TABLE 1.3 **Less common yet important electrostatic interactions found in proteins.**

Chemical species	Interaction	Interaction features
Aromatic rings	π–π	• Involves two aromatic rings • Occurs between partially negative and partially positive regions in the rings • Highly geometry-dependent
	cation-π	• Often involve cationic metals
	π hydrogen bonds	• The π electrons serve as the hydrogen bond acceptors • Weaker, yet geometrically more flexible than standard hydrogen bonds
Sulfur and thiol	Hydrogen bonds	• Involve the thiol (SH) group as a weak donor • May involve the two sulfur lone pairs as very weak acceptors
	Thiol-π	• Involve dipole-dipole interactions • May also involve interactions between the π electrons and the sulfur's low-lying $\sigma*$ orbitals • Highly geometry-dependent
Lone electrons	$n \longrightarrow \pi*$	• Involves the lone electrons of electronegative atoms and the antibonding orbitals of other atoms • Estimated energy: ~5%–25% of a standard hydrogen bond
Halogens	X-bonds	• Electrostatic, occurring between a C–Cl/Br/I group and an electron-dense species (fully or completely charged) • Involve the internal dipole in the carbon-bound halogen • Strength depends on halogen: Cl < Br < I