3.5 Red/Orange

3.5.1 Iron Oxide Red

Iron oxide red (**R01** - **R04**) derives its appearance from weak scattering and very strong absorption in the 400 - 600 nm band. One of the iron oxide reds (R01) exhibits moderate absorption across the NIR that may be due to doping of the Fe_2O_3 hematite crystals with impurities or result from broadband absorbing impurity phases such as Fe_3O_4; it is not a cool pigment. However, the remaining three iron oxide reds weakly absorb in the NIR and present both a dark red appearance and good NIR reflectance (0.53 - 0.67) over a white background. R02 also has a respectable NIR reflectance (0.38) over a black background, and has backscattering S comparable with TiO_2 white in the NIR.

3.5.2 Cadmium Orange

Cadmium orange (**R05**) has weak scattering and very strong absorption in the 400 - 600 nm band, followed by strong scattering and virtually no absorption at longer wavelengths. Applied over a white background, it appears bright orange and has very high NIR reflectance (0.87)—essentially the same as that of the white background. Cadmium orange (and cadmium yellow, below) are Cd(S,Se) direct bandgap semiconductors. They exhibit sharp transitions between absorbing and non-absorbing regions, and have high refractive indices (e.g., 2.5 for CdS) that lead to large scattering coefficients. However, sensitivity to acid and the toxicity of cadmium limit their applications.

3.5.3 Organic Red

Organic red pigments (**R06** - **R09**) such as acra burnt orange, acra red, monastral red, and naphthol red light have weak scattering and strong (sometimes very strong) absorption up to 600 nm, followed by very weak absorption and moderate-to-weak scattering at longer wavelengths. As a result they yield a medium-red color and a very high NIR reflectance (0.83 - 0.87) when applied over a white background. Masstones of acra burnt orange, acra red, and naphthol red light are all lightfast; their tints are slightly less so [2].

References

[1] Ronnen Levinson, Paul Berdahl, and Hashem Akbari. Solar spectral optical properties of pigments, Part I: model for deriving scattering and absorption coefficients from transmittance and reflectance measurements. *Solar Energy Materials & Solar Cells (accepted)*, 2004.

[2] Peter A. Lewis. *Pigment Handbook*, volume I. John Wiley and Sons, 1988.

[3] Gunter Buxbaum. *Industrial Inorganic Pigments*. Wiley-VCH, 2nd edition, 1998.

[4] Willy Herbst and Klaus Hunger. *Industrial Organic Pigments*. VCH, 1993.

[5] Y.S. Touloukian, D.P. DeWitt, and R.S. Hernicz. *Thermal Radiative Properties: Coatings*, volume 9 of *Thermophysical Properties of Matter*. IFI/Plenum, 1972.

[6] Ralph Mayer. *The Artist's Handbook of Materials and Techniques*. Viking Penguin, 5th edition, 1991.

[7] Society of Dyers and Colourists and American Association of Textile Chemists and Colorists. Colour index international: Fourth online edition. *http://www.colour-index.org*.

[8] B. R. Palmer, P. Stamatakis, C. G. Bohren, and G. C. Salzman. A multiple-scattering model for opacifying particles in polymer films. *Journal of Coatings Technology*, 61(779):41–47, 1989.

[9] E.S. Thiele and R.H. French. Computation of light scattering by anisotropic spheres of rutile titania. *Adv. Mater.*, 10(15):1271–1276, 1998.

[10] Paul Berdahl. Pigments to reflect the infrared radation from fire. *Journal of Heat Transfer*, 117:355–358, May 1995.

[11] D.J. Rutherford and L.A. Simpson. Use of a floculation gradient monitor for quantifying titanium dioxide pigment dispersion in dry and wet paint films. *Journal of Coatings Technology*, 57(724):75–84, May 1985.

[12] R.R. Blakey and J.E. Hall. *Pigment Handbook*, volume I, chapter A ("Titanium Dioxide"), pages 1–42. John Wiley and Sons, 1988.

[13] Daniel Russell Swiler. Manganese vanadium oxide pigments. U.S. Patent 6,485,557 B1, Nov 26 2002.

[14] Dry Color Manufacturer's Association (DCMA). *Classification and chemical description of the complex inorganic color pigments*. Dry Color Manufacturer's Association, P.O. Box 20839, Alexandria, VA 22320, 1991.

[15] E. B. Rabinovitch and J. W. Summers. Infrared reflecting vinyl polymer compositions. U.S. Patent 4,424,292, 1984.

[16] Terrence R. Sliwinski, Richard A. Pipoly, and Robert P. Blonski. Infrared reflective color pigment. U.S. Patent 6,174,360 B1, Jan 16 2001.

[17] V.A.M. Brabers. The electrical conduction of titanomagnetites. *Physica B*, 205:143–152, 1995.

[18] L.B. Glebov and E.N. Boulos. Absorption of iron and water in the Na_2O-CaO-MgO-SiO_2 glasses, II. Selection of intrinsic, ferric, and ferrous spectra in the visible and UV regions. *J. Non-Crystalline Solids*, 242:49–62, 1998.

[19] R.N. Clark. *Manual of Remote Sensing*, volume 3 ("Remote sensing for the earth sciences"), chapter 1 ("Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy", pages 3–58. John Wiley and Sons, http://speclab.cr.usgs.gov, 1999. Fig. 5.

[20] R.J.H. Clark and D.G. Cobbold. Characterization of sulfur radical anions in solutions of alkali polysulfides in dimethylformamide and hexamethylphosphoramide and in the solid state in ultramarine blue, green, and red. *Inorganic Chemistry*, 17:3169–3174, 1978.

[21] N.B. Mckeown. *Phthalocyanine Materials: Synthesis, Structure and Function.* Cambridge Univ. Press, Cambridge, UK, 1998.

[22] S. Wilbrandt O. Stenzel A. Stendal, U. Beckers and C. von Borczyskowski. The linear optical constants of thin phthalocyanine and fullerite films from the near infrared to the UV spectral regions: estimation of electronic oscillator strength values. *J. Phys. B*, 29:2589–2595, 1996.

[23] D. de Cogan and G.A. Lonergan. Electrical conduction in Fe_2O_3 and Cr_2O_3. *Solid State Communications*, 15:1517–1519, 1974.

[24] Hamnett Goodenough. *Landolt-Bornstein Numerical Data and Functional Relationships in Science and Technology, New Series, Group III: Crystal and Solid-State Physics*, volume 17g (Semiconductors: Physics of Non-Tetrahedrally Bonded Binary Compounds III), chapter 9.15.2.5.1: Oxides of chromium, pages 242–247,548–551. Springer-Verlag, Berlin, 1984.

[25] G.B. Smith, A. Gentle, P. Swift, A. Earp, and N. Mronga. Coloured paints based on coated flakes of metal as the pigment, for enhanced solar reflectance and cooler interiors: description and theory. *Solar Energy Materials & Solar Cells*, 79(2):163–177, 2003.

[26] G.B. Smith, A. Gentle, P. Swift, A. Earp, and N. Mronga. Coloured paints based on iron oxide and solicon oxide coated flakes of aluminium as the pigment, for energy efficient paint: optical and thermal experiements. *Solar Energy Materials & Solar Cells*, 79(2):179–197, 2003.