13.7

The dipole moment of H₂O is

\[ \mu_{\text{H}_2\text{O}} = (1.82 \text{ D})(3.336 \times 10^{-30} \text{ C m/ D}) = 6.072 \times 10^{-30} \text{ C m} \]

resulting in a dipole-dipole interaction of

\[ V = -2 \frac{\mu_{\text{H}_2\text{O}} \mu_{\text{H}_2\text{O}}}{4\pi\epsilon_0 r^3} \]

\[ V = -2 \frac{(6.072 \times 10^{-30} \text{ C m})^2}{4\pi(8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2})(2.76 \times 10^{-10} \text{ m})^3} \]

\[ = -3.15 \times 10^{-20} \text{ J} \]

Expressing this as energy per mole:

\[ V = (-3.15 \times 10^{-20} \text{ J})(6.02 \times 10^{23}/1 \text{ mol})(1 \text{ kJ}/1000 \text{ J}) = -19.0 \text{ kJ mol}^{-1} \]

13.14

(a) A “linear” water molecule would not be polar.

(b) Such a molecule could still form hydrogen bonds, although the structures would be different, closer to two-dimensional structures than three-dimensional clusters of water molecules. The “linear” water molecule would form hydrogen bonds that look like

\[
\begin{array}{c}
\text{H} \\
\text{O} \ldots \text{H} \text{O} \text{H} \\
\text{H}
\end{array}
\]
13.18
The stronger the intermolecular forces, the harder it is to melt a solid, thus a higher melting point. The \textit{para} isomer can form intermolecular hydrogen bonds, while the \textit{ortho} isomer can form also intramolecular hydrogen bonds, as illustrated below. Thus, the \textit{para} form, with stronger intermolecular forces, will have the higher melting point.

\[
\begin{align*}
&\text{O} \\
&\text{N} \\
&\text{O} \\
&\text{H} \\
&\text{O} \\
&\text{N} \\
&\text{O} \\
\end{align*}
\]

13.20
For one pair of bases, the ratio of the two separate strands to a hydrogen-bonded double helix is

\[
\exp[-\Delta E/RT] = \exp[-(10 \times 10^3) \text{ J mol}^{-1}/8.314 \text{ J K}^{-1} \text{ mol}^{-1})(300 \text{ K})] = 1.8 \times 10^{-2}
\]

For 100 base pairs, the ratio of the two separate strands to a hydrogen-bonded double helix is

\[
\exp[-(100)(10 \times 10^3) \text{ J mol}^{-1}/8.314 \text{ J K}^{-1} \text{ mol}^{-1})(300 \text{ K})] = 7.6 \times 10^{-175} \approx 0.
\]

13.25
The number of base pairs is

\[
(5.0 \times 10^9 \text{ g mol}^{-1})/(650 \text{ g mol}^{-1}) = 7.7 \times 10^6
\]

The length of the DNA molecule is

\[
(7.7 \times 10^6)(3.4 \times 10^{-8} \text{ cm}) = 0.26 \text{ cm}
\]
The hydrophobic interaction differs from other types of inter- and intra-molecular forces. Usually bonds form because this lowers the enthalpy and thus the Gibbs energy; it is energetically favorable (and enthalpically favorable) for two H atoms to form $\text{H}_2$. The origin of the hydrophobic interaction is different. It is entropically driven, and involves preventing water molecules from forming low entropy, ordered structures, in particular a clathrate cage that would otherwise form around a nonpolar solute (see Fig. 16.17). The clathrate cage that forms lowers the entropy, and thus raises the Gibbs energy. To prevent this, nonpolar solutes or side-chains cluster together; this is the hydrophobic interaction, which is largely an entropy-driven process. The liberation of these water molecules surrounding the non-polar species and their return to bulk water increases the entropy and promotes the aggregation of the non-polar entities. In proteins, nonpolar side chains tend to move away from the surrounding water and cluster together in the interior of the protein, forming a hydrophobic core. This again prevents water molecules from forming a cage (as in Fig. 16.17) around the nonpolar side chain.