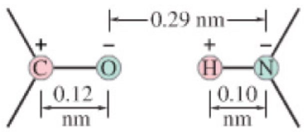

FIGURE 29–11 The C^+—O^- and H^+—N^- dipoles attract each other. (These dipoles may be part of, for example, cytosine and guanine molecules. See Fig. 29–12.) The + and − charges typically have magnitudes of a fraction of e.

Weak bonds are generally the result of attraction between dipoles. (Two equal point charges Q, of opposite sign, separated by a distance l, are called an **electric dipole**, as we saw in Chapter 17.) For example, Fig. 29–11 shows two molecules, which have permanent dipole moments, attracting one another. Besides such **dipole–dipole bonds**, there can also be **dipole–induced dipole bonds**, in which a polar molecule with a permanent dipole moment can induce a dipole moment in an otherwise electrically balanced (nonpolar) molecule, just as a single charge can induce a separation of charge in a nearby object (see Fig. 16–7). There can even be an attraction between two nonpolar molecules, because their electrons are moving about: at any instant there may be a transient separation of charge, creating a weak attraction. All these weak bonds are referred to as **van der Waals bonds**, and the forces involved **van der Waals forces**. The potential energy has the general shape shown in Fig. 29–8, with the attractive van der Waals PE varying as $1/r^6$.

When one of the atoms in a dipole–dipole bond is hydrogen, as in Fig. 29–11, it is called a **hydrogen bond**. A hydrogen bond is generally the strongest of the weak bonds, because the hydrogen atom is the smallest atom and can be approached more closely. Hydrogen bonds also have a partial "covalent" character: that is, electrons between the two dipoles may be shared to a small extent, making a stronger, more lasting bond.

PHYSICS APPLIED
DNA

Weak bonds are important in liquids and solids when strong bonds are absent (see Section 29–5). They are also very important for understanding the activities of cells, such as the double helix shape of DNA (Fig. 29–12), and DNA replication (see Section 16–11). The average kinetic energy of molecules in a living cell at normal temperatures ($T \approx 300\,\mathrm{K}$) is around $\frac{3}{2}kT \approx 0.04\,\mathrm{eV}$, about the magnitude of weak bonds. This means that a weak bond can readily be broken just by a molecular collision. Hence weak bonds are not very permanent—they are,

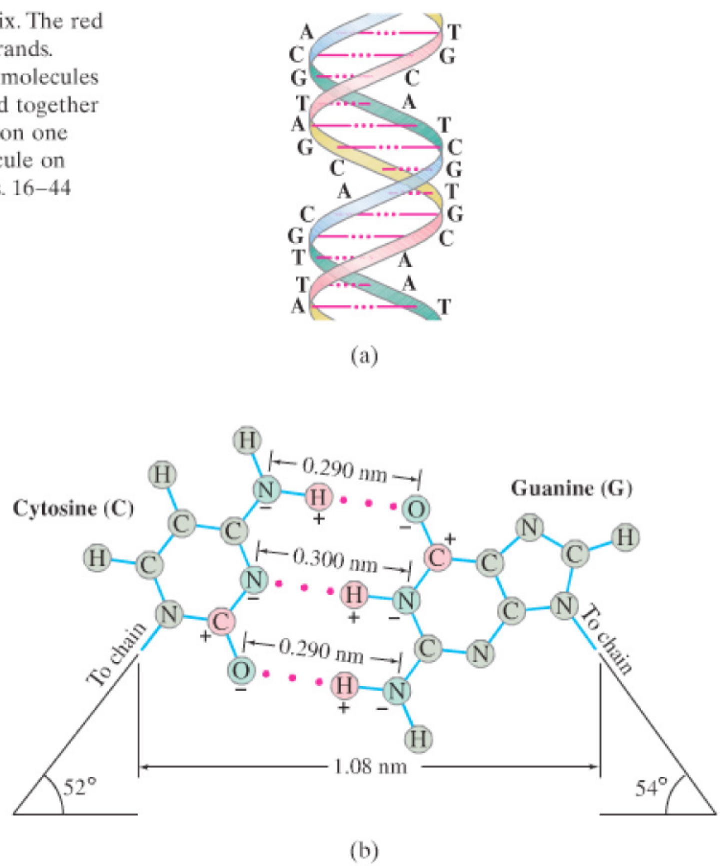

FIGURE 29–12 (a) Section of a DNA double helix. The red dots represent hydrogen bonds between the two strands. (b) "Close-up" view: cytosine (C) and guanine (G) molecules on separate strands of a DNA double helix are held together by the hydrogen bonds (red dots) involving an H^+ on one molecule attracted to an N^- or C^+—O^- of a molecule on the adjacent chain. See also Section 16–11 and Figs. 16–44 and 16–45.