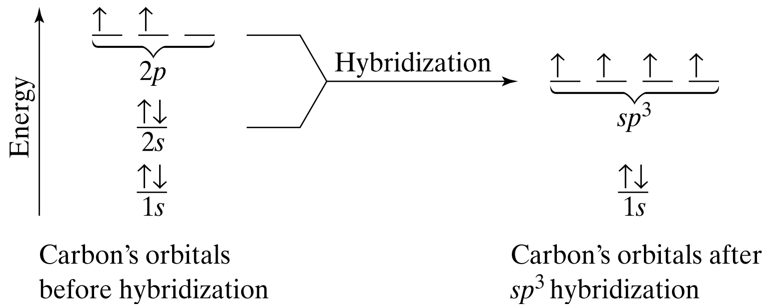
We know from experiments that a methane molecule has tetrahedral geometry. How does carbon form four equivalent, tetrahedrally arranged covalent bonds by orbital overlap with four other atoms?

Two of carbon's valence electrons occupy the $2s$ orbital, and two occupy the $2p$ orbitals. Recall that the $2s$ orbital and the $2p$ orbitals have different shapes. To achieve four equivalent bonds, carbon's $2s$ and three $2p$ orbitals *hybridize* to form four new, identical orbitals called sp^3 orbitals. The superscript 3 indicates that three p orbitals were included in the hybridization; the superscript 1 on the s is understood. The sp^3 orbitals all have the same energy, which is greater than that of the $2s$ orbital but less than that of the $2p$ orbitals, as shown in **Figure 23.**

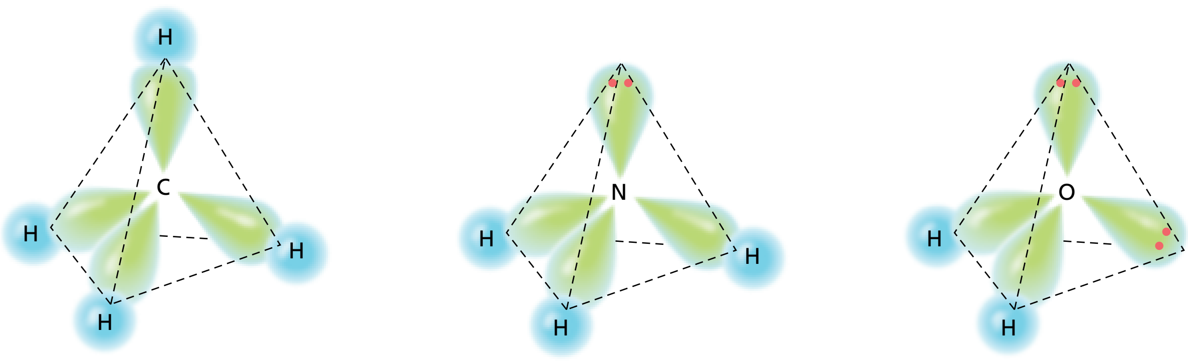
FIGURE 23 The sp^3 hybridization of carbon's outer orbitals combines one s and three p orbitals to form four sp^3 hybrid orbitals. Whenever hybridization occurs, the resulting hybrid orbitals are at an energy level between the levels of the orbitals that have combined.



Hybrid orbitals *are orbitals of equal energy produced by the combination of two or more orbitals on the same atom.* The number of hybrid orbitals produced equals the number of orbitals that have combined. Bonding with carbon sp^3 orbitals is illustrated in **Figure 24a** for a molecule of methane.

Hybridization also explains the bonding and geometry of many molecules formed by Group 15 and 16 elements. The sp^3 hybridization of a nitrogen atom ([He]$2s^22p^3$) yields four hybrid orbitals—one orbital containing a pair of electrons and three orbitals that each contain an unpaired electron. Each unpaired electron is capable of forming a single bond, as shown for ammonia in **Figure 24b.** Similarly, two of the four sp^3 hybrid orbitals on an oxygen atom ([He]$2s^22p^4$) are occupied by two electron pairs and two are occupied by unpaired electrons. Each unpaired electron can form a single bond, as shown for water in **Figure 24c.**

FIGURE 24 Bonds formed by the overlap of the $1s$ orbitals of hydrogen atoms and the sp^3 orbitals of (a) carbon, (b) nitrogen, and (c) oxygen. For the sake of clarity, only the hybrid orbitals of the central atoms are shown.



(a) Methane, CH_4 **(b)** Ammonia, NH_3 **(c)** Water, H_2O