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Generalities on Colour and Colorimetry

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The *Commission Internationale de l'Éclairage* (CIE) is the official institution devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology.

CIE publications are the main reference for this book.[1–3] This book is about colorimetry and has the definitions of colour and colorimetry as its starting point.

1.1 Colour

In non-specialist language, the word 'colour' is ambiguous, because it is used to describe the quality of the objects, self-luminous and non-luminous, and to describe a quality of the viewing experience. These meanings of the same word 'colour' are different but they are not disjoint, because the first one is the stimulation of the visual experience and the other the visual experience itself. Between these two meanings there is a correspondence and colorimetry quantitatively describes this correspondence.

The colour of self-luminous and non-luminous objects is associated with a physical quantity, which is properly called *colour stimulus* and is measurable because it is external to the body of the observer:

> "*Colour stimulus* – visible radiation entering the eye and producing a sensation of colour, either chromatic or achromatic."[1]

The definition of colour as an effect of the colour stimulus is given by the *Optical Society of America* (OSA) in the 1952 report:

> "Color consists of the characteristics of light other than spatial and temporal inhomogeneities; light being the aspect of radiant energy of which a human being is aware through the visual sensations which arise from the stimulation of the retina of the eye."[4]

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Among the many definitions of colour, the most comprehensive, albeit in its brevity, is given by the *American Society for Testing and Materials* (ASTM),[5] which with the definitions opens highly technical discussions, which are clarified later in the book:

1. "*Colour of an object* – aspect of object appearance distinct from form, shape, size, position, or gloss that depends upon the spectral composition of the incident light, the spectral reflectance or transmittance of the object, and the spectral response of the observer, as well as the illuminating and viewing geometry."[5]

2. "*Perceived colour* – attribute of visual perception that can be described by colour names such as white, grey, black, yellow, brown, vivid red, deep reddish purple, or by combinations of such names. *Discussion* – perceived colour depends greatly on the spectral power distribution of the colour stimulus, but also on the size, shape, structure, and surround of the stimulus area, the state of adaptation of the observer's visual system, and the observer's experience with similar observations."[5]

The 'perceived colour' is defined using the names of the colours. This means that the names of the colours represent fundamental concepts, which are not definable in other words. The perceived colour is incommunicable. Humans evoke the perceived colour in the interlocutors with conventional words – red, yellow, green, blue, black, grey, white, so on –.

1.2 Colorimetry

Robert W. Hunt[6,7] distinguishes between:

"*Psychophysical colour terms* **–** terms denoting objective measures of physical variables that are evaluated so as to relate to the magnitudes of important attributes of light and colour. These measures identify stimuli that produce equal responses in a visual process in specified viewing conditions."

and

"*Psychometric colour terms* **–** terms denoting objective measures of physical variables that are evaluated so as to relate to differences between magnitudes of important attributes of light and colour and such that equal scale intervals represent approximately equal perceived differences in the attribute considered. These measures identify pairs of stimuli that produce equally perceptible differences in response in a visual process in specified viewing conditions."[6]

Psychophysical colour terms regard *Psychophysical colorimetry* and psychometric colour terms regard *Psychometric colorimetry*. Both definitions of *psychophysical* and *psychometric colour* refer to colour stimuli, whose measurement and processing are same as those in the human visual system. The human visual system is a tool that measures the colour stimulus, as a camera, (psychophysics) and processes the signals produced quantifying the colour attributes according to a perceptive scale (psychometrics).

Psychophysical colorimetry is limited to the measurement of colour stimuli, attributing the same specification to different colour stimuli which induce equal colour sensations. This is exactly what happens in a photographic camera.

The human eye, unlike the camera, has a sensor – the retina – that has not the same optical properties in all its parts. The central part, for acute vision, is different from the surrounding parts, for which, according to a simplified diagram, there are two different colorimetries. In 1931 the CIE defined a colorimetry for

Table 1.1 *Scheme of the colour specification according to historical steps, stages of vision, visual fields and referred to the CIE standard systems.*

		Historical steps/stages of vision/systems		
		First stage of vision: transduction	Second stage of vision: colour difference and illuminant discounting	Third stage of vision: colour appearance and adaptation
		Psychophysics (Chapter 9)	Psychometrics (Chapter 11)	Colour appearance
visual field	Visual field < 4°	CIE 1931 standard observer (X, Y, Z), Vos observer 2° CIE fundamental observer	CIELUV system (L^*, u^*, v^*) CIELAB system (L^*, a^*, b^*)	CIECAM97 CIECAM02 Retinex
	10° visual field	CIE 1964 supplementary standard observer (X_{10}, Y_{10}, Z_{10}) 10° CIE fundamental observer	CIELUV system (L^*_{10}, u^*_{10}, v^*_{10}) CIELAB system (L^*_{10}, a^*_{10}, b^*_{10})	

acute vision – observer with a visual field of 2° described in Section 9.2 – and in 1964 a colorimetry for non-acute vision – observer with the field of view of 10° described in Section 9.3 –.

The distinctions between psychophysical and psychometric colorimetries, and between the 2° and 10° visual fields, have led to four different colorimetries, as summarized in Table 1.1.

Over time, the study of colour-vision has led to improving the standard observers by adding new cases within the schema of Table 1.1, that is, Vos and fundamental observers described in Sections 9.5 and 9.6. These improvements are considered so small that the industries and laboratories continue to use the standard CIE 1931 and CIE 1964.

This distinction among different colorimetries corresponds to a distinction among the historical phases of colorimetry[7]:

A first phase concerned with 'which colours match' and is termed *psychophysical* in strict sense (Chapter 9) and also *classical colorimetry* or *tristimulus colorimetry*.

A second phase concerned with 'whether colour differences are equal' and is termed *psychometric* (Chapter 11).

A third phase concerned with 'what colours look like' and is termed "*colour appearance*:

i. aspect of visual perception by which things are recognized and
ii. in psychophysical studies, visual perception in which the spectral and geometric aspects of a visual stimulus are integrated with its illuminating and viewing environment."[1]

The third phase of colour-appearance colorimetry is in rapid progress and is a subject of debate; therefore, it is not considered in this book.

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