1. Atomic structure determines the behavior of an element

- Each element consists of unique atoms.
- An **atom** is the smallest unit of matter that still retains the properties of an element.
  - Atoms are composed of even smaller parts, called subatomic particles.
  - Two of these, **neutrons** and **protons,** are packed together to form a dense core, the atomic nucleus, at the center of an atom.
  - **Electrons** form a cloud around the nucleus.

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- Each electron has one unit of negative charge.
- Each proton has one unit of positive charge.
- Neutrons are electrically neutral.
- The attractions between the positive charges in the nucleus and the negative charges of the electrons keep the electrons in the vicinity of the nucleus.

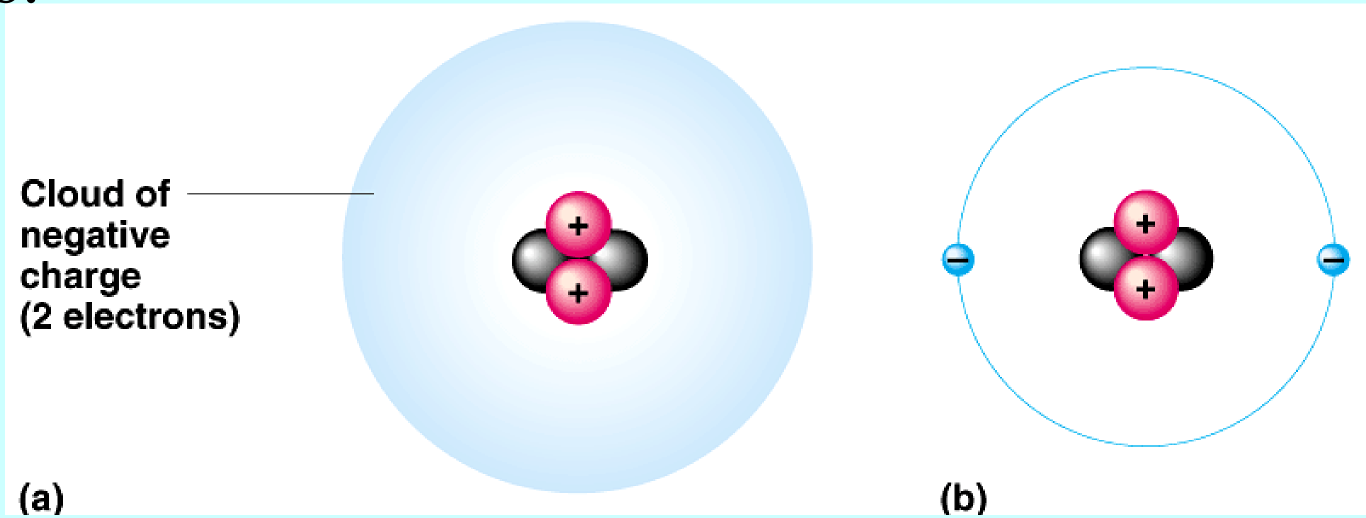

Fig. 2.5

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- All atoms of a particular element have the same number of protons in their nuclei.
  - Each element has a unique number of protons, its unique **atomic number**.
  - The atomic number is written as a subscript before the symbol for the element (for example, $_{2}He$).
- Unless otherwise indicated, atoms have equal numbers of protons and electrons - no net charge.
  - Therefore, the atomic number tells us the number of protons and the number of electrons that are found in a neutral atom of a specific element.

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- The **mass number** is the sum of the number of protons and neutrons in the nucleus of an atom.
  - Therefore, we can determine the number of neutrons in an atom by subtracting the number of protons (the atomic number) from the mass number.
  - The mass number is written as a superscript before an element's symbol (for example, ^{4}He).
- The **atomic weight** of an atom, a measure of its mass, can be approximated by the mass number.
  - For example, ^{4}He has a mass number of 4 and an estimated atomic weight of 4 daltons.
  - More precisely, its atomic weight is 4.003 daltons.

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- While all atoms of a given element have the same number of protons, they may differ in the number of neutrons.
- Two atoms of the same element that differ in the number of neutrons are called **isotopes**.
- In nature, an element occurs as a mixture of isotopes.
  - For example, 99% of carbon atoms have 6 neutrons (^{12}C).
  - Most of the remaining 1% of carbon atoms have 7 neutrons (^{13}C) while the rarest isotope, with 8 neutrons is ^{14}C.

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- Most isotopes are stable; they do not tend to loose particles.
  - Both ^{12}C and ^{13}C are stable isotopes.
- The nuclei of some isotopes are unstable and decay spontaneously, emitting particles and energy.
  - ^{14}C is a one of these unstable or **radioactive isotopes**.
  - In its decay, an neutron is converted to a proton and electron.
  - This converts ^{14}C to ^{14}N, changing the identity of that atom.

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- The chemical behavior of an atom is determined by its electron configuration - the distribution of electrons in its electron shells.
  - The first 18 elements, including those most important in biological processes, can be arranged in 8 columns and 3 rows.
    - Elements in the same row use the same shells.
    - Moving from left to right, each element has a sequential addition of electrons (and protons).

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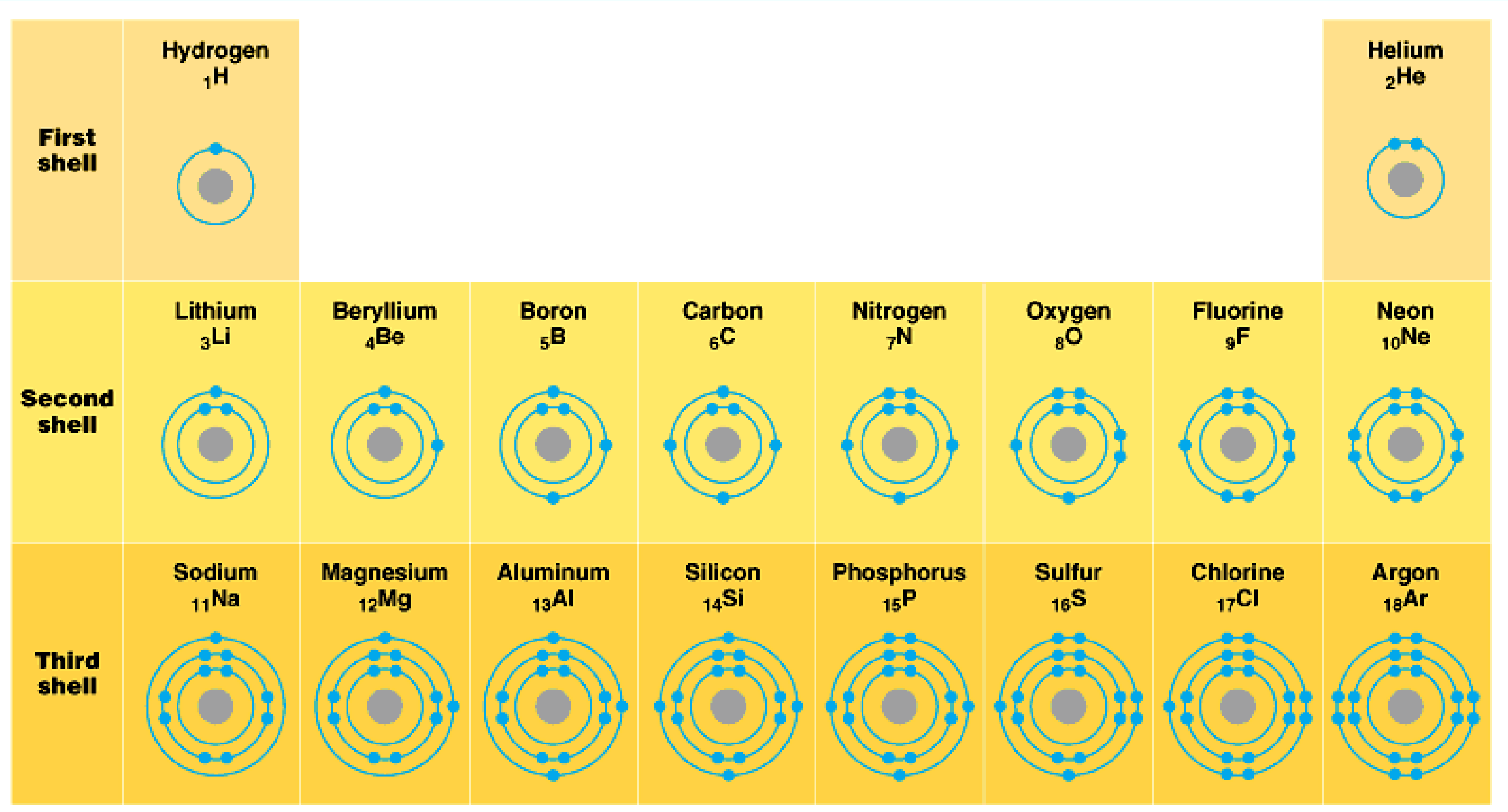

Fig. 2.10

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- The first electron shell can hold only 2 electrons.
  - The two electrons of Helium fill the first shell.
- Atoms with more than two electrons must place the extra electrons in higher shells.
  - For example, Lithium with three electrons has two in the first shell and one in the second shell.
- The second shell can hold up to 8 electrons.
  - Neon, with 10 total electrons, has two in the first shell and eight in the second, filling both shells.

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- The chemical behavior of an atom depends mostly on the number of electrons in its outermost shell, the **valence shell**.
  - Electrons in the valence shell are known as **valence electrons**.
- Atoms with the same number of valence electrons have similar chemical behavior.
- An atom with a completed valence shell is unreactive.
- All other atoms are chemically reactive because they have incomplete valence shells.

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2. Atoms combine by chemical bonding to form molecules

- Atoms with incomplete valence shells interact by either sharing or transferring valence electrons.
- These interactions typically result in the atoms remaining close together, held by an attractions called **chemical bonds**.
  - The strongest chemical bonds are covalent bonds and ionic bonds.

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- A **covalent bond** is the sharing of a pair of valence electrons by two atoms.
  - If two atoms come close enough that their unshared orbitals overlap, each atom can count both electrons toward its goal of filling the valence shell.
  - For example, if two hydrogen atoms come close enough that their 1s orbitals overlap, then they can share the single electrons that each contributes.

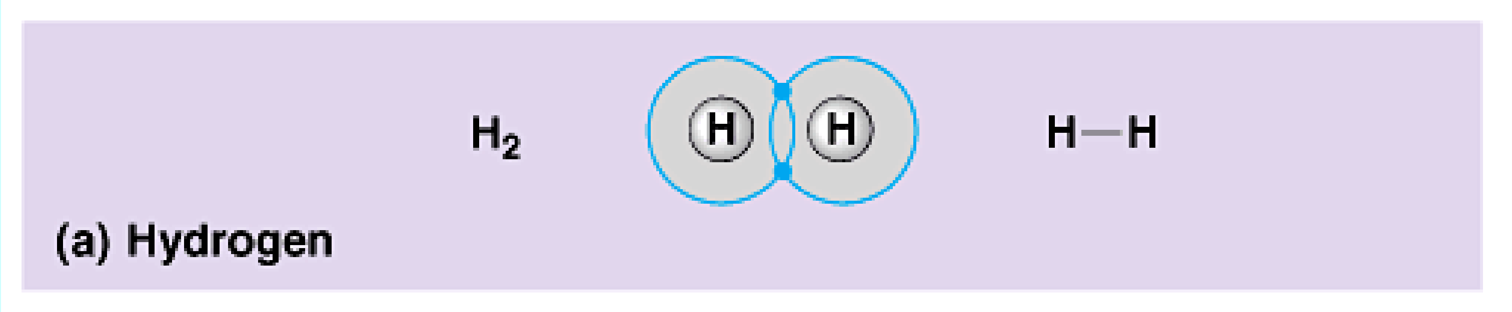

Fig. 2.12a

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- Two or more atoms held together by covalent bonds constitute a **molecule**.
- We can abbreviate the structure of this molecule by substituting a line for each pair of shared electrons, drawing the **structural formula**.
  - H-H is the structural formula for the covalent bond between two hydrogen atoms.
- The **molecular formula** indicates the number and types of atoms present in a single molecule.
  - H_2 is the molecular formula for hydrogen gas.

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- Oxygen needs to add 2 electrons to the 6 already present to complete its valence shell.
  - Two oxygen atoms can form a molecule by sharing *two* pairs of valence electrons.
  - These atoms have formed a **double covalent bond**.

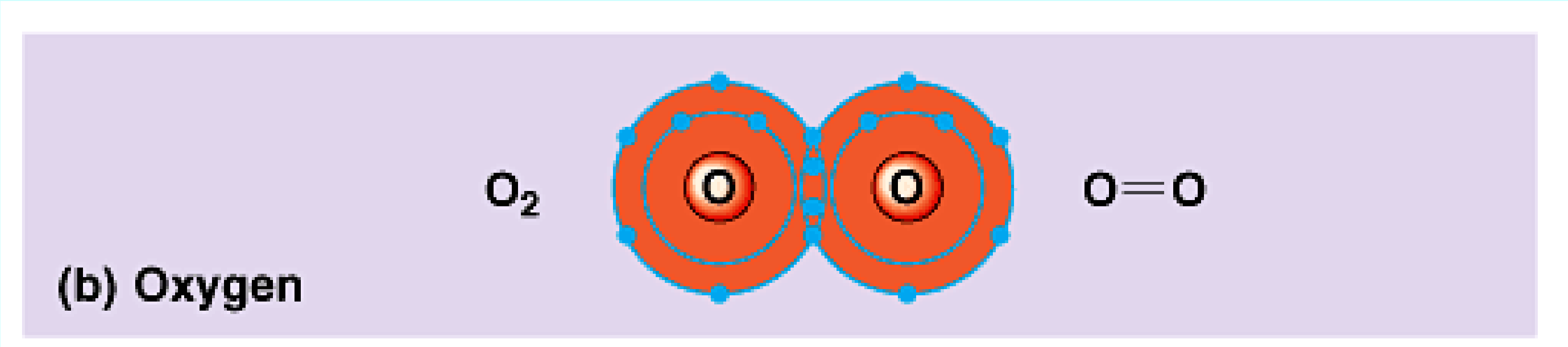

Fig. 2.12b

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- Every atom has a characteristic total number of covalent bonds that it can form - an atom's **valence**.
  - The valence of hydrogen is 1.
  - Oxygen is 2.
  - Nitrogen is 3.
  - Carbon is 4.
  - Phosphorus should have a valence of 3, based on its three unpaired electrons, but in biological molecules it generally has a valence of 5, forming three single covalent bonds and one double bond.

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- Covalent bonds can form between atoms of the same element or atoms of different elements.
  - While both types are molecules, the latter are also compounds.
  - Water, H_2O, is a compound in which two hydrogen atoms form single covalent bonds with an oxygen atom.
    - This satisfies the valences of both elements.

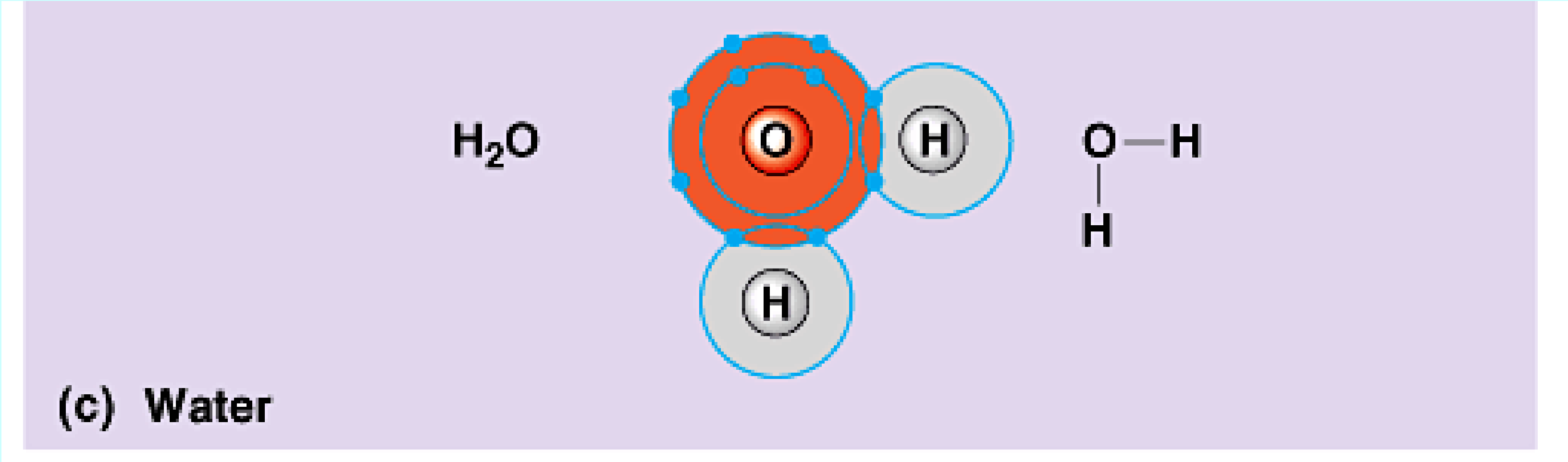

Fig. 2.12c

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- Methane, CH_4, satisfies the valences of both C and H.

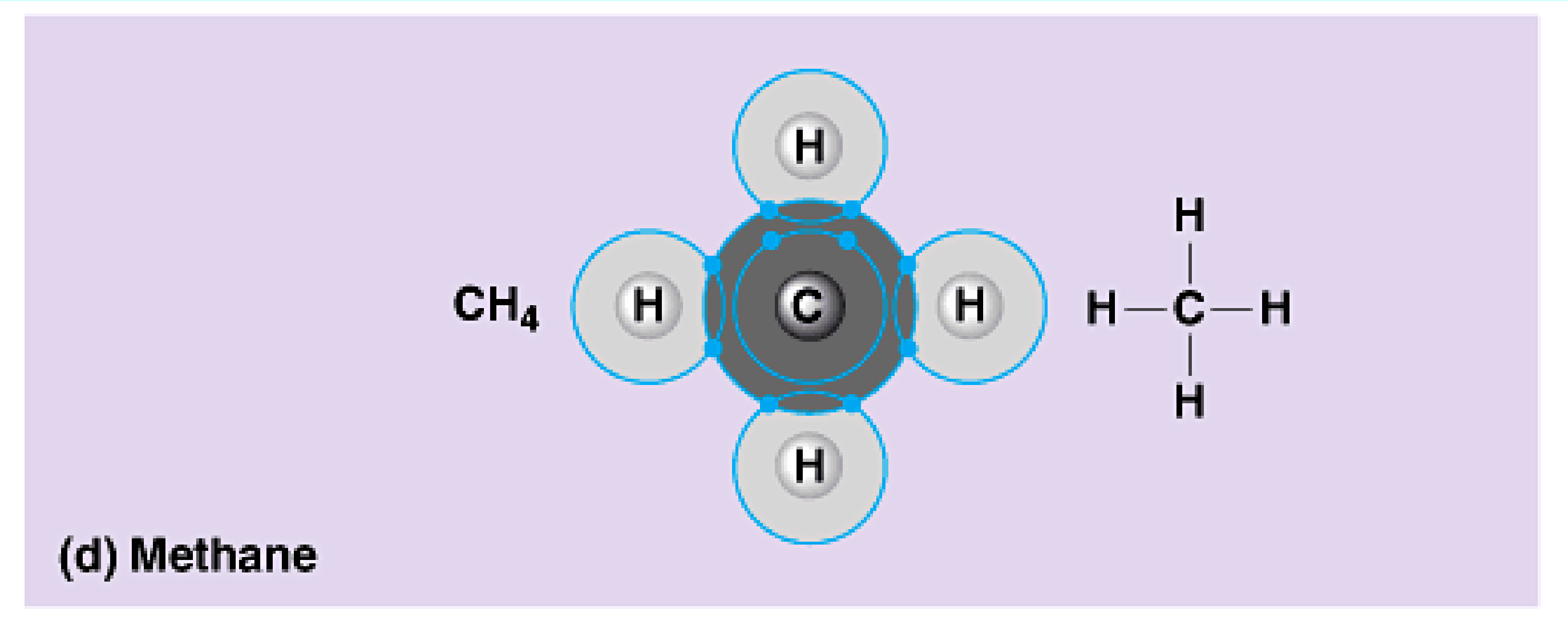

Fig. 2.12d

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- The attraction of an atom for the electrons of a covalent bond is called its **electronegativity.**
  - Strongly electronegative atoms attempt to pull the shared electrons toward themselves.
- If electrons in a covalent bond are shared equally, then this is a **nonpolar covalent bond**.
  - A covalent bond between two atoms of the same element is always nonpolar.
  - A covalent bond between atoms that have similar electronegativities is also nonpolar.
    - Because carbon and hydrogen do not differ greatly in electronegativities, the bonds of CH_4 are nonpolar.

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- If the electrons in a covalent bond are not shared equally by the two atoms, then this is a **polar covalent bond.**
  - The bonds between oxygen and hydrogen in water are polar covalent because oxygen has a much higher electronegativity than does hydrogen.
  - Compounds with a polar covalent bond have regions that have a partial negative charge near the strongly electronegative atom and a partial positive charge near the weakly electronegative atom.

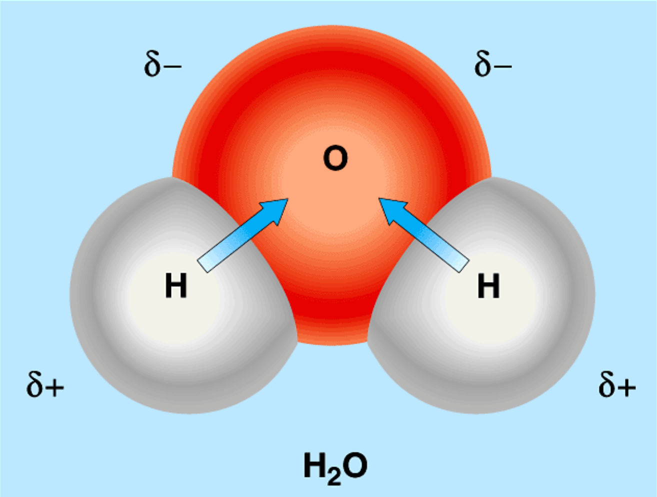

Fig. 2.13

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- An **ionic bond** can form if two atoms are so unequal in their attraction for valence electrons that one atom strips an electron completely from the other.
    - For example, sodium with one valence electron in its third shell transfers this electron to chlorine with 7 valence electrons in its third shell.
    - Now, sodium has a full valence shell (the second) and chlorine has a full valence shell (the third).

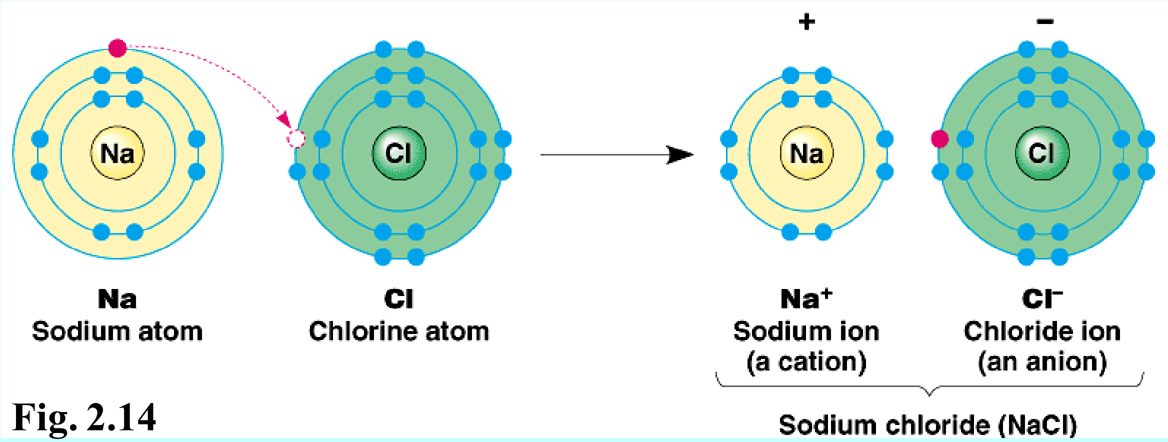

Fig. 2.14

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- After the transfer, both atoms are no longer neutral, but have charges and are called **ions**.
- Sodium has one more proton than electrons and has a net positive charge.
    - Atoms with positive charges are **cations**.
- Chlorine has one more electron than protons and has a net negative charge.
    - Atoms with negative charges are **anions**.

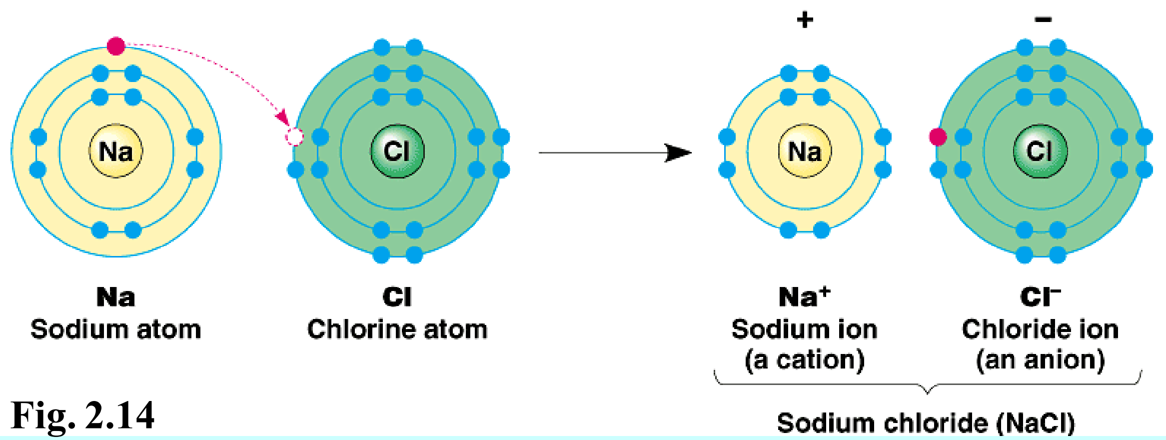

Fig. 2.14

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- Because of differences in charge, cations and anions are attracted to each other to form an **ionic bond**.
  - Atoms in an ionic bonds need not have acquired their charge by electrons transferred with each other.

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- Compounds formed by ionic bonds are **ionic compounds** or **salts,** like NaCl or table salt.
- The formula for an ionic compound indicates the ratio of elements in a crystal of that salt.
    - Atoms in a crystal do not form molecules with a definitive size and number of atoms as in covalent bonds.

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- Ionic compounds can have ratios of elements different from 1:1.
  - For example, the ionic compound magnesium chloride ($MgCl_2$) has 2 chloride atoms per magnesium atom.
    - Magnesium needs to loose 2 electrons to drop to a full outer shell, each chlorine needs to gain 1.
- Entire molecules that have full electrical charges are also called ions.
  - In the salt ammonium chloride (NH_4Cl), the anion is Cl^- and the cation is $NH_4{}^+$.
- The strength of ionic bonds depends on environmental conditions.

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3. Weak chemical bonds play important roles in the chemistry of life

- Within a cell, weak, brief bonds between molecules are important to a variety of processes.
  - For example, signal molecules from one neuron use weak bonds to bind briefly to receptor molecules on the surface of a receiving neuron.
  - This triggers a momentary response by the recipient.
- Weak interactions include ionic bonds (weak in water), hydrogen bonds, and van der Waals interactions.

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- **Hydrogen bonds** form when a hydrogen atom that is already covalently bonded to a strongly electronegative atom is attracted to another strongly electronegative atom.
  - These strongly electronegative atoms are typically nitrogen or oxygen.
  - Typically, these bonds result because the polar covalent bond with hydrogen leaves the hydrogen atom with a partial positive charge and the other atom with a partial negative charge.
  - The partially positive charged hydrogen atom is attracted to negatively charged (partial or full) molecules, atoms, or even regions of the same large molecule.

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- For example, ammonia molecules and water molecules link together with weak hydrogen bonds.
  - In the ammonia molecule, the hydrogen atoms have partial positive charges and the more electronegative nitrogen atom has a partial positive charge.
  - In the water molecule, the hydrogen atoms also have partial positive charges and the oxygen atom partial negative charges.
  - Areas with opposite charges are attracted.

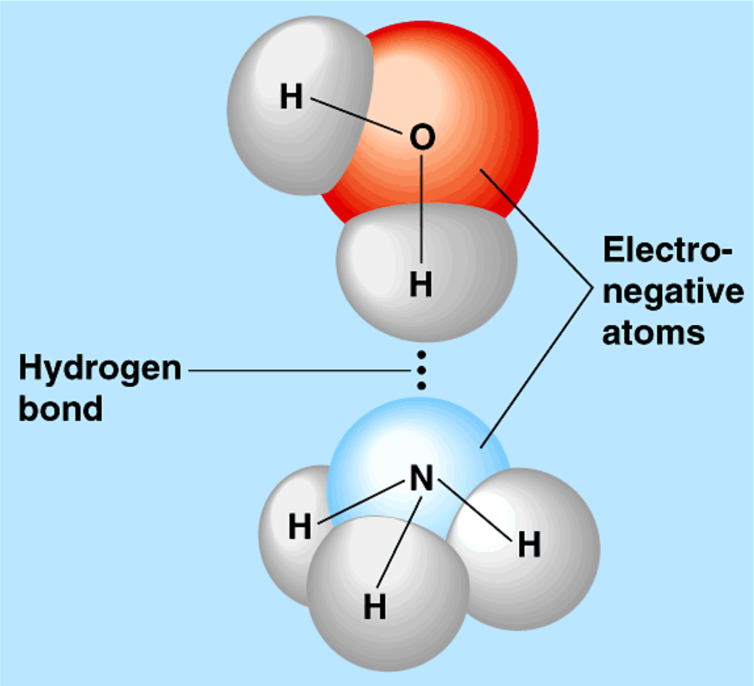

Fig. 2.16

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- Even molecules with nonpolar covalent bonds can have partially negative and positive regions.
  - Because electrons are constantly in motion, there can be periods when they accumulate by chance in one area of a molecule.
  - This created ever-changing regions of negative and positive charge within a molecule.
- Molecules or atoms in close proximity can be attracted by these fleeting charge differences, creating **van der Waals interactions**.
- While individual bonds (ionic, hydrogen, van der Waals) are weak, collectively they have strength.

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5. Chemical reactions make and break chemical bonds

- In **chemical reactions** chemical bonds are broken and reformed, leading to new arrangements of atoms.
- The starting molecules in the process are called **reactants** and the end molecules are called **products.**
- In a chemical reaction, all of the atoms in the reactants must be accounted for in the products.
  - The reactions must be "balanced".

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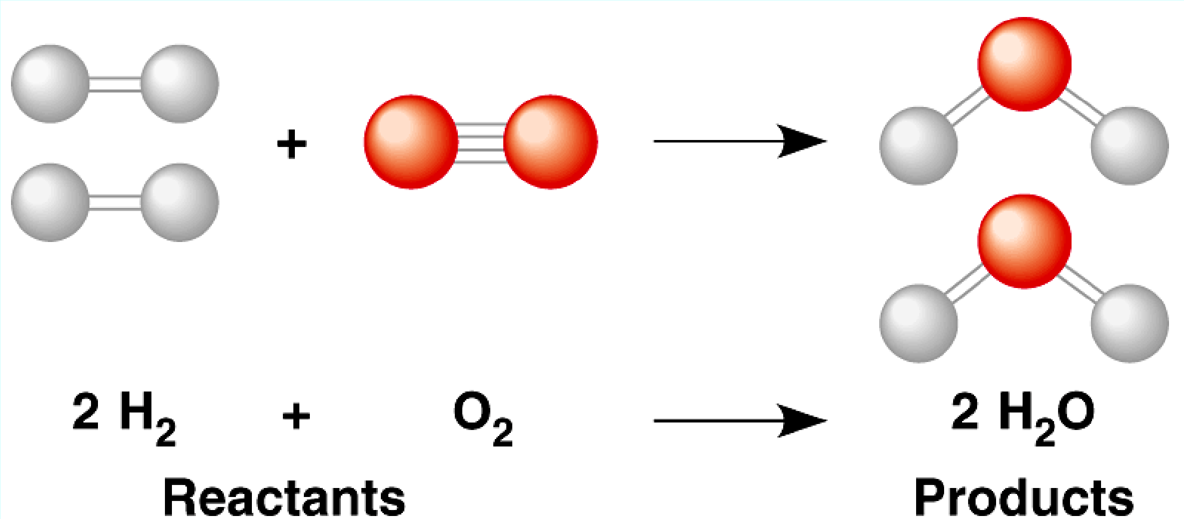
- For example, we can recombine the covalent bonds of H_2 and O_2 to form the new bonds of H_2O.
- In this reaction, two molecules of H_2 combine with one molecule of O_2 to form two molecules of H_2O.
- The ratios of molecules are indicated by coefficients.



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- Photosynthesis is an important chemical reaction.
- Green plants combine carbon dioxide (CO_2) from the air and water (H_2O) from the soil to create sugar molecules and molecular oxygen (O_2), a byproduct.
- This chemical reaction is powered by sunlight.
- Humans and other animals depend on photosynthesis for food and oxygen.
- The overall process of photosynthesis is
  - $6CO_2 + 6H_2O \text{ -> } C_6H_{12}O_6 + 6H_2O$
- This process occurs in a sequence of individual chemical reactions.

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- Eventually, the rate of formation of products is the