

Topic 3F - Intermolecular Forces

Interparticle Forces

Ion-Ion

(100's of kJ/mol)

Ions only

$$\text{P.E.} \propto \frac{Q_1 Q_2}{r}$$

Ion-Dipole

(10–20 kJ/mol)

Ions & polar molecules

$$\text{P.E.} \propto \frac{|Z|\mu}{r^2}$$

Dipole-Dipole

(< 5 kJ/mol)

Polar molecules

$$\text{P.E.} \propto -\frac{\mu_1^2 \mu_2^2}{r^3}$$

(stationary)

$$\text{P.E.} \propto -\frac{\mu_1^2 \mu_2^2}{r^6}$$

(rotating)

London

(< 5 kJ/mol)

All molecules

$$\text{P.E.} \propto -\frac{\alpha_1 \alpha_2}{r^6}$$

where

Q_i = Charge

μ_i = Dipole moment

α_i = Polarizability

r = Separation distance

TABLE 6.1 Interionic and Intermolecular Interactions*

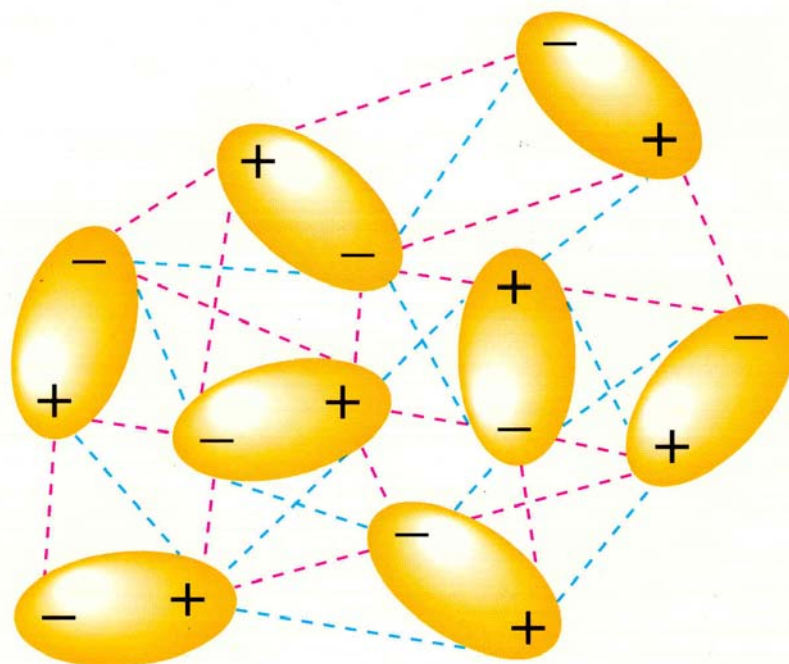
Type of interaction	Typical energy ($\text{kJ}\cdot\text{mol}^{-1}$)	Interacting species
ion-ion	250	ions only
ion-dipole	15	ions and polar molecules
dipole-dipole	2	polar molecules, stationary
	0.3	polar molecules, rotating
dipole-induced-dipole	2	molecules, at least one must be polar
London (dispersion) [†]	2	all types of molecules
hydrogen bonding	20	molecules containing an N—H, O—H, or F—H bond; a shared H atom links the molecules

*The total interaction experienced by a species is the sum of all the interactions in which it can participate.

[†]Also known as the induced-dipole-induced-dipole interaction.



(a)



Attraction ————
Repulsion ————

(b)

Figure 10.2
Dipole-dipole attractions

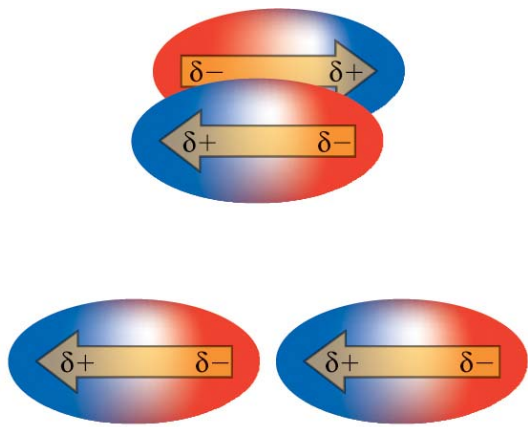


FIGURE 6.4 Polar molecules attract each other by the interaction between the partial charges of their electric dipoles (represented by the arrows). Both the relative orientations shown (end to end or side by side) result in a lower energy than a random distribution of orientations.

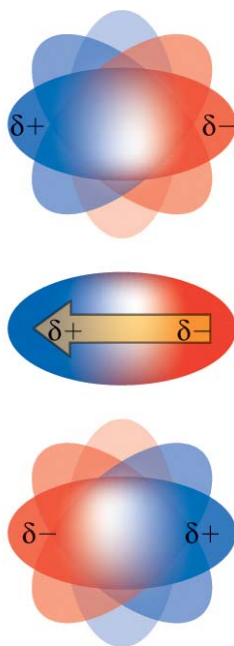


FIGURE 6.5 A polar molecule rotating near another polar molecule spends more time in the low-energy orientations (bottom) that maximize attractions, and so the net interaction is attractive, but not as strong as it would be if the molecules were not rotating.

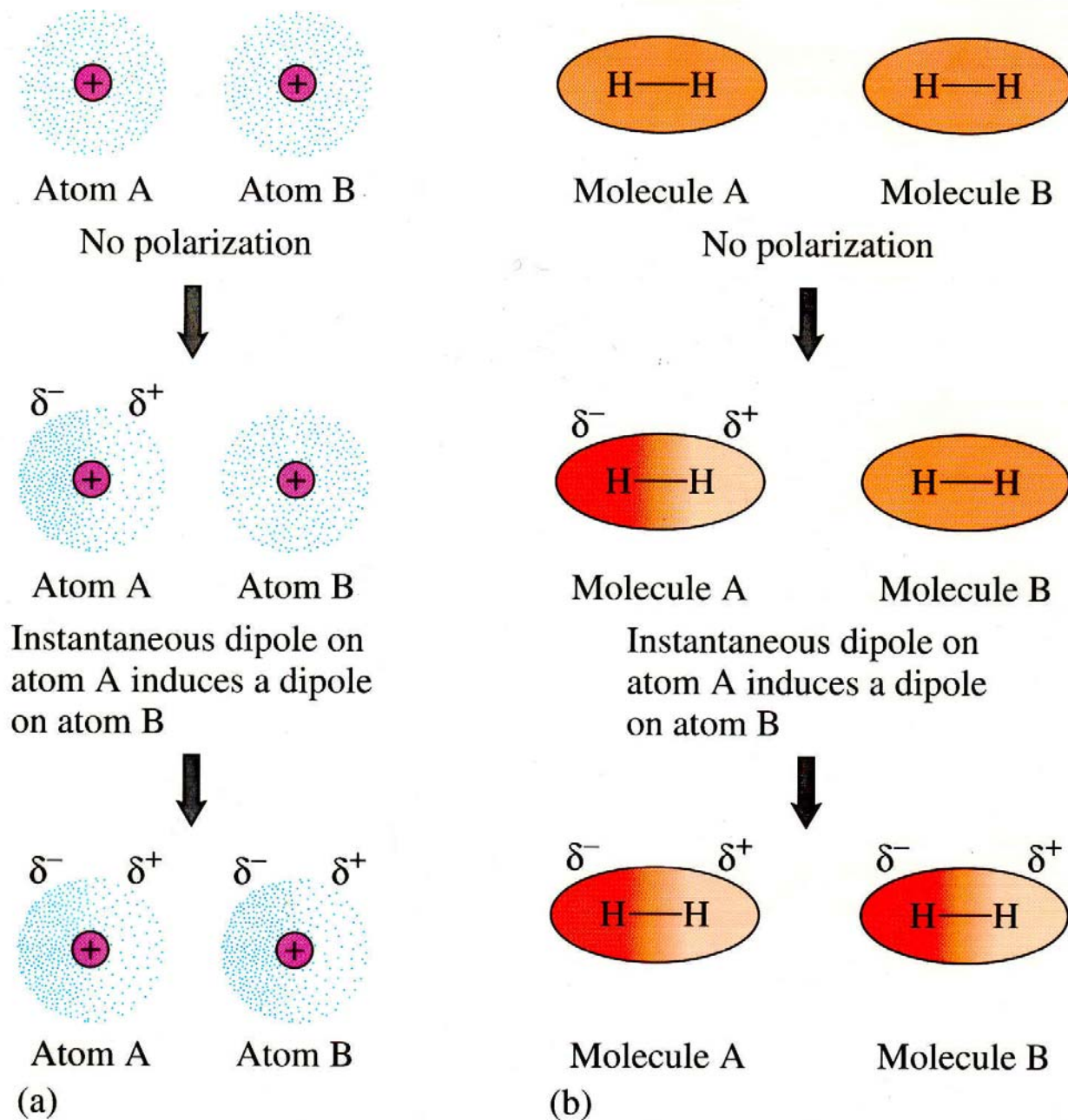


Figure 10.5
London dispersion forces

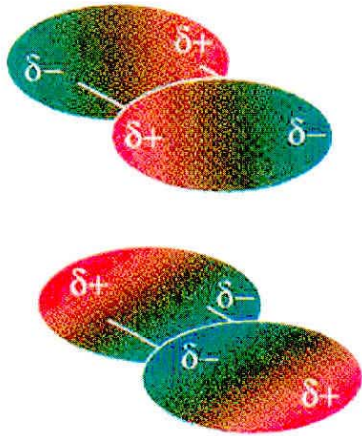


FIGURE 5.5 A fluctuation in the electron distribution in two neighboring molecules results in two instantaneous electric dipole moments that attract each other. The fluctuations move, but each new arrangement in one molecule induces an arrangement in the other that results in mutual attraction.

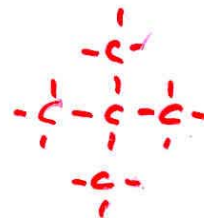
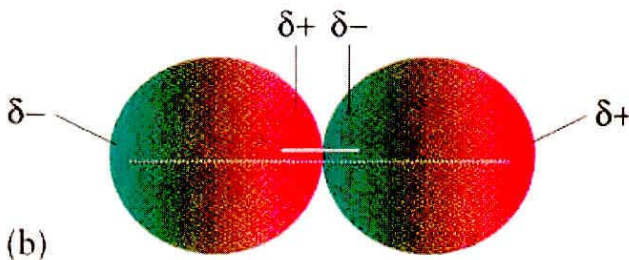
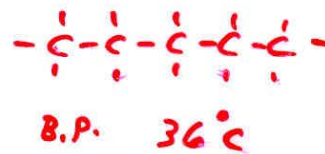
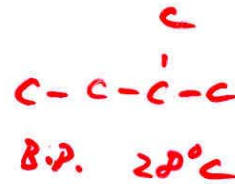


FIGURE 5.7 (a) The instantaneous dipole moments in two neighboring rod-shaped molecules tend to be close together and interact strongly. (b) Those on neighboring spherical molecules tend to be farther apart and interact ^{more} weakly.

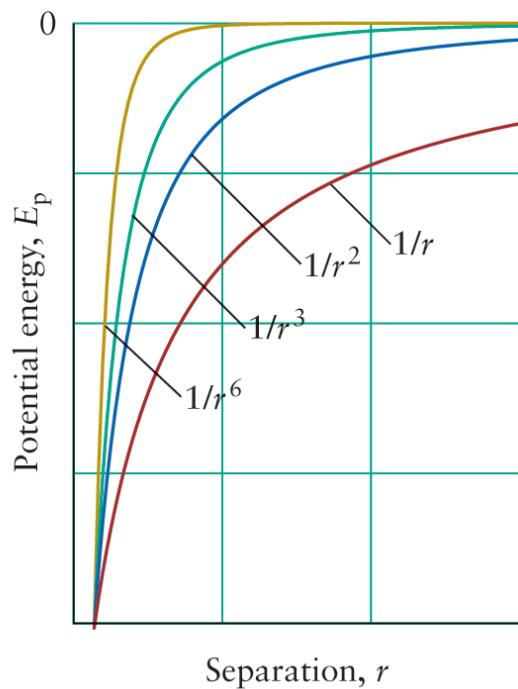
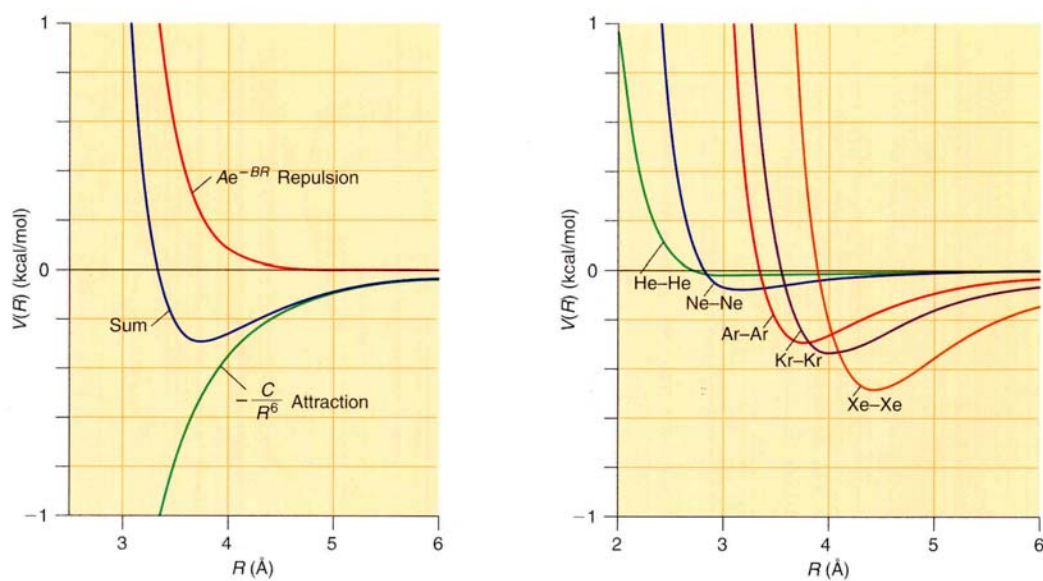


FIGURE 6.3 The distance dependence of the potential energy of the interaction between ions (red, lowest line), ions and dipoles (blue), stationary dipoles (green), and rotating dipoles (brown, uppermost line).

Figure 14.14: Repulsive and Attractive Intermolecular Forces



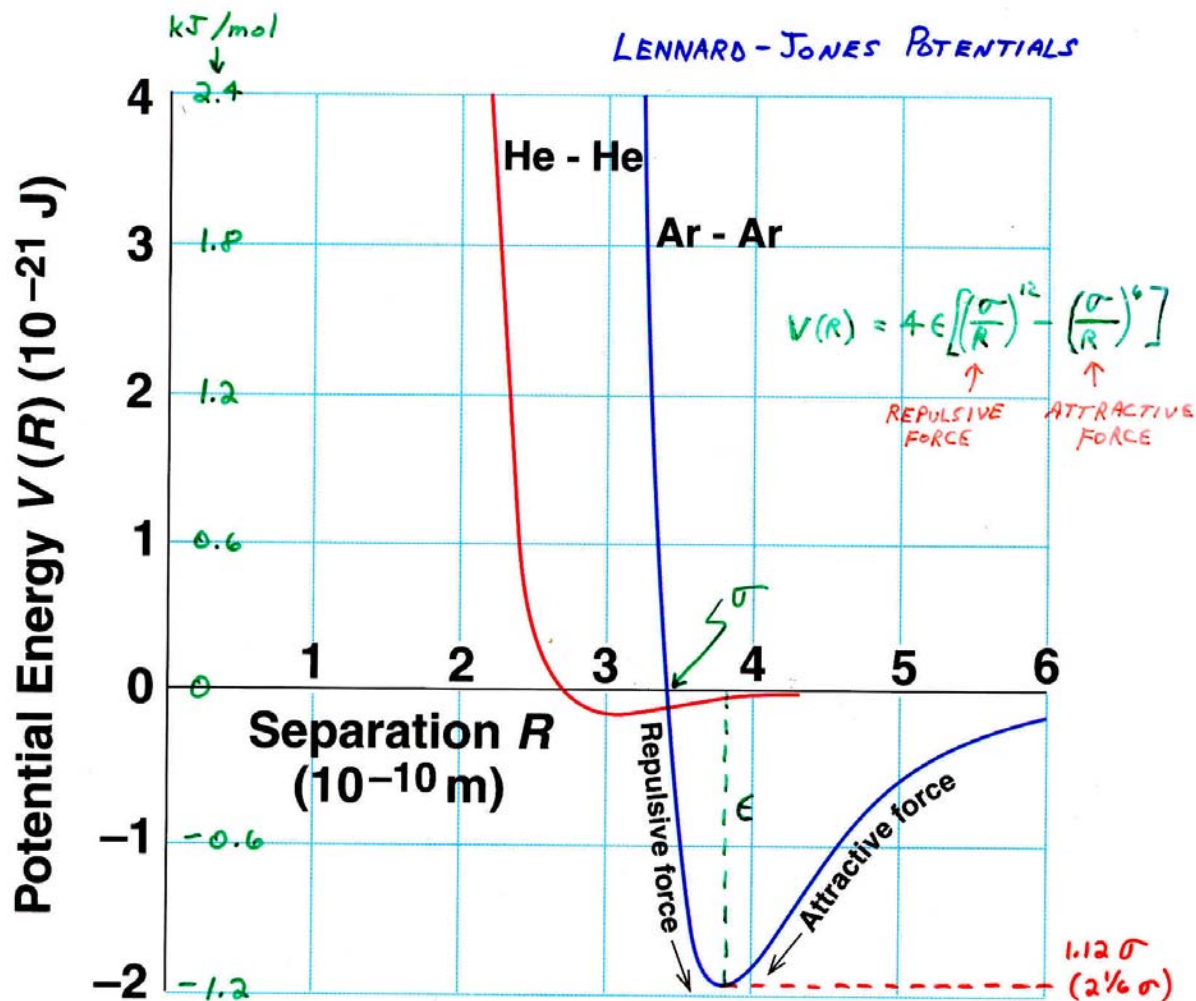


Table 3-4 Lennard-Jones Parameters for Atoms and Molecules

Substance	σ (m)	B.P. ($^{\circ}$ C)	ϵ (J)
He	2.56×10^{-10}	-269	1.41×10^{-22}
Ne	2.75×10^{-10}	-246	4.92×10^{-22}
Ar	3.40×10^{-10}	-186	1.654×10^{-21}
Kr	3.60×10^{-10}	-152	2.36×10^{-21}
Xe	4.10×10^{-10}	-107	3.06×10^{-21}
H ₂	2.93×10^{-10}	-253	5.11×10^{-22}
O ₂	3.58×10^{-10}	-183	1.622×10^{-21}
CO	3.76×10^{-10}	-192	1.383×10^{-21}
N ₂	3.70×10^{-10}	-196	1.312×10^{-21}
CH ₄	3.82×10^{-10}	-164	2.045×10^{-21}

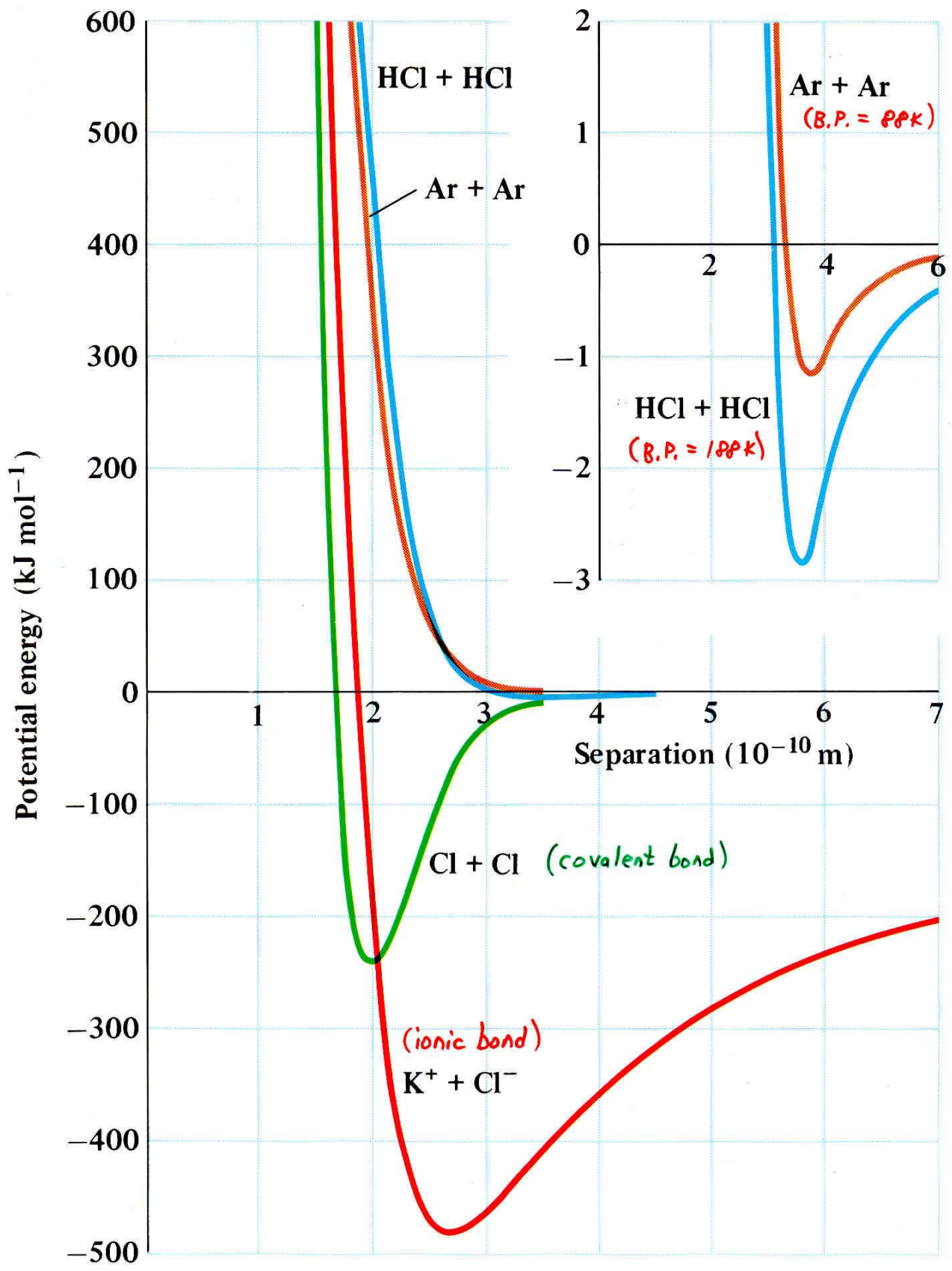


Figure 14.12: Dependence of Boiling Point and Heat of Vaporization on the Period n

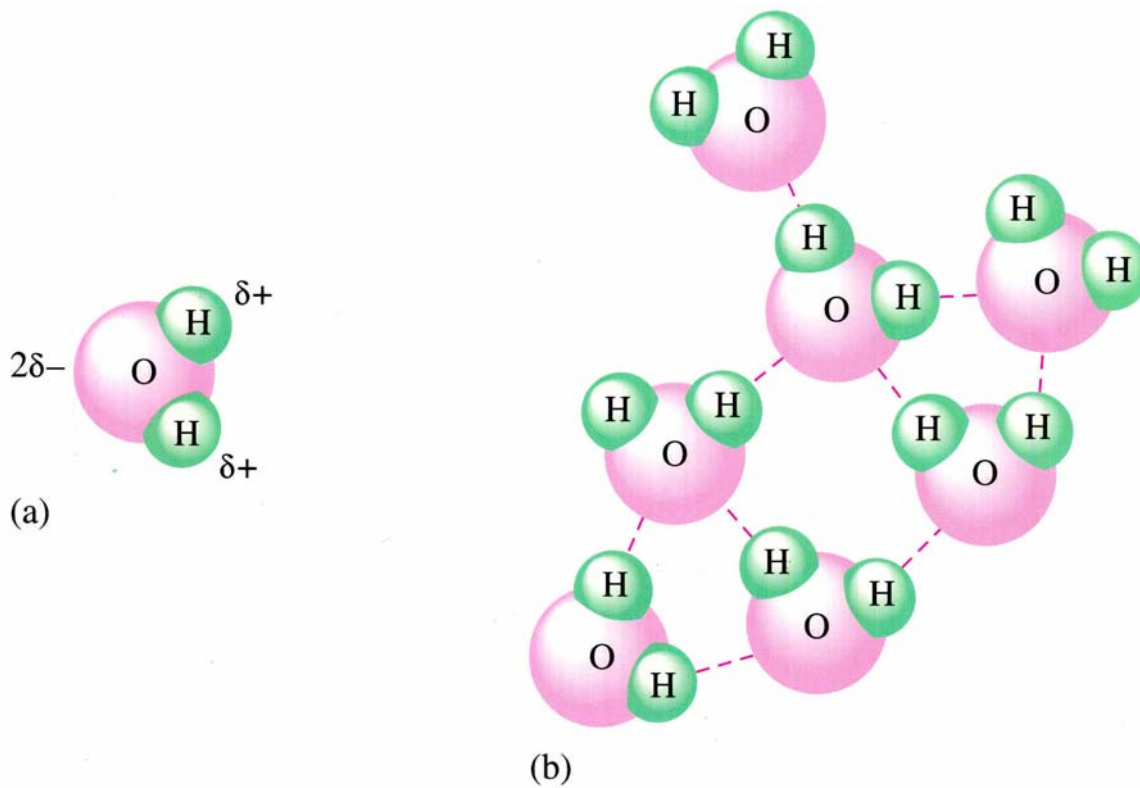
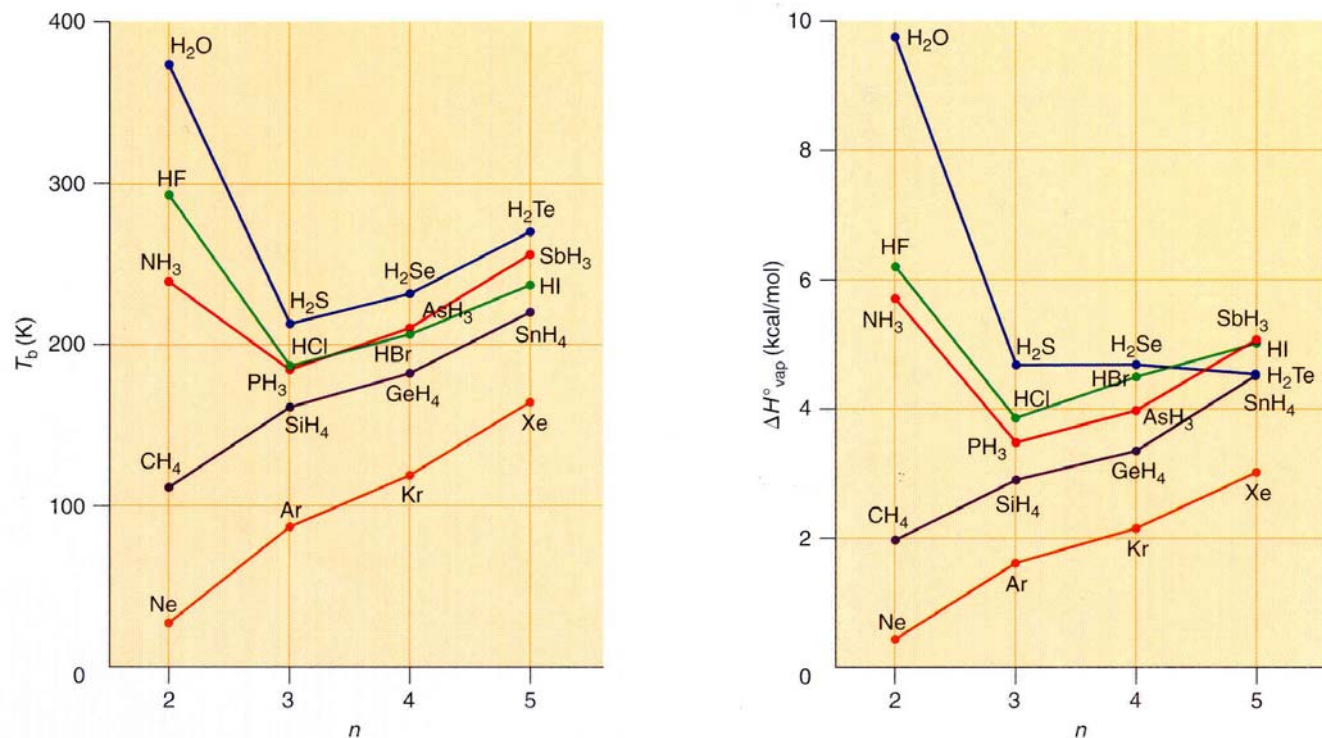
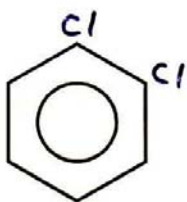
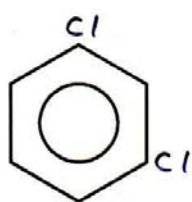


Figure 10.3
Hydrogen bonding among water molecules

M.W.

1,2-DICHLOROBENZENE

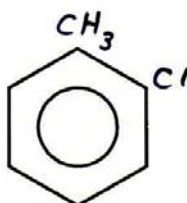


1,3-DICHLOROBENZENE

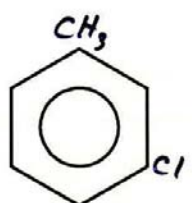


1,4-DICHLOROBENZENE

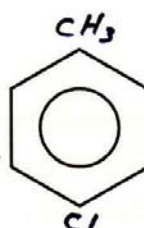
147

M.P.
B.P.-17
181-25
17353
174

2-CHLOROTOLUENE

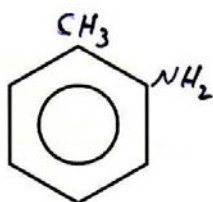


3-CHLOROTOLUENE

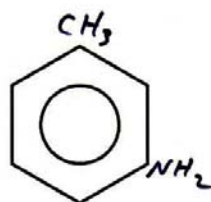


4-CHLOROTOLUENE

127

M.P.
B.P.-35
159-48
1628
162

o-TOLUIDINE

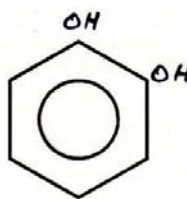


m-TOLUIDINE

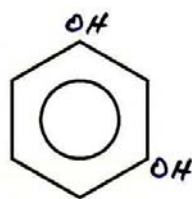


p-TOLUIDINE

107

M.P.
B.P.-15
200-30
20344
200

CATECHOL



RESORCINO-



HYDROXYQUINONE

110

M.P.
B.P.105
245111
280173
285

Contribution of the dispersion to the total intermolecular interaction energy

Molecule pair	% of the total energy of interaction
Ne-Ne	100
CH ₄ -CH ₄	100
HI-HI	99
HCl-HI	96
HBr-HBr	96
H ₂ O-CH ₄	87
HCl-HCl	86
CH ₃ Cl-CH ₃ Cl	68
NH ₃ -NH ₃	57
H ₂ O-H ₂ O	24

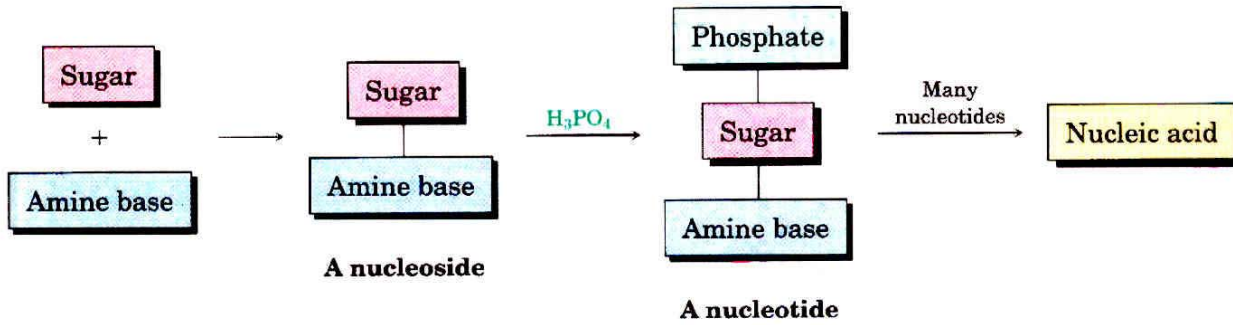
TABLE 6.2 Melting and Boiling Points of Substances*

Substance	Melting point (°C)	Boiling point (°C)	Substance	Melting point (°C)	Boiling point (°C)
Noble gases			Inorganic substances with small molecules		
He	-270 (3.5 K) [†]	-269 (4.2 K)	H ₂	-259	-253
Ne	-249	-246	N ₂	-210	-196
Ar	-189	-186	O ₂	-218	-183
Kr	-157	-153	H ₂ O	0	100
Xe	-112	-108	H ₂ S	-86	-60
Halogens			NH ₃	-78	-33
F ₂	-220	-188	CO ₂	—	-78s
Cl ₂	-101	-34	SO ₂	-76	-10
Br ₂	-7	59	Organic compounds		
I ₂	114	184	CH ₄	-182	-162
Hydrogen halides			CF ₄	-150	-129
HF	-93	20	CCL ₄	-23	77
HCl	-114	-85	C ₆ H ₆	6	80
HBr	-89	-67	CH ₃ OH	-94	65
HI	-51	-35	glucose	142	d
			sucrose	184d	—

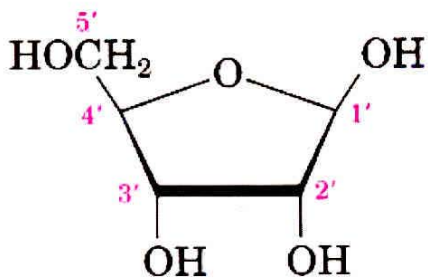
*Abbreviations: s, solid sublimes; d, solid decomposes.

[†]Under pressure.

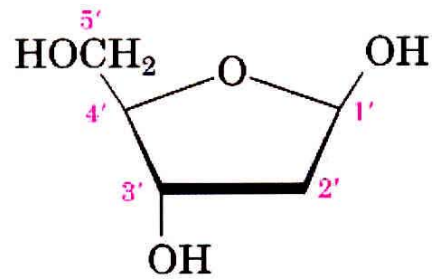
Nucleic Acid Synthesis



In RNA, "Sugar" is Ribose. In DNA "Sugar" is 2'-Deoxyribose:



Ribose



2'-Deoxyribose

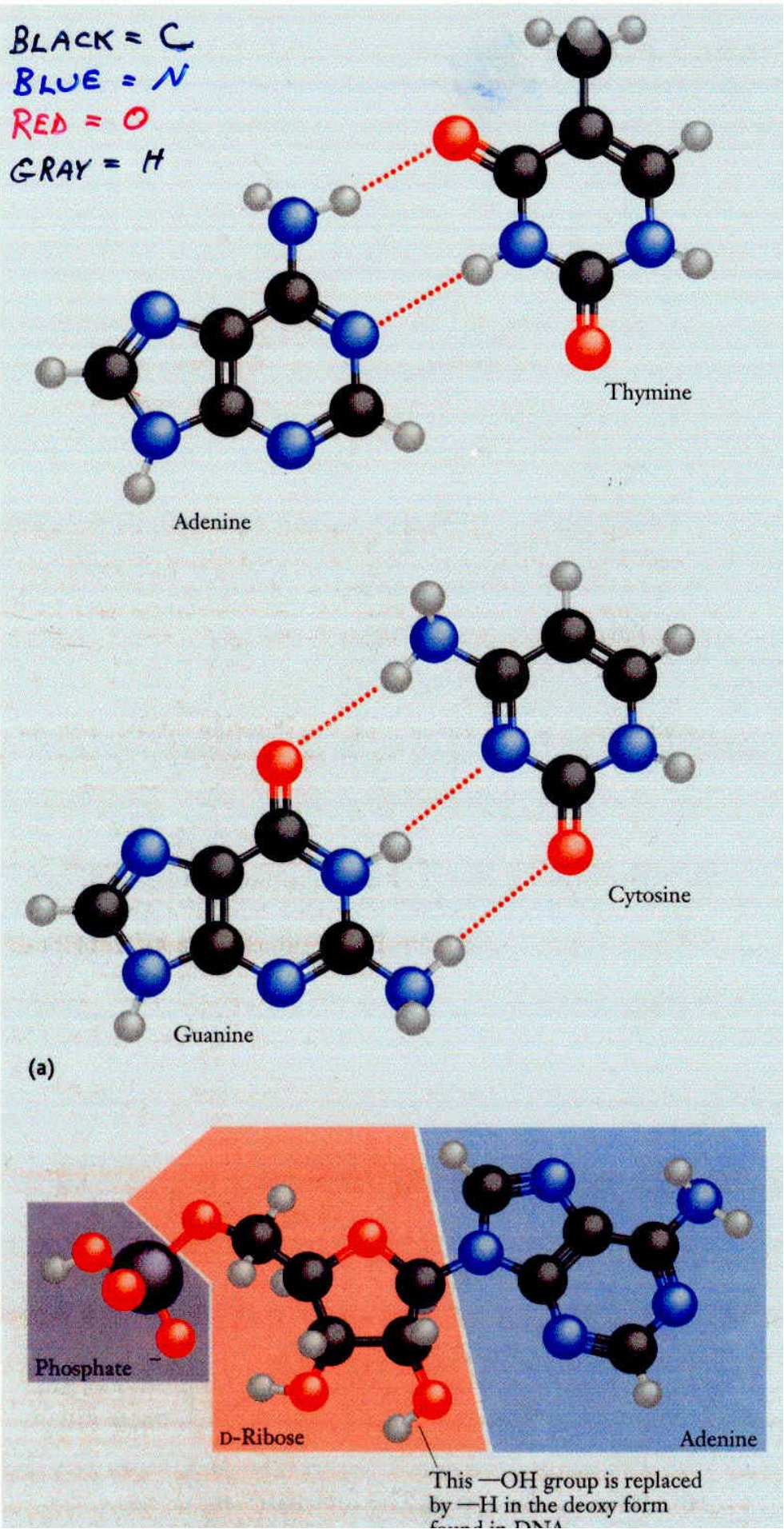


FIGURE 28.5 ▼

Generalized structure of DNA.

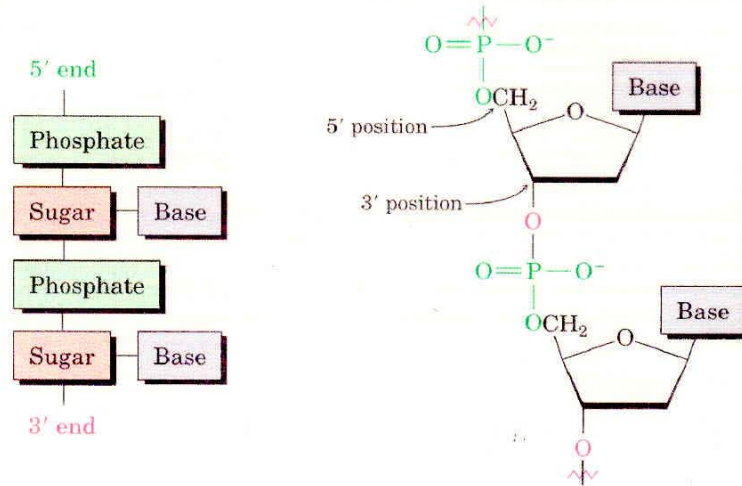
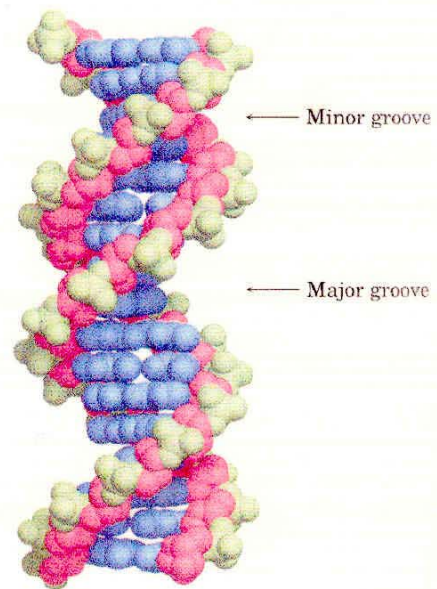
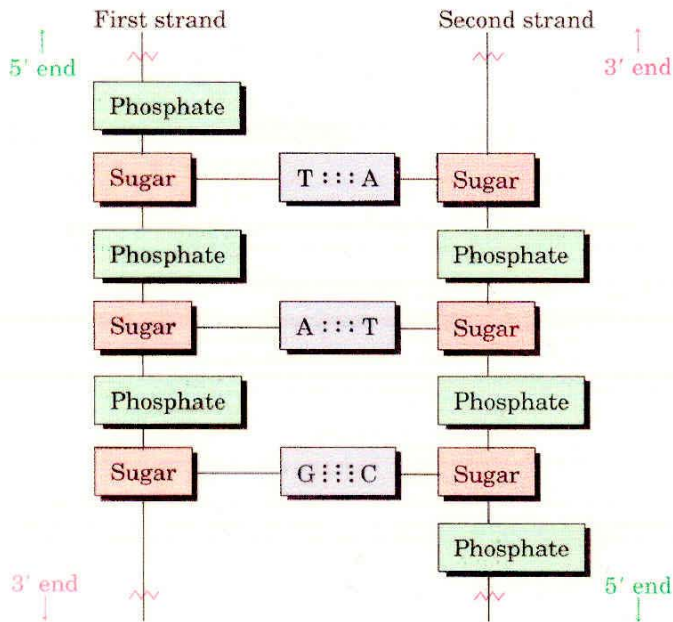


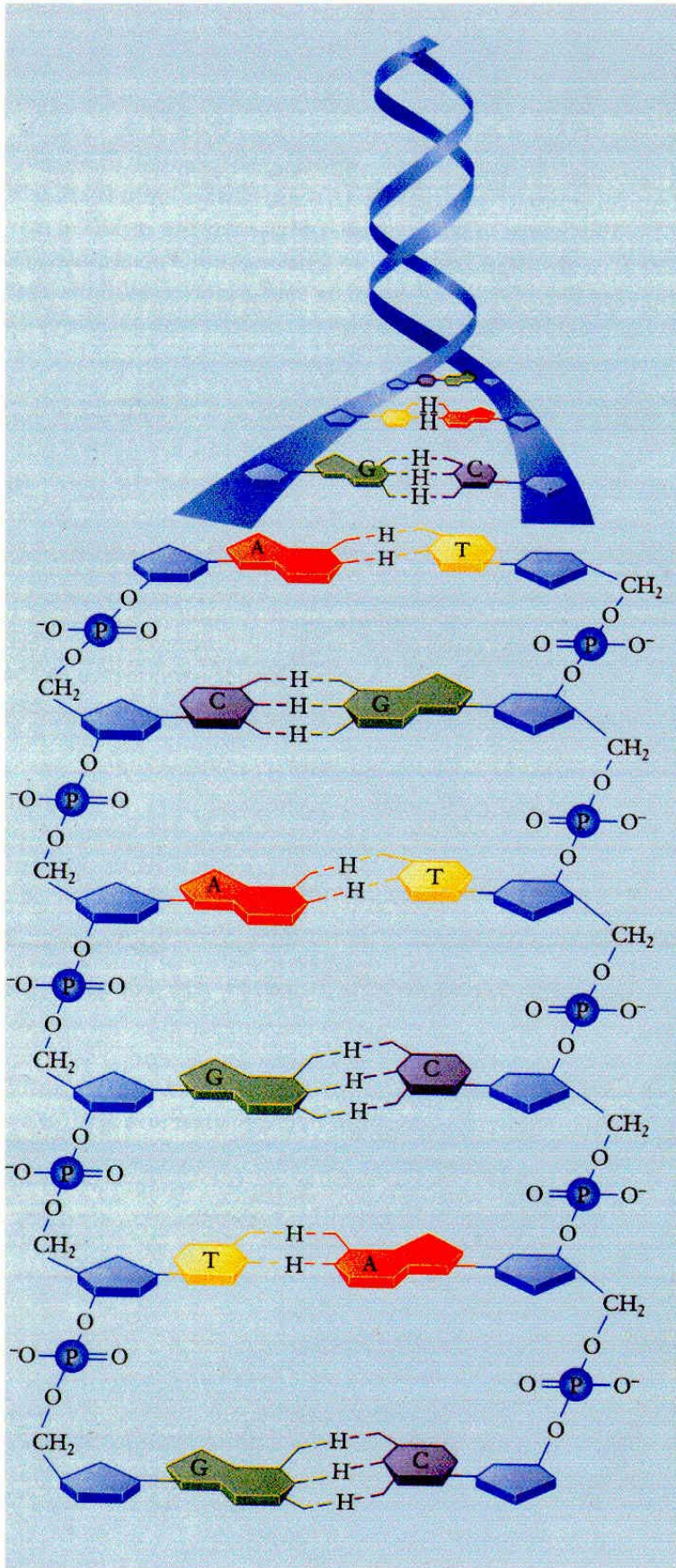
FIGURE 28.7 ▼

Complementarity in base pairing in the DNA double helix. The sugar-phosphate backbone runs along the outside of the helix, while the amine bases hydrogen-bond to one another on the inside. Both major and minor grooves are visible.



DNA double helix





A = ADENINE } BASE PAIR
 T = THYMINE }

C = CYTOSINE } BASE PAIR
 G = GUANINE }

FIGURE 28.8 ▼

Schematic representation of DNA replication. The original double-stranded DNA partially unwinds, bases are exposed, nucleotides line up on each strand in a complementary manner, and two new strands begin to grow.

