photosensitizers has not been attained. This is believed to be because the HOMO level of Ru complexes derived from the d orbitals of the Ru metal center (i.e. the redox potential of Ru(II)/Ru(III)) is best matched to the iodine redox potential to accept electrons effectively.

Porphyrin [131–134] and phthalocyanine [135] derivatives have also been employed as photosensitizers in the DSSC. A nanocrystalline TiO_2 solar cell sensitized by Cu chlorophyllin produced 2.6% efficiency ($J_{SC} = 9.4$ mA cm^{-2} and $V_{OC} = 0.52$ V) under 100 mW cm^{-2} [131]. To develop new efficient metal complex photosensitizers, an increase in the absorption coefficient of the metal complex as well as an increase in the red shift of the absorption region is needed because the absorption coefficient decreases as the red shift increases.

15.3.2.2 Organic and natural dye photosensitizers

Organic dyes whose HOMO and LUMO levels match the conduction-band level of the semiconductor and the iodine redox potential can also be utilized as photosensitizers. As described in Section 15.1.1, organic dyes such as 9-phenylxanthene dyes were used as photosensitizers in early researches. Organic dyes have several advantages as photosensitizers: (1) they have a variety of structures for molecular design, (2) they are cheaper than metal complexes, and (3) they have large absorption coefficients attributed to intermolecular $\pi-\pi^*$ transition. Construction of nanocrystalline DSSCs using organic dye photosensitizers has been reported, and some structures are shown in Figure 15.13 [90, 91, 136–145].

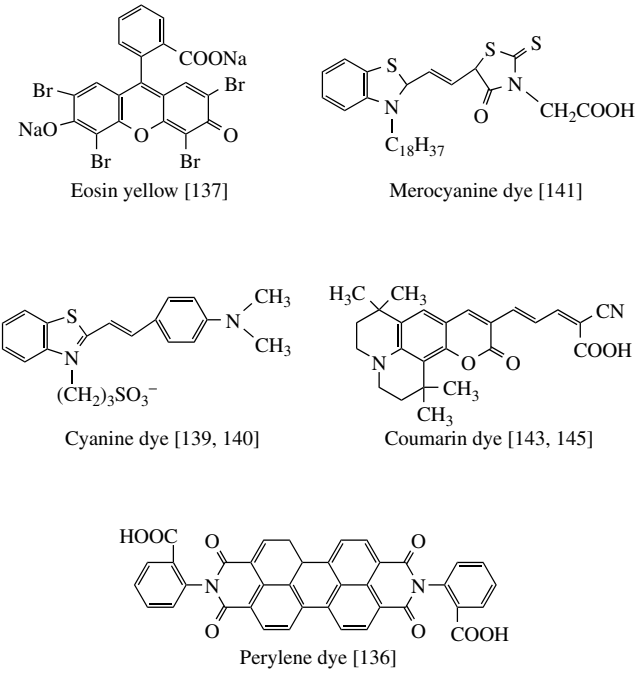

Figure 15.13 Molecular structures of organic dye photosensitizers