar molecular with H-F, O-H, or N-H	molecules	HF, H <sub>2</sub> O, NH <sub>3</sub> , alcohols	hydrogen bonds

# Predicting Types of Particles



# Predicting Types of Attractions



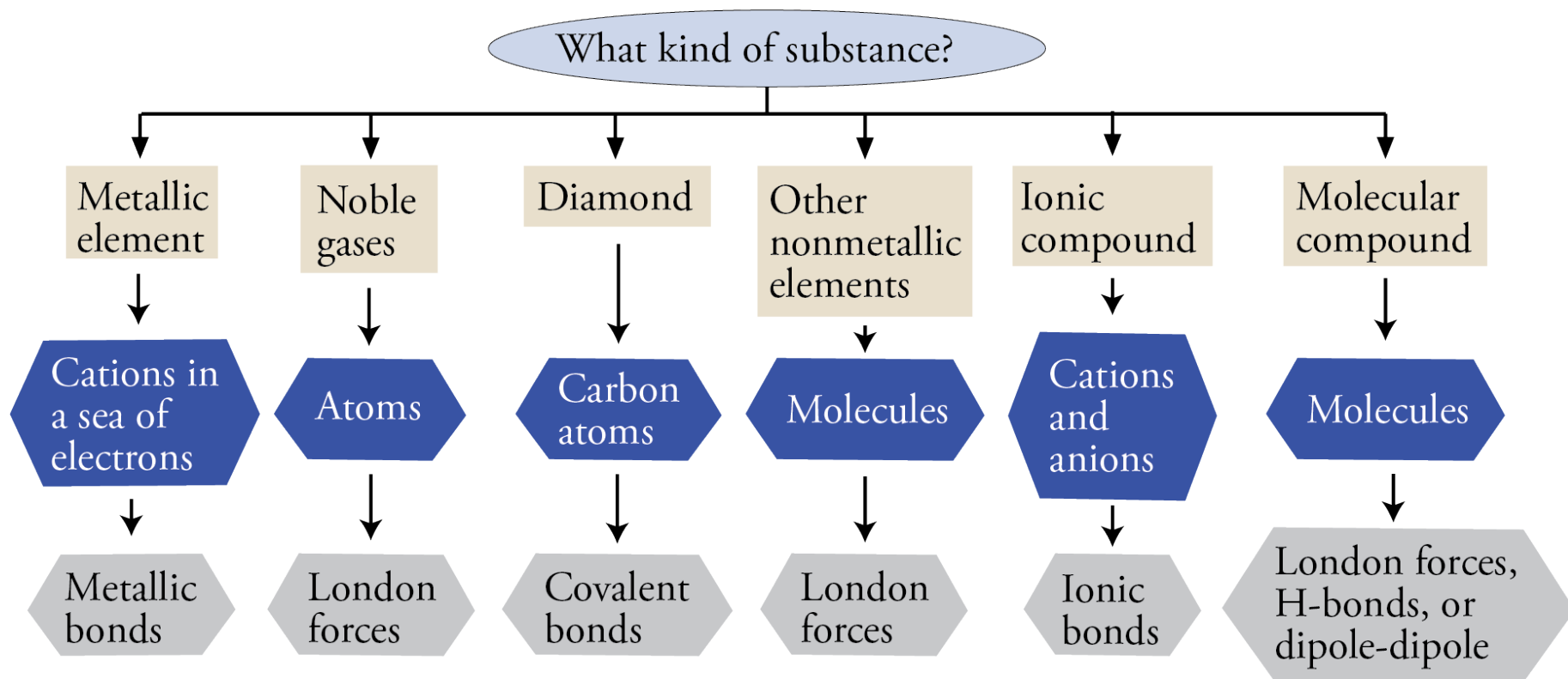
# Example 1



- For iron, specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.

# Predicting Types of Attractions

## Iron, Fe



## Example 2

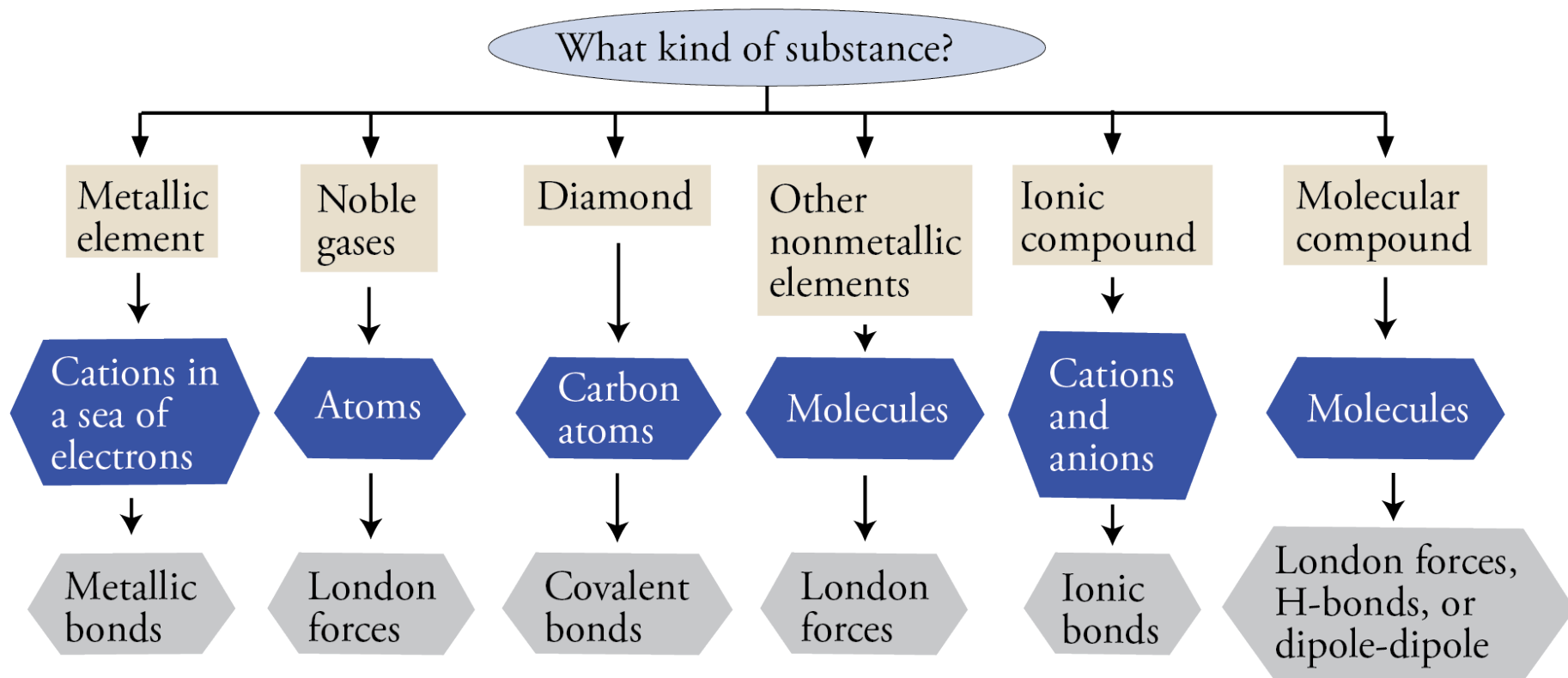


- For iodine, specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.



# Predicting Types of Attractions

## Iodine, I<sub>2</sub>



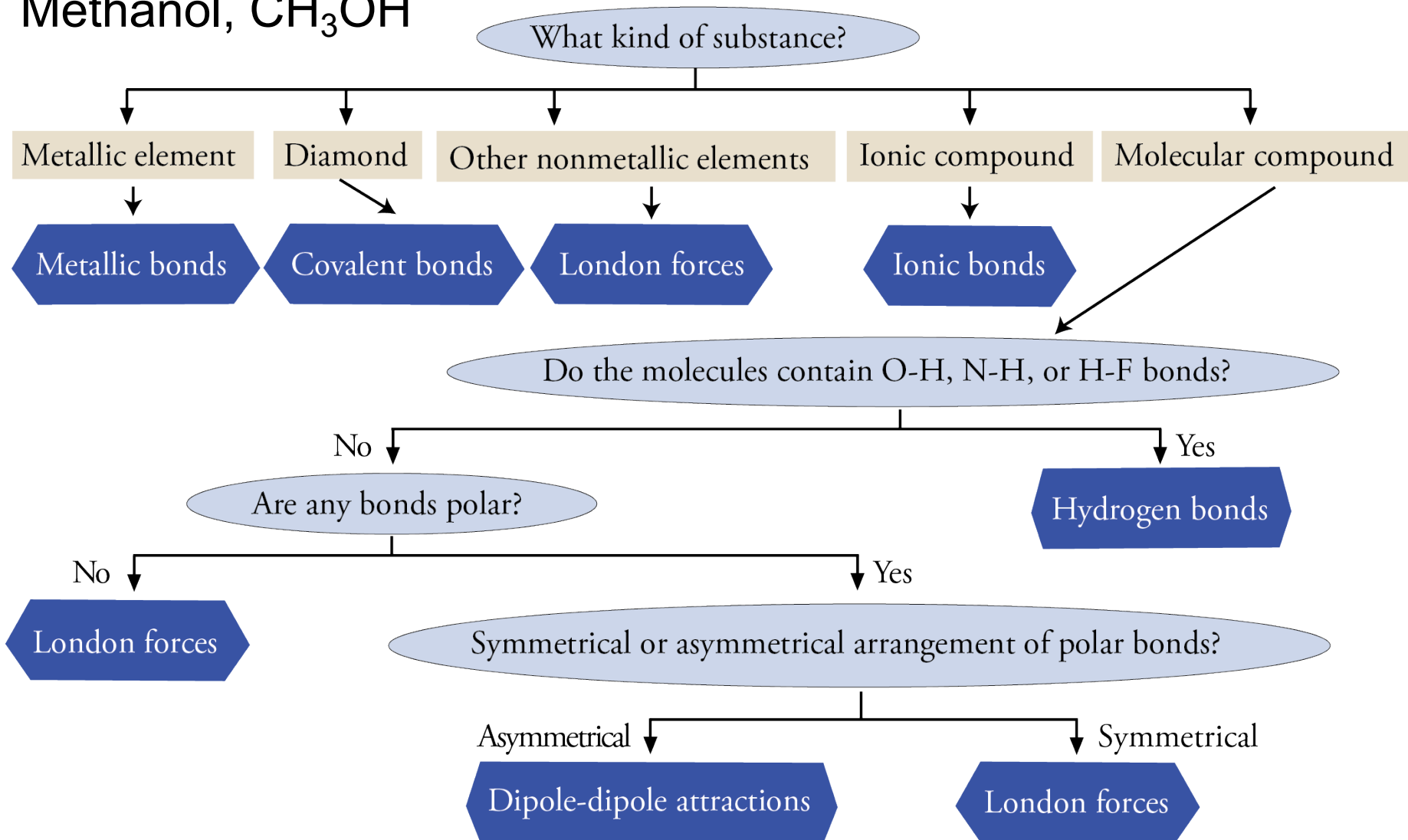
## Example 3



- For methanol,  $\text{CH}_3\text{OH}$ , specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.

# Predicting Types of Attractions

Methanol, CH<sub>3</sub>OH



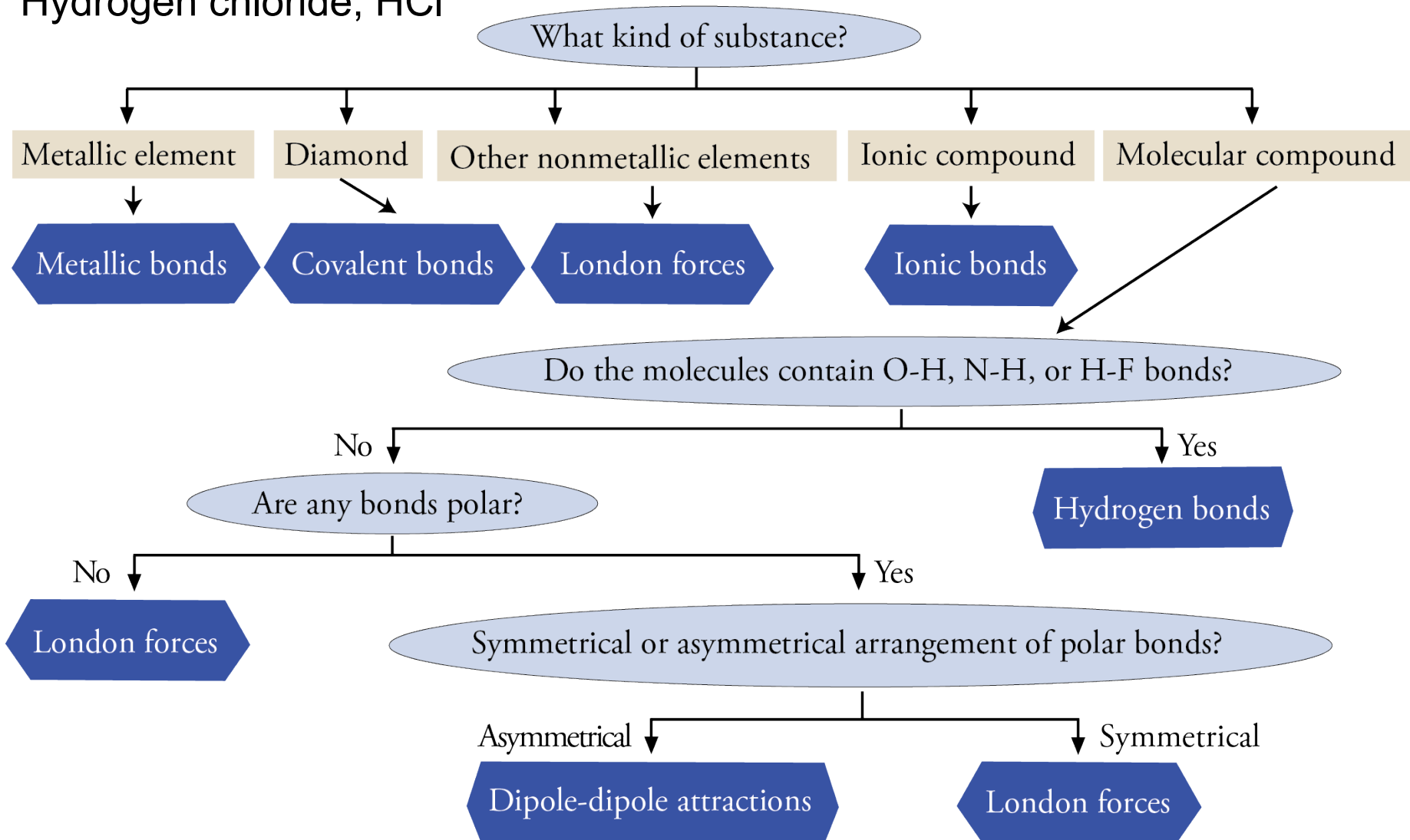
## Example 4



- For hydrogen chloride, specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.

# Predicting Types of Attractions

Hydrogen chloride, HCl



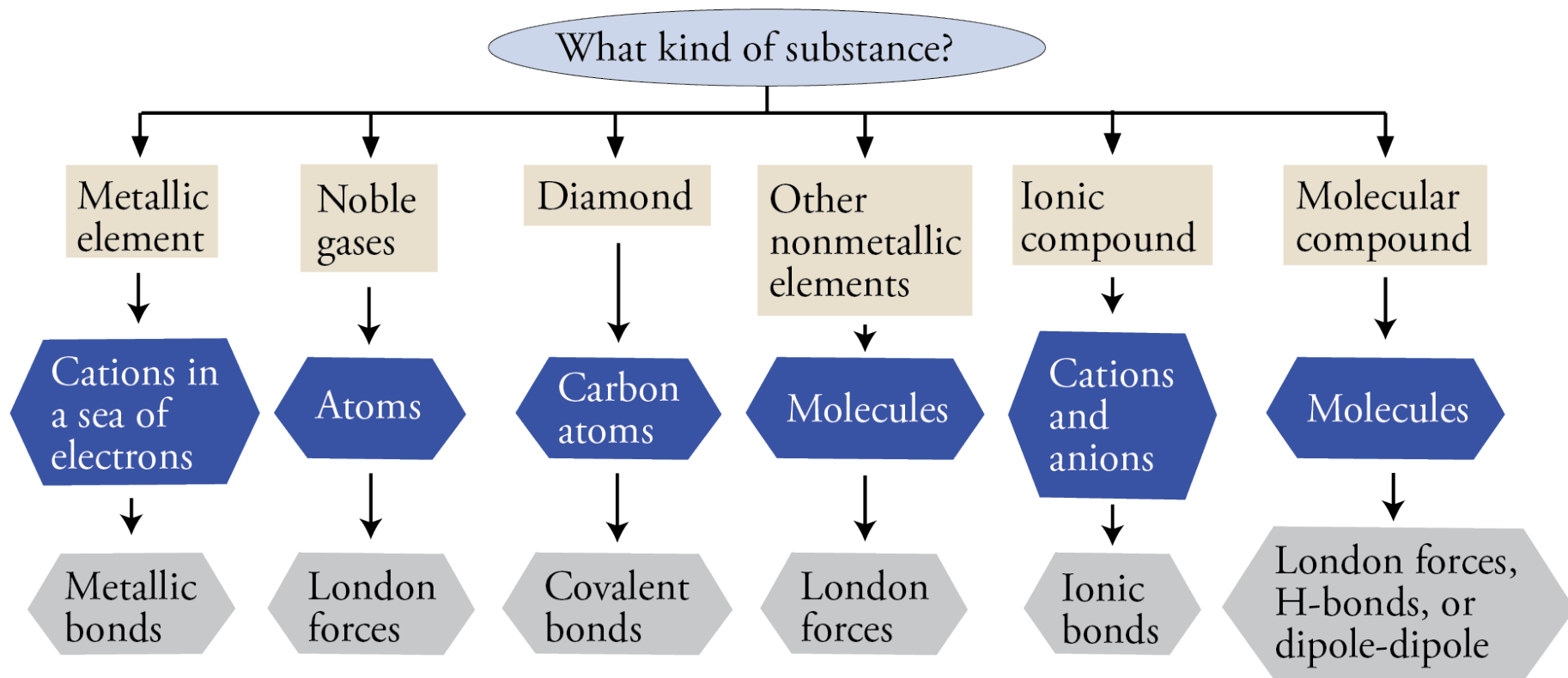
## Example 6



- For potassium fluoride, specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.

# Predicting Types of Attractions

Potassium fluoride, KF



## Example 7



- For carbon in the diamond form, specify (1) the type of particle that forms the substance's fundamental structure and (2) the name of the type of attraction that holds these particles in the solid and liquid form.



# Predicting Types of Attractions

## Carbon (diamond)

