GOVERNMENT GAZETTE

OF THE

REPUBLIC OF NAMIBIA

R6,40 WINDHOEK — 1 September 1990 No. 68

CONTENTS

Government Notice

DEPARTMENT OF WORKS, TRANSPORT AND COMMUNICATION

No. 47 1990

AMENDMENT OF ROAD TRAFFIC REGULATIONS

The President has under section 165 of the Road Traffic Ordinance, 1967 (Ordinance 30 of 1967), further amended the regulations promulgated under Government Notice 95 of 1967, as set out in the Schedule.

SCHEDULE

1. The following regulation is hereby substituted for regulation 2:

"2. Subject to the provisions of regulations 3 and 5, the registration mark of a motor vehicle shall be displayed on a plate which complies with the Standard Specification for Retro-Reflective Registration Plates for Motor Vehicles as set out in Schedule 4 to these Regulations, and which is hereinafter referred to as a registration plate.".

2. Regulation 3 is hereby amended -

(a) by the substitution for subregulation (1) of the following subregulation:

"(1) The colour of a registration plate shall be as follows, namely -

(a) for a motor vehicle owned by a member, agent or officer of or a delegate to any public international organization or institution and registered as being entitled to diplomatic immunity as contemplated in section 33 of the Ordinance, all letters and figures shall be black and the remainder of the registration plate shall be in a reflective white colour;

(b) for a motor vehicle owned by a person (other than a person referred to in paragraph (a)) registered as being entitled to diplomatic immunity as contemplated in section 33 of the Ordinance, all letters and figures shall be white and the remainder of the registration plate shall be in a reflective red colour;

(c) for a motor vehicle of which any department of state of the Republic of Namibia is the owner, all letters and figures shall be white and the remainder of the registration plate shall be in a reflective green colour; and

(d) for a motor vehicle not included under paragraphs (a), (b) or (c), all letters and figures shall be black and the remainder of the registration plate shall be in a reflective yellow colour"; and

(b) by the deletion of subregulation (4).

3. Regulation 4 is hereby amended by the deletion of subregulation (1).

4. The following regulation is hereby substituted for regulation 4A:

"4A. Notwithstanding anything to the contrary contained in these regulations -

(a) the registration mark of a motor vehicle may -

(i) with effect from 1 January 1991; and

(ii) in the case of a motor vehicle which is registered on or after 1 September 1990, with effect from that date; and

(b) such registration mark shall with effect from 7 March 1992,

be displayed on a registration plate in a manner which complies with the said Standard Specification for Retro-Reflective Registration Plates for Motor Vehicles as set out in Schedule 4 to these Regulations.".

5. Regulation 5 is hereby amended by the substitution for subregulation (1) of the following subregulation:

"(1) In the case of a registration plate not used under the authority of a motor vehicle dealer's licence, the letters and figures shall be arranged either -

(a) in the case of a motor vehicle referred to in paragraph (a) of regulation 3(1), with all letters and figures in one line in which event such letters shall precede such figures;

(b) in the case of a motor vehicle referred to in paragraph (b) of the said regulation 3(1), with figures preceding letters in one line and figures preceding a letter in one line immediately below;

(c) in the case of a motor vehicle referred to in paragraph (c) of the said regulation 3(1) -

(i) with all letters and figures in one line in which event such letters shall precede and follow such figures; or

(ii) with letters in one line, figures in one line immediately below and letters in one line immediately below such figures; or

(d) in the case of a motor vehicle referred to in paragraph (d) of the said regulation 3(1) -

(i) with all letters and figures in one line in which event such letters shall precede and follow such figures; or

(ii) with a letter in one line, the figures in one line immediately below and the letters in one line immediately below such figures.".

6. The following Schedule is hereby added to the Regulations:

"SCHEDULE 4"

SCHEDULE 4

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

CONTENTS

PART I

3

STANDARD SPECIFICATION

for

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART I : BLANKS

1. SCOPE

1.1 This part of the specification covers requirements for two types of blanks intended for use in the production of embossed registration plates covered by Part II of the specification.

Note: (a) The standard referred to in this part of the specification is noted in Part V and VI.

(b) Except under the standardization mark scheme, special agreement between the manufacturer and the purchaser is required for assessment of compliance with the requirements of the specification of those blanks on which the retro-reflective material is applied during the process of embossing the registration number.

2. DEFINITIONS

2.1 For the purposes of this part of the specification the following definitions shall apply:

Blank

A flat metal plate having on one side an embossed border and at least the area within this border covered with retro-reflective material, the material being supplied as a loose sheet if it is intended to be subsequently applied as part of the embossing process of the registration number.

Chromaticity

Chromaticity as defined by the International Commission on Illumination (CIE) in Part V.

Defective

A blank that fails in one or more respects to comply with the appropriate requirements of this part of the specification.

Embossing

A process by which a raised border is moulded onto a plate (to form a blank) or by which characters are so moulded onto a blank that they stand out in relief on the retro-reflective surface of a registration plate.

Illuminants A and D65

Illuminants A and D65 as defined by the International Commission on Illumination (CIE) in Part V.

Lot

Not less than 500 and not more than 10 000 blanks of the same materials, made by one manufacturer, and submitted at any one time for inspection and testing.

Luminance factor

(at a point on the surface of a non-selfradiating body, in a given direction, and under specific conditions of illumination). The ratio of the luminance of the material to that of a perfect reflecting diffuser identically illuminated.

Registration mark or registration number

A combination of letters and numerals as prescribed by the relevant Road Traffic Ordinance.

Registration plate (Plate)

A plate displaying the registration mark of a motor vehicle or trailer (see Fig. 1 and 4 in Part II of the specification).

Retro-reflection

Reflection in which light is reflected in directions close to the direction of incidence irrespective of the angle of incidence at the reflecting surface.

3. REQUIREMENTS

3.1 TYPE.

A blank shall be of one of the following types:

(a) Type A.

A blank

1) the front face of which, other than the embossed border, is covered with retro-reflective material (This material may be supplied as a loose sheet if it is intended to be subsequently applied as part of the embossing process of the registration number.);

2) having a substrate of a black polymer film below the retro-reflective material; and

3) intended for use in an embossing process that obviates the need for painting the raised surfaces of the characters.

(b) Type B

A blank the front face of which is completely covered with retro-reflective material, and intended for use in an embossing process in which the raised surfaces of the characters and the border are painted black.

3.2 MATERIALS

3.2.1 Metal.

The metal base of a blank shall be one of the following materials and shall be suitable for the embossing process:

a) Aluminium sheet of thickness at least 0,9 mm and complying with the appropriate of the following minimum tensile strength requirements:

Blank size, mm	Tensile strenght, min., MPa
440 x 120	95
250 x 205	80

b) Mild steel of thickness at least 0,5 mm.

3.2.2 Retro-reflective Material for colours Yellow and White

3.2.2.1 Colour and luminance factor

a) Colour.

The colour of the retro-reflective material shall be yellow or white and when the colour is tested in accordance with 6.8 (with Illuminant D65), the chromaticity co-ordinates shall be within the area on a chromaticity diagram defined by the points having the appropriate values given in Table 1.

b) Luminance factor

When the luminance factor of the material is determined in accordance with 6.8, it shall be not less than the appropriate value given in Table 1.

TABLE 1 - CHROMATICITY CO-ORDINATES AND LUMINANCE FACTORS

1	2	3	4	5	6	7
		Value of co-ordinate				
Colour	Co-ordinate	1	2	3	4	Luminance factor, min.
Yellow	x	0,545	0,487	0,427	0,465	
	y	0,454	0,423	0,483	0,534	0,27
White	x	0,355	0,305	0,285	0,335	
	y	0,355	0,305	0,325	0,375	0,35

3.2.2.2 Coefficients of retro-reflection

When the coefficients of retro-reflection of the material are determined in accordance with 6.9, they shall be not less than the relevant given values in Table 2.

TABLE 2 - COEFFICIENTS OF RETRO-REFLECTION

1	2	3	4
Observation angle, degrees	Entrance angle, degrees	Coefficient of retro-reflection when measured with Standard Illuminant A. cd/(lx.m²), min.	
		Yellow	White
*0,33	*5	35	50
2	30	1,5	2,5

*The coefficient of retro-reflection at angles of observation and entrance of 0,33° and 5° respectively, shall not exceed 100 cd/(lx.m²) for yellow material and 160 cd/(lx.m²) for white material.

3.2.2.3 Flexibility

After a piece of retro-reflective material, complete with protective lining for the adhesive backing, of size 200 mm x 100 mm has been conditioned for 4 h at 25 ± 2° C and then wrapped, reflecting surface outwards, lengthwise around a mandrel of diameter 20 mm and length at least 250 mm (i.e. the retro-reflective material has been wrapped with its longer axis parallel to that of the mandrel), there shall be no evidence of cracking of the retro-reflective material.

3.2.3. Colour and Luminance Factor for colours Red, Green and Blue

NOTE: For the purposes of this specification, one type of daylight surface colours are specified, i.e. retro-reflective colours.

a) When the chromaticity co-ordinates of a new specimen are measured in accordance with 3.2.3.2 , they shall be within the relevant region on the chromaticity diagram (see Fig. 1), appropriate to the type of colour.

NOTE

1) The chromaticity co-ordinates of the corners (points of intersection) of the regions on the diagram (see Fig. 1) for new specimens are given in Table 4.

Red - Signal red A11
Green - Flag green E08
Blue - National Flag blue F04

b) After the specimen has been weathered in accordance with 3.2.3.4 and 3.2.3.5 , the chromaticity co-ordinates shall be within the relevant region on the chromaticity diagram (see Fig. 1).

TABLE 3 COEFFICIENTS OF RETRO-REFLECTION

1	2	3	4	5	6
Class	Observation angle, degrees	Entrance angle, degrees	Coefficient of retro-reflection for different colours of material, when measured with Standard Illuminant A * , $cd/lx.m^2$, min		
			Red	Green	Blue
I	0,33	5	10	7	3
	2	30	0,4	0,3	0,1
II	0,33	5	20	14	6
	2	30	0,4	0,3	0,1
III	0,33	5	30	21	9
	2	30	0,4	0,3	0,1

3.2.3.1 TEST FOR COEFFICIENT OF RETRO-REFLECTION TABLE 3.

Determine the coefficients of retro-reflection of a specimen in accordance with Part VI. On each specimen, take the average of two readings at rotation angles (about the reference axis) that are 90° apart, and check for compliance.

3.2.3.2 COLOUR AND LUMINANCE FACTOR TEST.

Use a spectrophotometer or other equally suitable colour measuring device to determine the chromaticity co-ordinates and luminance factor of the specimen in accordance with Part V and VI, using Standard Illuminant D65 and 45/O geometry.

3.2.3.3 SPECULAR GLOSS TEST.

Measure the gloss of a specimen in accordance with an acceptable international method.

3.2.3.4 ACCELERATED NATURAL WEATHERING TEST

NOTE: Signs intended for use in coastal areas shall be tested in Swakopmund and signs intended for use inland shall be tested in Windhoek.

So mount the specimen that it faces northwards with the inclination to the horizontal as given below:

Windhoek Swakopmund

Protect the edges and corners of the test specimen with a coat of spar varnish (or other suitable material) and subject the test specimen to unprotected outdoor exposure for the appropriate period of 1800 h.

After every 6 months, rinse the specimen with water, wash it with a neutral detergent solution, using a soft bristle brush or a sponge to avoid scratching and give it a final rinse with de-ionized water. Examine the specimen and then repeat the tests given in 3.2.3.1, 3.2.3.2 and 3.2.3.3 and check for defects.

3.2.3.5 ARTIFICIAL WEATHERING TEST.

Protect the edges and corners of the test specimen with a coat of spar varnish (or other suitable material) and subject the test specimen to artificial weathering for the appropriate period of 1800 h. Examine the specimen and then repeat the tests given in 3.2.3.1, 3.2.3.2 and 3.2.3.3 and check for compliance with relevant requirements.

3.2.3.6 SALT FOG TEST.

On a coated specimen enscribe a mark of length about 70 mm through the coating to the substrate. Using international acceptable apparatus, salt solution, test conditions and procedures, subject the specimens (including steel fasteners) to the test for a period of 240 h.

TABLE 4 - CHROMATICITY CO-ORDINATES FOR DAYLIGHT COLOURS OF NEW SPECIMENS

1	2	3	4	5	6	7
Colour	Type*	Chromaticity co-ordinates of the corners of the region on the chromaticity diagram (illuminant D65, 45/0 geometry)				
		Co-ordinate	1	2	3	4
Red		x	0,690	0,640	0,606	0,655
		y	0,310	0,312	0,342	0,345
Green		x	0,170	0,110	0,110	0,170
		y	0,415	0,415	0,500	0,500
Blue		x	0,160	0,130	0,130	0,160
		y	0,086	0,086	0,140	0,140
White		x	0,335	0,305	0,295	0,325
		y	0,345	0,315	0,325	0,355

NOTE: The chromaticity co-ordinates of the corners (points of intersection) of the regions on the diagram for weathered specimens are given in Table 5.

c) When the luminance factor of a new and a weathered specimen is measured in accordance with 3.2.3.2, it shall be at least the relevant value given in Table 6, appropriate to the type of colour and class of the retro-reflective material.

TABLE 5 - CHROMATICITY CO-ORDINATES FOR DAYLIGHT COLOURS OF WEATHERED SPECIMENS

1	2	3	4	5	6	7
Colour	Type*	Chromaticity co-ordinates of the corners of the region on the chromaticity diagram (Illuminant D65, 45/0 geometry)				
		Co-ordinate	1	2	3	4
Red		x	0,690	0,595	0,569	0,655
		y	0,310	0,315	0,341	0,345
Green		x	0,300	0,300	0,170	0,026
		y	0,690	0,450	0,364	0,399
Blue		x	0,078	0,196	0,023	0,137
		y	0,171	0,250	0,160	0,038

TABLE 6 - LUMINANCE FACTOR

1	2	3	4	5
Colour	Luminance factor, min.			
	Ordinary	Retro-reflective		
		Class I	Class II	Class III
Red	0,07	0,05	-	-
Green	0,10	0,04	-	-
Blue	0,05	0,01	-	-

15

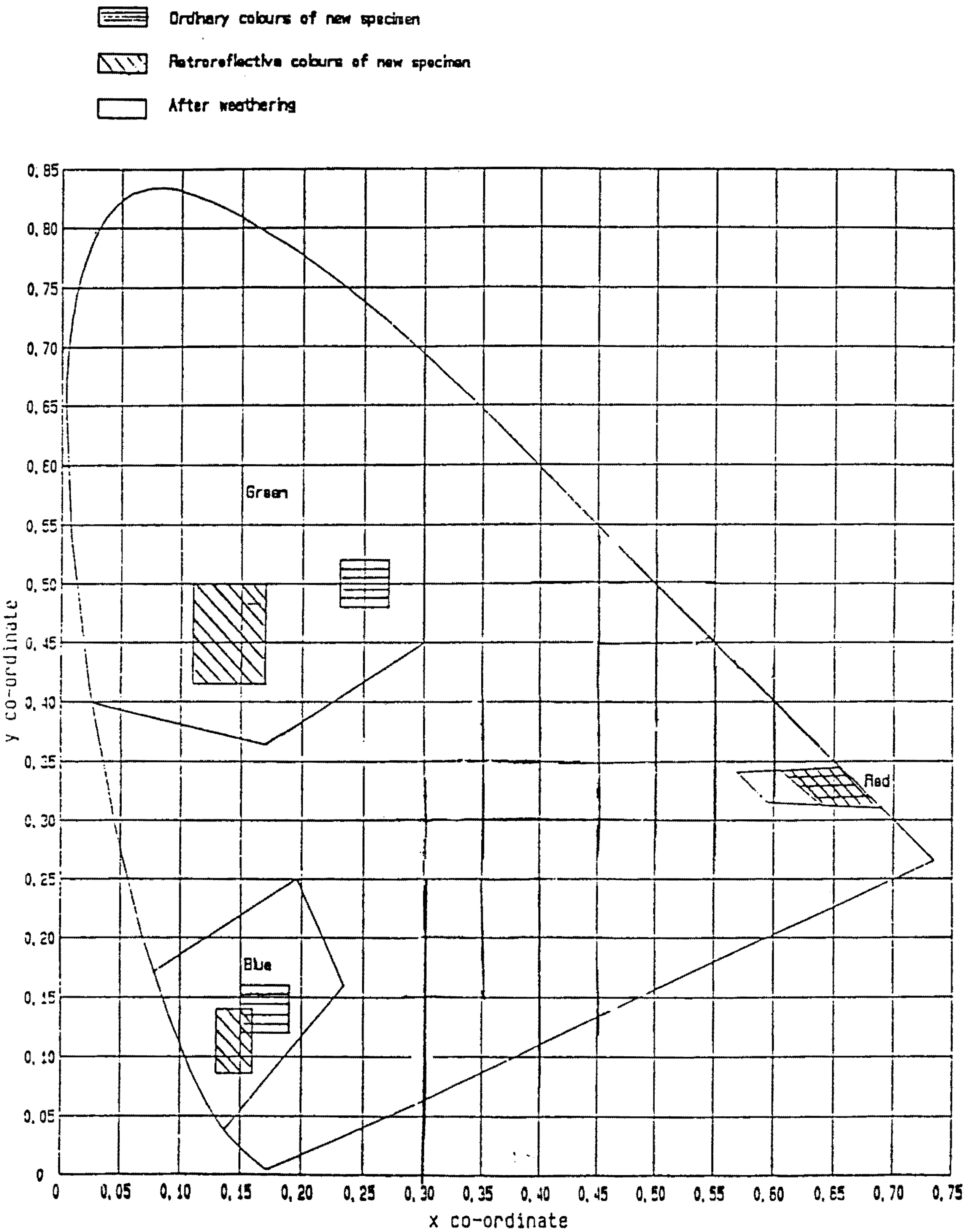


Fig. 1 – Boundaries for daylight surface colours

3.3 SHAPE AND DIMENSIONS

Blanks shall be rectangular in shape and, subject to a tolerance of ± 1 mm on each dimension, shall be of one of the following sizes:

a) 440 mm x 120 mm
b) 250 mm x 205 mm

The corners of each blank shall be rounded to a radius of 15 ± 2 mm.

3.4 PREPARATION

3.4.1 Cleanness

The surface of the metal base to which the retro-reflective material is applied shall be dry and free from grease, oil, corrosion, and any form of contamination before the retro-reflective material is applied (see 3.5) and, when relevant, before it is coated (see 3.4.2 and 3.4.3).

3.4.2 Coating of Aluminium

3.4.2.1 Type A blanks

The front surface of each Type A blank having an aluminium base shall (before the application of the retro-reflective material (see 3.5)) be coated with

a) an epoxy resin primer (having a dry film thickness of at least 5μm) followed by a coat (having a dry film thickness of at least 20μm) of a black polyester resin; or
b) An epoxy resin primer (having a dry film thickness of at least 3μm) followed by a coat (having a dry film

thickness of at least 100μm) of a black polyvinyl chloride plastisol.

3.4.2.2 Type B blanks

The surfaces of each Type B blank having an aluminium base that are coated (before the application of the retro-reflective material (see 3.5)) shall have a coat consisting of

a) a black powder coating that has a dry film thickness of at least 35μm, or

b) a suitable surface-conversion coating followed by a coat (that has a dry film thickness of at least 20μm) of a black baking enamel.

3.4.3 Coating of Steel

3.4.3.1 Type A Blanks

The surfaces of each Type A blank having a steel base shall (before the application of the retro-reflective material (see 3.5)) be coated with zinc applied by a continuous process (the coating having an average mass of at least 185 g/m^2 for both sides, a single spot measurement of at least 152 g/m^2, and a percentage of zinc, on any one side of the blank, of at least 40% of the total) followed by a suitable chemical preparation of the zinc surface on the front face.

The front face of each Type A steel blank shall, after the application of the zinc coat, be coated with the coating given in 3.4.2.1(a) or (b).

3.4.3.2 Type B blanks

The surfaces of each Type B blank having a steel base shall (before the application of the retro-reflective material (see 3.5)) be

a) coated by the application of

1) a coat (having a dry film thickness of at least 25μm) of a medium oil-based or semi-drying oil-based zinc chromate primer (having a pigment volume concentration of 35-40% and containing at least 300 g/kg of zinc chromate in the pigment), followed by a coat (having a dry film thickness of at least 25μm) of a black baking enamel; or

2) a black powder coating that has a dry film thickness of at least 35μm; or

3) a coat (having a dry film thickness of 2 - 3μm) of a water-based composition of chromium compounds in solution, the composition containing sufficient metallic zinc in suspension to give a surface density in the dry coating of at least 3,5 g/m^2, followed by a coat (having a dry film thickness of at least 13μm) of a solvent-based coating, containing sufficient metallic zinc dispersed in an epoxy resin to give a surface density of zinc in the dry coating of at least 55 g/m^2; or

b) subjected to an iron phosphate surface conversion process that produces a coating mass of at least 430 mg/m^2, and then be so coated with an anti-corrision epoxy resin baking primer followed by a black baking enamel as to produce a paint coating that has a total dry film thickness of at least 24μm; or

c) coated with zinc applied by a continuous process (the coating having an average mass of at least 185 gm/m^2 for both sides, a single spot measurement of at least 152 g/m^2, and a percentage of zinc, on any one side of the blank, of at least 40% of the total) followed by a suitable chemical preparation of the zinc surface.

3.5 APPLICATION OF RETRO-REFLECTIVE MATERIAL

Blanks other than those on which the retro-reflective material is intended to be applied during the process of embossing the registration number shall have the material applied to the front surface. In all cases the retro-reflective material shall be of such a size that

a) in the case of a Type A blank, the area inside the embossed border (see 3.6) is covered with retro-reflective material; or

b) in the case of a Type B blank, the retro-reflective material so covers the whole of the surface of the blank that at no part is the width of the retro-reflective material less than the width of the blank by more than 2 mm, and at no part is the distance between the edges of the retro-reflective material and the adjacent edges of the blank more than 1.3 mm.

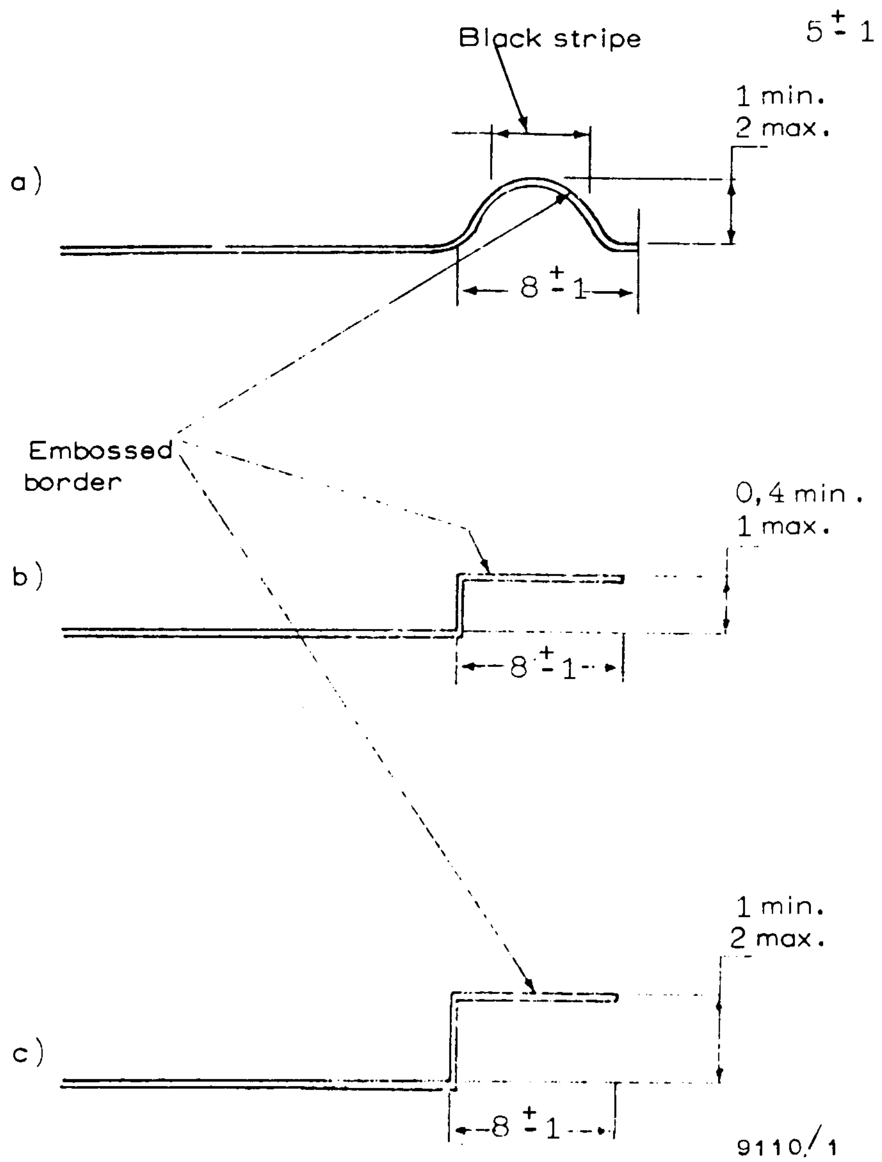
3.6 EMBOSSED BORDER

The embossed border of a blank shall be of curved or flat cross-section, generally as given in Fig 2. The embossing shall extend around the periphery of the blank and shall have an overall width of 8 ± 1 mm and a height above the surface of the blank of,

a) in the case of a Type A blank, not less than 0,4 mm and not more than 1 mm provided that in the case of a Type A blank where the application of the retro-reflective material is part of the embossing process of the registration number, the embossing height of the border shall be not less than 1 mm and not more than 2 mm; or

b) in the case of a Type B blank, not less than 1 mm and not more than 2 mm.

The front face of the embossed border of a Type A blank shall be matt black and the edges of the black area shall be straight and sharply defined. Subject to a tolerance of ± 1,3 mm over the length of a blank, the border shall be parallel to the edges of the plate.



Dimensions in millimetres

Fig. 2 - Typical Embossed Borders

3.7 WORKMANSHIP

Blanks shall be free from creases, crevices, and sharp or jagged edges, and retro-reflective and coated surfaces shall be free from creases, cracks, chips, blisters, discoloration, and spots.

3.8 PERFORMANCE

3.8.1 Resistance to Weathering

When blanks are tested in accordance with 6.3,

a) the chromaticity co-ordinates shall still be within the area of the appropriate chromaticity diagram as defined in 3.2.2.1 and 3.2.3;

b) The coefficient of retro-reflection at angles of observation and entrance of 0,33° and 5° respectively, shall be at least 80% of the minimum values given in Table 2 and 3;

c) the retro-reflective material shall show no sign of cracking, blistering, or loss of adhesion; and

d) when relevant, the painted or powder-coated surface shall show no sign of chalking or checking.

3.8.2 Resistance to Impact

When blanks are tested in accordance with 6.4, the retro-reflective material and (when relevant) the painted or powder-coated surface shall show no loss of adhesion and no evidence of cracking.

3.8.3 Resistance to Scratching

When blanks are tested in accordance with 6.5, the scratch produced

a) on the retro-reflective material shall not have penetrated through the retro-reflective material; and

b) (when relevant) on the painted or powder-coated surface shall be free from jagged edges and shall not have penetrated through to the substrate.

3.8.4 Resistance to Salt Fog

When blanks are tested in accordance with 6.6, no surface shall show any sign of corrosion and the retro-reflective material and any painted or powder-coated surface shall show no sign of blistering, delamination, edge lifting, or loss of adhesion except that, in the case of a painted or powder-coated surface, any blister or creep (or both) or corrosion shall not extend further than 2 mm on each side of the scribe mark.

3.8.5 Resistance to Bending

When blanks are tested in accordance with 6.7, there shall, after each bending operation, be no sign of cracking of the metal, or of cracking or loss of adhesion of the retro-reflective material or (when relevant) the paint or powder coating.

4. PACKING AND MARKING

4.1 PACKING

The blanks and, when relevant, the retro-reflective material shall be so packed as to ensure that they are not damaged during transportation and storage.

4.2 MARKING

Each blank shall bear the manufacturer's trade name or trade mark, given in legible and indelible marking on the surface not covered by the retro-reflective material.

5. SAMPLING AND COMPLIANCE WITH PART I OF THE SPECIFICATION

NOTE : This section applies to the sampling for inspection and testing before acceptance or rejection of single lots (consignments) in cases where no information about the implementation of quality control or testing during manufacture is available to help in assessing the quality of the lot.

5.1 SAMPLING

The following sampling procedure shall be applied in determining whether a lot complies with the appropriate requirements of this part of the specification. The samples so taken shall be deemed to represent the lot.

5.1.1 Sample for Inspection

After checking the lot for compliance with the requirements of 4.1, draw at random from the lot the number of blanks given in Column 2 of Table 7 relative to the appropriate lot size shown in Column 1, ensuring that the sample includes blanks of the different sizes in, as near as practicable, the same proportions as they occur in the lot.

5.1.2 Sample for Testing

After inspection (see 6.1) of the sample taken in accordance with 5.1.1, draw from it at random the appropriate number of test sets given in Column 4 of Table 7.

TABLE 7 - SAMPLE SIZES

1	2	3	4
	Sample for inspection		
Lot size, blanks	Sample size, blanks	Acceptance number	Sample for testing, test sets*
500- 1 200	80	7	5
1 201- 3 200	125	10	8
3 201-10 000	200	14	13

*A test set consists of two blank.

5.2 COMPLIANCE WITH PART I OF THE SPECIFICATION

The lot shall be deemed to comply with the requirements of this part of the specification if

a) on inspection of the sample taken in accordance with 5.1.1, the number of defectives found does not exceed the appropriate acceptance number given in Column 3 of Table 7; and

b) on testing of the sample taken in accordance with 5.1.2, no defective is found.

6. INSPECTION AND METHODS OF TEST

Note : In the case of blanks where the retro-reflective material is intended to be applied as part of the embossing process of the registration number, inspections and tests shall be carried out on test specimens on which the retro-reflective material has been permanently applied using the registration number embossing process but no number having been embossed.

6.1 INSPECTION

Visually examine and measure each blank in the sample taken in accordance with 5.1.1, for compliance with all the appropriate requirements of the specification compliance with which is not assessed by the tests given in 6.3 - 6.9 (inclusive).

6.2 TEST SPECIMENS

From each test set taken in accordance with 5.1.2, cut the following test specimens:

a) <u>Resistance to weathering</u>

One test specimen of width at least 70 mm and of length at least 150 mm, having not more than one cut edge.

b) <u>Resistance to impact</u>

A test specimen of any convenient size. The test may be carried out on an end of the specimen cut in terms of (e) below before it is subjected to bending.

c) <u>Resistance to scratching</u>

A test specimen of width at least 55 mm and of length at least 100 mm.

d) <u>Resistance to salt fog</u>

One test specimen in the case of a blank without any paint or powder coating on the rear surface and two specimens in other cases, of width at least 100 mm and of length at least 150 mm and having not more than two cut edges.

e) Bending test

One test specimen of width between 100 mm and 120 mm and of length at least 250 mm, and having embossed on it one character of a registration mark complying with the appropriate requirements of Part II of the specification, except that the character, in the case of a Type B blank, shall be unpainted.

6.3 RESISTANCE TO WEATHERING

6.3.1 Apparatus

A weathering unit the essential details of which are as follows:

a) Test chamber

A test chamber constructed of corrosion-resistant materials enclosing eight fluorescent UV lamps, a heated water pan, test specimen racks, and provisions for controlling and recording operating times and temperatures.

b) Lamps

Lamps of Type FS 40 fluorescent UV lamps or equivalent, the spectral energy distribution curve having a maximum at a wavelength of 313 nm with less than 1 % of the peak intensity at 280 nm. The lamps have a length of 1 220 mm and a nominal rating of 40 W when operated from a ballast providing a controlled current of 430 mA at 102 V.

c) Lamp and test specimen arrangement

The lamps are mounted in two banks of four lamps each to provide a uniform distribution of irradiance. The lamps in each bank are mounted parallel on 70 mm centres. The test specimens are mounted in two stationary racks each of height 300 mm and width 1 154 mm, the test surface being in each case parallel to the plane of one bank of lamps and at a distance of 50 mm from the nearest surface of the lamps.

d) Condensation mechanism

Water vapour is generated by the heating of a water pan extending under the entire specimen area and containing a minimum water depth of 25 mm. Specimen racks and the test specimens themselves constitute the side walls of the chamber. The back surface of each specimen is exposed to the cooling effect of the ambient room air. The resulting heat transfer causes water vapour, saturated with air, to condense on the test surface.

The specimens are so arranged that condensate runs off the test surface by gravity and is replaced by fresh condensate in a continuous process. Vents along the bottom of the test chamber are provided to admit ambient air and so prevent oxygen depletion of the condensate.

e) Water supply

The water supply has an automatic control to regulate the level in the water pan. Distilled, de-ionized, or potable tap water may be used.

f) Cycle timer

A continuously operating cycle timer is provided to program the selected cycle of UV radiation periods and condensation periods. An hour meter is provided to record total time of operation and total time of UV exposure.

6.3.2 Temperature Measurement

a) The temperature is measured by means of a dial-type thermometer the bulb of which is inserted in a black aluminium panel of size 75 mm x 100 mm x 2,5 mm. The thermometer is accurate to 1°C through a range of 30 - 80 °C. The indicator dial is located outside the test chamber.

b) The aluminium panel and thermometer bulb are so positioned in the centre of the exposure rack that they are subjected to the same conditions as the specimens.

6.3.3 Temperature Control

a) During UV exposure, the selected equilibruim temperature is maintained within ± 3 °C by the supply of heated air to the test chamber.

b) During condensation exposure, the selected equilibruim temperature is maintained within ± 3° C by the heating of the water in the pan.

c) The UV and condensation temperature controls are independent of each other.

d) Doors are located on the room air side of the specimen rack to act as insulation during the UV exposure and to minimize draughts. The doors do not interfere with the room air cooling of the specimen during the condensation exposure.

6.3.4 Procedure

a) Seal the cut edge of each specimen (see 6.2(a)).

b) Mount the test specimens in the specimen racks with the test surfaces facing the lamps.

c) Select the following cycle conditions:

1) 4 h UV exposure at 60° C.

2) 4 h condensation exposure at 50° C.

d) Except for servicing the apparatus and inspecting the specimens, repeat the cycle continuously for 240 h.

e) At regular intervals during the specified exposure period, examine the specimens under 10% magnification.

f) Check for compliance with 3.8.1.

6.4 RESISTANCE TO IMPACT

6.4.1 Apparatus

a) Striker

A cylindrical piece of steel of length and diameter approximately 230 mm and 25 mm respectively, having a hardened steel ball of diameter 12,7 ± 0,1 mm mounted at its bottom end and having a mass of 900 ± 10 g.

b) Tube

A slotted or split vertical tube graduated in millimetres, of approximately length 500 mm and of diameter large enough to enable the striker to drop freely through it.

c) Base plate

A horizontal steel plate with a hole of diameter 16 mm, the plate being so placed that the hole is concentric with and directly below the opening of the tube.

6.4.2 Procedure

a) So place the specimen (see 6.2(b)) on the base plate that an impact will be made at any point on the retro-reflective surface.

b) Raise the striker to the appropriate height and allow it to fall with an energy of 2,25 J in the case of steel blanks, and 1,15 J in the case of aluminium blanks.

c) When relevant, repeat (a) and (b) but with the point of impact at any point on a painted or powder-coated surface.

d) Using a 10-power lens, examine the dented part(s) of the specimen for compliance with 3.8.2.

6.5 RESISTANCE TO SCRATCHING

6.5.1 Apparatus

a) Needle and arm

A needle with a hardened steel hemispherical point of diameter 1 mm, fixed vertically, point downwards, to the end of a counterpoised horizontal arm. The horizontal arm provides for the loading of masspieces directly above the needle and it may be set in equilibrium on its fulcrum by adjustment of the counter-mass before masspieces are loaded above the needle.

b) Masspieces

A set of forty 50 g masspieces.

c) Base with sliding specimen holder

A sliding specimen holder that moves freely and automatically on its base under the loaded needle (which is perpendicular to the specimen holder).

d) Electric current supply and ammeter

The needle and specimen holder are so connected in series with an ammeter and an electric current supply that, when the coated surface of a specimen is penetrated, the needle makes electrical contact with the underlying metal, and this penetration is indicated by a flow of current through the ammeter.

6.5.2 Procedure

a) Set the horizontal arm in equilibrium. Clamp the specimen (see 6.2(c)) to the specimen holder with the retro-reflective material upwards. Load the needle with masspieces of total mass 2 000 g and lower the needle carefully onto the retro-reflective surface while starting to slide the holder. Alternatively, put the end of the needle on a razor blade on the retro-reflective surface so that the needle can slide off the sharp edge of the blade onto the surface. Slide the holder at a uniform speed of approximately 30 mm/s for a distance of about 90 mm.

b) Use a 10-power lens to examine the edges of the groove.

c) Check for compliance with the relevant requirements of 3.8.3.

d) Repeat (a) to (c) above on two other parts of the retro-reflective surface.

e) When relevant, repeat (a) to (d) above on the painted or powder-coated surface of the specimen.

6.6 RESISTANCE TO SALT FOG

6.6.1 Apparatus

A fog cabinet having the following features:

a) Exposure chamber

A chamber made from, or coated with, a suitable corrosion-resistant material, so constructed that the spray circulates freely and equally about all specimens, and having baffles to prevent the salt fog from striking the specimens directly.

b) Racks for supporting the specimens

Removable racks made from, or coated with, a suitable corrosion-resistant material and so constructed that the specimens are held without touching each other or any other metal and that salt solution will not drip from one specimen onto another.

c) Salt solution reservoir

A reservoir of adequate size and made from, or coated with, a suitable corrosion-resistant material. It is so constructed that there is no recirculation of the salt solution.

d) Atomizing nozzles

Nozzles made from a suitable plastics material and so designed that they will produce a finely divided salt solution fog.

e) Air supply

A compressed air supply for the atomizing nozzles, filtered to remove all impurities. Means are provided to humidify and heat the compressed air as required. The air pressure is constant to within ± 700 Pa and sufficient to produce a finely divided salt solution fog.

f) Heating of chamber and temperature control

The exposure chamber is suitably heated and its temperature is controlled by means of a thermostat.

NOTE : The use of an immersion heater is not permitted.

6.6.2 Salt Solution

The salt solution is made up as follows:

a) Salt

Sodium chloride containing sodium iodide not exceeding 1 g/kg of salt, and total impurities not exceeding 3 g/kg of salt, calculated on the dry basis.

b) Water

Water containing total solids not exceeding 200 mg/kg of water.

c) Preparation

The salt solution is prepared by dissolving 5 ± 0,5 parts by mass of salt in 95 parts by mass of water and filtering the solution.

6.6.3 Conditions of Test

a) Temperature

Maintain the temperature in the exposure zone at 33-36° C.

b) Salt fog

Ensure that the degree of atomization of the salt solution is such that suitable fog collectors placed at any point in the exposure zone will collect, over an average running period of at least 16 h, 65-375 ml of solution per hour per square metre of horizontal collecting area. Ensure that the solution so collected has a pH value of 6,5 -7,2 when measured electrometrically.

6.6.4 Procedure

a) In the case of specimens (see 6.2(d)) that have a paint or powder coating, use a suitable cutting tool and carefully make (with the cutting edge of the cutting tool held at an angle of about 30° to the surface and the plane of the blade perpendicular to that surface) a scribe mark of length about 75 mm, by cutting through the coating to the base.

b) Establish the test conditions in the exposure chamber. Mount the specimens on the supporting racks and insert the racks in the exposure chamber.

c) Close the exposure chamber and operate the cabinet continuously for 240 h.

d) After the test period, remove the specimens and rinse them thoroughly with distilled water. Examine the following for compliance with the applicable requirements of 3.8.4.:

1) When relevant, the paint or powder coating immediately after removal of the specimens from the exposure chamber;

2) the retro-reflective material, after a 24 h recovery period has elapsed.

6.7 BENDING TEST

So place the unlaminated surface of the test specimen (see 6.2(e)) against a mandrel of diameter 50 ± 1 mm that the line of maximum bending coincides with the vertical middle line of the letter or numeral. Taking about 3 s, bend the specimen through an angle of 90 ± 2 ° over the mandrel, and then examine it for compliance with 3.8.5. Immediately following this procedure and taking about 3 s, so bend the specimen back through the same angle that it is approximately in its original alignment and again examine it for compliance with 3.8.5.

6.8 COLOUR AND LUMINANCE FACTOR TEST

Determine the chromaticity co-ordinates and luminance factor of the specimen by means of a spectrophotometer or other equally suitable colour measuring device in accordance with Part V and VI, using Standard Illuminant D65 and 45/0 geometry.

Check for compliance with 3.2.2.1 and 3.2.3.2.

6.9 PHOTOMETRIC TEST

Determine the coefficients of retro-reflection in accordance with Part VI, using the values of both observation angle and entrance angle given in Columns 1 and 2 of Table 2 and 3. On each specimen, take the average of two readings at rotation angles (about the reference axis) that are 90° apart.

37

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART II PLATES

CONTENTS

PART II

STANDARD SPECIFICATION

for

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART II : REGISTRATION PLATES

1. SCOPE

1.1 This part of the specification covers registration plates produced by the embossing of blanks (see Part I of the specification) with a registration mark and intended for use on motor vehicles (including motor cycles and motor tricycles) and trailers.

NOTE : The standard referred to in this part of the specification is noted in Part I.

2. DEFINITIONS

2.1 For the purposes of this part of the specification the definitions, other than the definitions of "Defective" and "Lot", given in Part I of the specification and the following definitions shall apply:

<u>Defective</u>

A registration plate that fails in one or more respects to comply with the appropriate requirements of this part of the specification.

<u>Lot</u>

Not less than 10 and not more than 1 200 registration plates of the same materials, made by one manufacturer, and submitted any one time for inspection and testing.

3. REQUIREMENTS

3.1 REGISTRATION MARK

3.1.1 General

The registration mark on a registration plate shall have been embossed on a blank that complies with the relevant requirements of Part I of the specification, and the registration mark and, when relevant, the border on each plate shall be painted black in accordance with the requirements of 3.1.5. No marking other than the registration mark, the marking required in terms of 4.2, and the border, shall appear on the front surface of a registration plate.

3.1.2 Embossing

The height above the surface of the retro-reflective background of the embossed characters of a registration mark on a plate shall be not less than 0,4 mm and not more than 2 mm.

3.1.3 Form and Dimensions of Characters of Registration Marks

a) The surfaces of the characters (letters and numerals) of a registration mark with

1) not more than seven characters appearing in one line on a plate of size 440 mm x 120 mm (see Fig. 1(a)-(c)), or

2) not more than four characters on the lower line on a plate of size 250 mm x 205 mm (see Fig. 1(d)-(f)), shall, subject to a tolerance of ± 0,5 mm, have shapes and dimensions conforming to those of the appropriate characters given in Fig. 3. (An example of a device used for checking the shapes and dimensions of characters is given in Fig. 2.)

b) The surfaces of the characters of a registration mark with

1) more than seven characters appearing in one line on a plate of size 440 mm x 120 mm (see Fig. 4(a)), and

2) more than four characters on the lower line on a plate of size 250 mm x 205 mm (see Fig. 4(b)), shall have shapes similar to those of the appropriate characters given in Fig. 3 and dimensions and tolerances as follows:

Height of characters....................... 75 ± 1 mm
Width of characters, other than the letters
"I", "M", and "W", and the numeral "1"...... 35 ± 1 mm
Width of letters "M" and "W"................ 40 ± 1 mm
Width of the letter "I" and stroke in cha-
racters.................................... 10 ± 0,5mm
Width of numeral "1"....................... 15 ± 1 mm

3.1.4 Setting out of Characters of Registration Marks

3.1.4.1 All registration marks

The layout of the characters on a registration plate shall be such that the registration mark is symmetrically placed on the plate.

3.1.4.2 Registration marks with not more than seven characters (see Fig. 1)

a) In the case of a plate bearing not more than seven characters, for the purpose of setting out the characters at their correct spacing, each character shall (except where otherwise shown in Fig. 3) be regarded as lying within a frame of height 75 mm (see frame lines "c" and "d") and of width equal to the distance between the frame lines "a" and "b" shall be as shown in Fig. 3. The characters shall be so set out that the frame lines of adjacent characters are coincident (see Fig. 5) except that

1) in the case of a plate having seven characters in one line (see Fig. 1(a) and Fig. 5(a)), the width of each space that separates the frame lines of adjacent letters and numerals shall be at least 5 mm and subject to a tolerance of ± 1 mm, two such spaces shall be of the same width;

2) in the case of a plate having seven characters in two lines (see Fig. 5(c)), the width of the space that separates the frame lines of adjacent numerals and letters in the lower line shall be at least 5 mm;

3) in the case of a plate having less than seven characters in one line (see Fig. 5(b)), the width of the space that separates the frame lines of adjacent letters and numerals shall be not less than 20 mm and not more than 50 mm; and

4) in the case of a plate in which the characters are in two lines (see Fig. 5(c) and 5(d)), the top line shall be separated from the bottom line by a space, between frame lines, of height 10 ± 1 mm.

b) In the case of a plate bearing seven characters, the width of the spaces between the outside edges of the plate and the frame lines of the first and last characters

1) of a plate in which all seven characters are in one line (see Fig. 5(a)), and

2) in the lower line of a plate in which the seven characters are in two lines (see Fig. 5(c)), shall conform to the appropriate value given below, and, subject to a tolerance of ± 1 mm, the two outside spaces shall be of the same width.

Width of space between frame lines of letter(s) and numerals, mm	Width of space at outside edge, mm
5 to less than 15	10 ± 1
15 or more	15 ± 1

3.1.4.3 Registration marks with more than seven characters (see Fig. 4)

In the case of a plate bearing more than seven characters, the characters shall be arranged

a) in one line on a plate of size 440 mm x 120 mm with the letters preceding the numerals (see Fig. 4(a)); and

b) in two lines on a plate of size 250 mm x 205 mm with the letters on the upper line and the numerals on the lower line (see Fig. 4(b)), except in the case of a registration mark having six numerals, when the first two numerals shall be placed on the same line as and to the right of the letters (see Fig. 4(c)).

The characters shall be placed as follows:

Width of space between adjacent letters......10 mm, min.
Width of space between adjacent numerals.....10 mm, min.
Width of space separating adjacent groups of
letters and numerals on a plate bearing a
single row of characters and on a plate

bearing a double row of characters including
six numerals (see Fig. 4(a) and 4(c))........25 mm, min.
Width of spaces between outside edges of
plate and the first and last characters on
a plate bearing a single row of characters
(see Fig. 4(a))..............................20 mm, min.
Width of spaces between outside edges of
plate and the first and last numerals on a
plate bearing a double row of characters
including five numerals (see Fig. 4(b))......15 mm, min.
Width of space between top line and bottom
line on a plate bearing a double row of
characters..................................10 ± 1 mm

In the case of a plate bearing a single row of characters including six numerals there shall be a dash of length at lest 15 mm between the third and fourth numerals (see Fig. 4(a)).

3.1.5 Painted Surfaces of Characters and Borders on Registration Plates

The raised surfaces of the characters and the border of a registration plate manufactured from Type B blanks (see Part I of the specification) shall have been coated by the application of at least one coat of matt black paint that is compatible with the retro-reflective material except that, in the case of a border with curved embossing (see Fig. 1(a) of Part I of the specification), the painted surface shall consist of a black stripe centrally positioned along the border and of width 5 ± 1 mm. The total dry film thickness of the black paint, determined by means of a dry film thickness gauge, which in the case of steel plates is of the magnetic flux type, and in the case of aluminium plates is of the eddy current type, shall be at least 25μm.

3.1.6 Workmanship

The registration mark shall be clearly defined. An embossed plate shall be of such flatness that when it is laid with the registration mark upwards on a truly flat surface, no part of the unembossed portion of the plate shall be more than 3 mm from the surface. The coating on the raised surface of the characters and border shall be free from creases cracks, chips, blisters, discoloration, and spots.

3.2 PERFORMANCE

3.2.1 Resistance to Impact

When a plate is tested in accordance with 6.3, the coating on the raised surface of the character shall show no sign of loss of adhesion to the substrate and no evidence of cracking.

3.2.2 Resistance to Fuel Mixture

When the marking (see 4.2) and the coating on the raised surfaces of the characters and on the border are tested in accordance with 6.4, there shall be no sign of solution or softening of the marking or of the coating.

3.2.3 Resistance to Scratching

When the marking (see 4.2) and the coating on the raised surfaces of the characters and on the border are tested in accordance with 6.5 (after completion of the test given in 6.4), the scratch produced on the coating and on the marking shall not have penetrated through to the substrate.

3.2.4 Resistance to Abrasion

When the coating on the raised surfaces of the characters and on the border is tested in accordance with 6.6, there shall be no sign of penetration through the coating to the substrate.

3.2.5 Resistance to Weathering

When a plate is tested in accordance with 6.7, the coating on the raised surface of the characters and on border shall show no sign of cracking, blistering, or loss of adhesion.

3.2.6 Resistance to Salt Fog

When a plate is tested in accordance with 6.8, the coatings on the raised surface of the characters and on the border shall show no sign of blistering, delamination, or loss of adhesion.

4. PACKING, MARKING, AND LABELLING

4.1 PACKING

The plates shall be so packed as to ensure that they are not damaged during transportation and storage.

4.2 MARKING

The front surface of each plate shall bear, in legible and indelible marking, the embosser's trade name or trade mark in a space of size approximately 5 mm in height and 25 mm in length.

4.3 LABELLING

On the rear surface of at least one plate in each set of plates that bear the same registration mark there shall be a securely attached label that provides at least the following information:

a) A warning that plates should not be fastened by any means that may obscure them or affect their legibility;

b) a warning that fasteners used for attaching the plates to a vehicle should on no account be made of copper, brass, or bronze, or of unprotected mild steel;

c) a warning that a plate should be fitted to the vehicle only where it is fully supported by the bodywork of the vehicle or, by a backing plate of tensile strength at least equal to that of the plate.

5. SAMPLING AND COMPLIANCE WITH PART II OF THE SPECIFICATION

NOTE : This section applies to the sampling for inspection and testing before acceptance or rejection of single lots (consignments) in cases where no information about the implementation of quality control or testing during manufacture is available to help in assessing the quality of the lot.

5.1 SAMPLING

The following sampling procedure shall be applied in determining whether a lot complies with the appropriate requirements of this part of the specification. The samples so taken shall be deemed to represent the lot.

5.1.1 <u>Sample for Inspection</u>

After checking the lot for compliance with the requirements of 4.1, draw at random from the lot the number of registration plates given in Column 2 of Table 1 relative to the appropriate lot size shown in Column 1, ensuring that the sample includes registration plates of the different sizes in, as near as practicable, the same proportions as they occur in the lot.

5.1.2 Samples for Testing

a) After inspection (see 6.1) of the sample taken in accordance with 5.1.1, draw from it, when relevant, at random, the appropriate number of registration plates given in Column 4 of Table 1.

b) From the blanks used in the manufacture of the lot take at random two blanks, including at least one of nominal dimensions 440 mm x 120 mm. In the case of Type A, the two blanks shall have no retro-reflective material applied and, in the case of Type B, the two blanks shall be supplied with enough paint and other material necessary for the preparation of the test specimens given in 6.2.2.

TABLE 1 - SAMPLE SIZES

1	2	3	4
	Sample for inspection		
Lot size, registration plates	Sample size, registration plates	Acceptance number	Sample for testing, registration plates
10 - 15	3	0	2
16 - 25	5	0	2
26 - 50	8	1	3
51 - 90	13	2	3
91 - 150	20	3	3
151 - 280	32	5	5
281 - 500	50	7	5
501 - 1 200	80	10	5

5.2 COMPLIANCE WITH PART II OF THE SPECIFICATION

The lot shall be deemed to comply with the requirements of this part of the specification if

a) on inspection of the sample taken in accordance with 5.1.1, the number of defectives found does not exceed the appropriate acceptance number given in Column 3 of Table 1; and

b) on testing of the sample taken in accordance with 5.1.2, no defective is found.

6. INSPECTION AND METHODS OF TEST

6.1 INSPECTION

Visually examine and measure each plate in the sample taken in accordance with 5.1.1 for compliance with all the appropriate requirements of this part of the specification compliance with which is not assessed by the tests given in 6.3-6.8 (inclusive).

6.2 TEST SPECIMENS

6.2.1 Resistance to Impact, Weathering, and Salt Fog

From each registration plate in the sample taken in accordance with 5.1.2(a), cut the following test specimens:

a) Resistance to impact

A test specimen of any convenient size.

b) Resistance to weathering

One test specimen, of width at least 70 mm and of length at least 150 mm, and containing at least two characters.

c) Resistance to salt fog

One test specimen, of width at least 100 mm and of length at least 150 mm, and containing at least two characters.

6.2.2 Resistance to Fuel Mixture, Scratching, and Abrasion

From the blanks taken in accordance with 5.1.2(b), cut test specimens of the following approximate sizes:

		Length	Width
a)	Resistance to fuel mixture and scratching	100 mm	55 mm
b)	Resistance to abrasion	400 mm	100 mm

On the retro-reflective surface of each specimen from Type B blanks so coat an area of suitable size with the black paint used for coating the raised surfaces of the plates in the lot, that the dry thickness of the coat is at least 25μm.

Using the method and material used by the embosser of the registration mark, apply to an uncoated part of the retro-reflective surface of specimen (a) above the marking as given on the plates in the lot (see 4.2).

6.3 RESISTANCE TO IMPACT

Use the method given in Subsection 6.4 of Part I of the specification to test each specimen (see 6.2.1), but set up the apparatus so that an impact will be made at any point on a character. Check for compliance with 3.2.1.

6.4 RESISTANCE TO FUEL MIXTURE

Apply to approximately 25 cm^{2}of the painted area on the retro-reflective surface or the exposed polymer film (as relevant) of the specimen (see 6.2.2) about 5 ml of a fuel mixture consisting of denatured ethanol (two parts by volume) and benzine (one part by volume), and apply also enough of this mixture to cover the marking on the specimen. In a draught-free area, allow the mixture to evaporate completely and then immediately inspect the treated surface and the marking for compliance with 3.2.2.

6.5 RESISTANCE TO SCRATCHING

Use the method given in Subsection 6.5 of Part I of the specification to test the marking and the surface of the specimen that was used for the test given in 6.4, but use visual means to check for compliance with 3.2.3.

6.6 RESISTANCE TO ABRASION

6.6.1 Apparatus

a) Washability testing apparatus (see Fig. 6) consisting of a brush with stiff black butt-cut Chinese hog bristles securely wired into an aluminium brush block of size approximately 90 mm x 40 mm x 13 mm. There are 60 holes in the block, each about 4 mm in diameter, solidly filled with bristle. The abrading surface of the bristles (which extend 20 mm below the block) is dressed down with sandpaper or, if necessary, levelled on a hotplate so that it is as nearly plane as possible. The brush is held in a metal frame on which masspieces are symmetrically loaded to bring the total mass of the brush assembly to 450 ± 5 g. A suitable driving mechanism is connected to wires fastened to a vertical peg at each end of the frame to enable the brush to be moved back and forth over the specimen under test at a constant speed of 35 - 40 oscillations (70 - 80 strokes) per minute. The length of each stroke is adjusted to approximately 330 mm, and the wires do not exert any vertical force component. The apparatus is mounted on a horizontal table that is provided with means for securing the specimen under test. A supply of cleaning solution is so arranged that it can be allowed to drip onto the specimen and there is suitable means for collecting excess solution and for ensuring that the specimen is at no time completely immersed in the cleaning solution. Replace the brush when the bristles have become so worn that they extend less than 16 mm from the block.

b) Detergent solution

A 0,5% solution in distilled water of a detergent having the following composition:

	% (m/m)
Sodium pyrophospate..................	51
Sodium sulphate, anhydrous...........	16
Sodium alkyl aryl sulphonate.........	23
Sodium metasilicate, soluble.........	8,5
Sodium carbonate.....................	1,5

6.6.2 Procedure

a) Immerse the brush bristles to a depth of about 13 mm in water at 25 - 30° C for 30 min. Shake the brush vigorously to remove excess water and then soak it for 5 min in the specified cleaning solution.

b) Mount the specimen (see 6.2.2) firmly on the washing apparatus, place the wet brush on the test surface so that the 90 mm dimension is in the direction of motion, wet the surface, and start oscillating the brush immediately. During the test, allow additional cleaning solution to drop in the path of the brush in sufficient quantities to keep the test surface wet. Run the apparatus for 10 000 oscillations.

c) Remove the specimen, wash it immediately with water at a moderate temperature, and examine the test surface within the middle 100 mm of the brush path for compliance with 3.2.4.

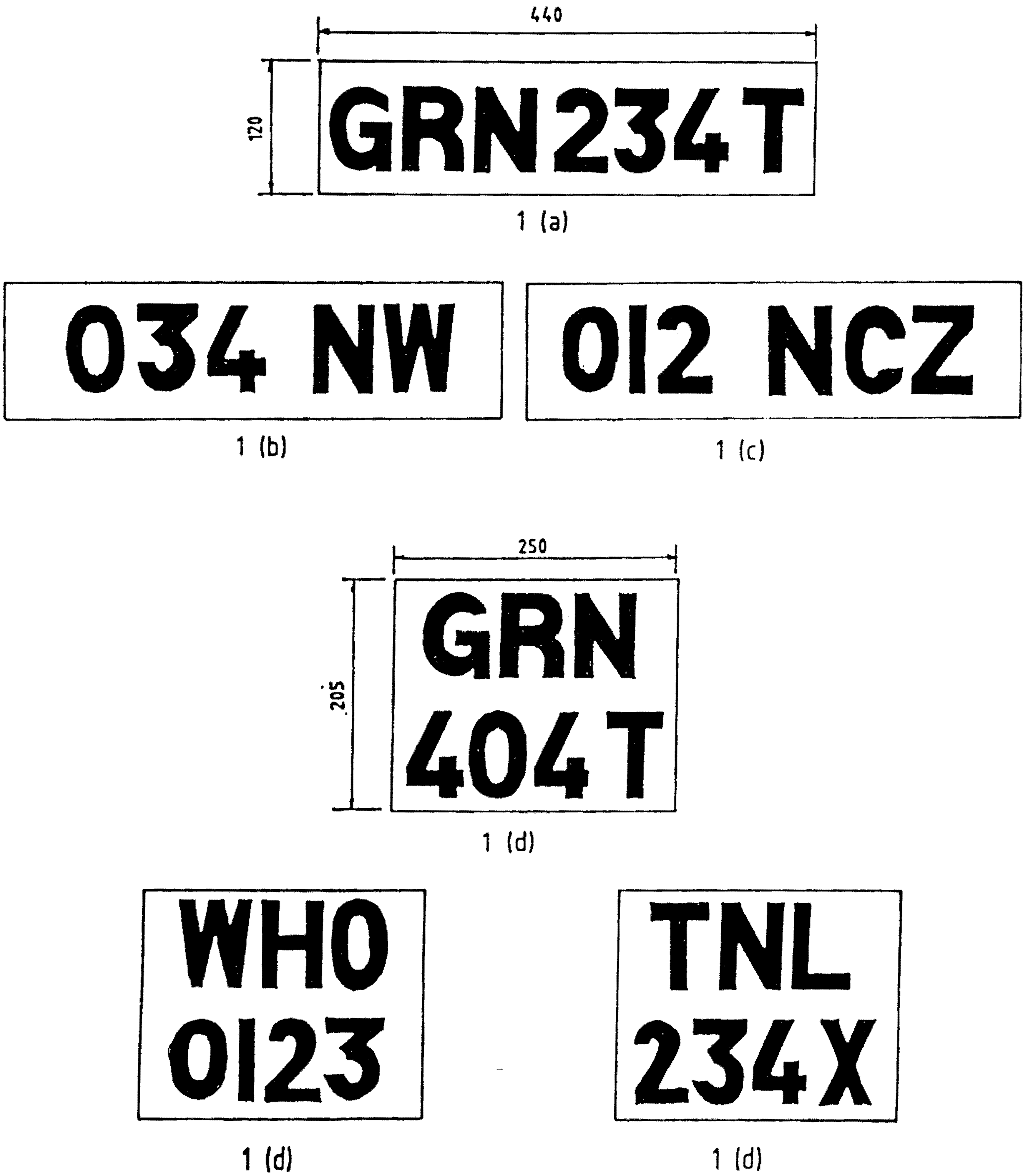
6.7 RESISTANCE TO WEATHERING

Use the method given in Subsection 6.3 of Part I of the specification to test each specimen (see 6.2.1) and check for compliance with 3.2.5.

6.8 RESISTANCE TO SALT FOG

Use the method given in Subsection 6.6 of Part I of the specification to test each specimen (see 6.2.1) and check for compliance with 3.2.6.

54

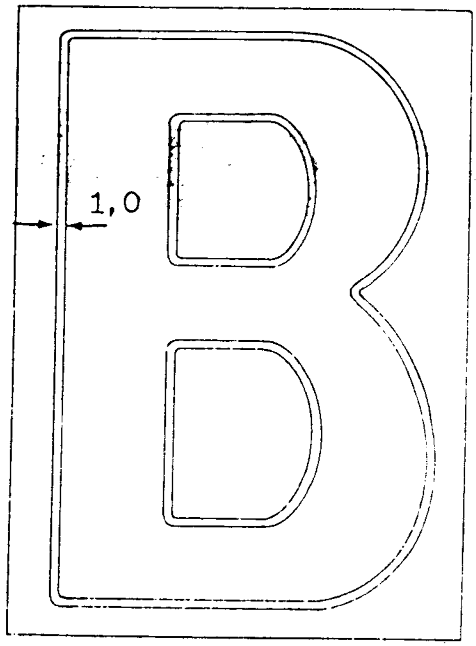


Dimensions in millimetres

7167

FIG. 1 — Examples of Layout of Registration Marks with not more than Seven Characters

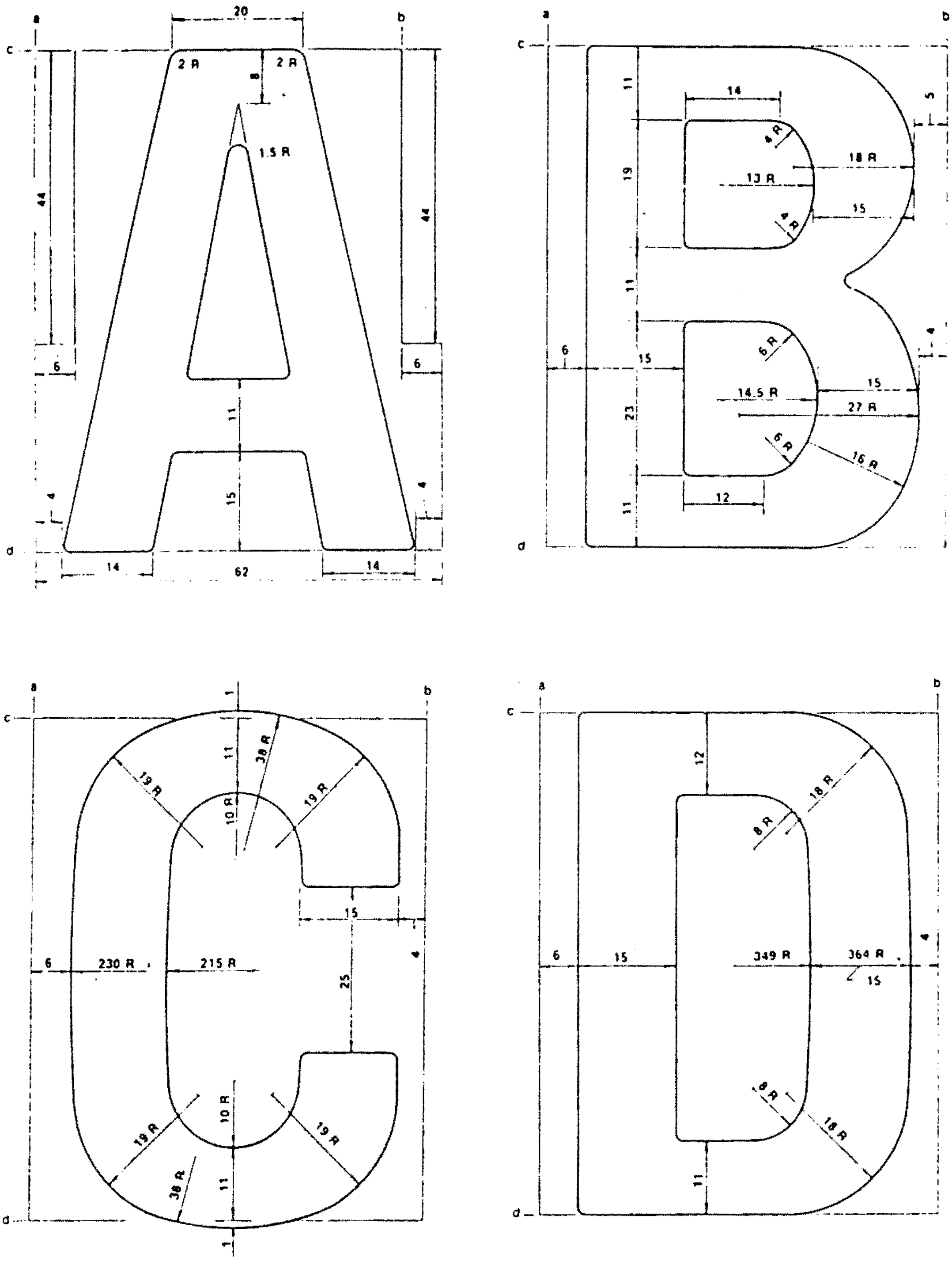
55



NOTE
a) Dimensions in millimetres.
b) The dimensions of the template are such that the outline of the appropriate character should form the median of the double lines of the template.

Fig. 2 - Typical Transparent Template for Checking Characters

56



NOTE
a) Dimensions in millimetres.
b) Dimensions between frame lines for letters and numbers, except where shown, are as follows:
Width (between frame lines "a" and "b"):
Letters: 60 mm
Numbers: 54 mm
Height (between frame lines "c" and "d"): 75 mm
c) All radii, except where shown: 1 mm.

Fig. 3 - Shapes and Sizes of Letters and Numerals

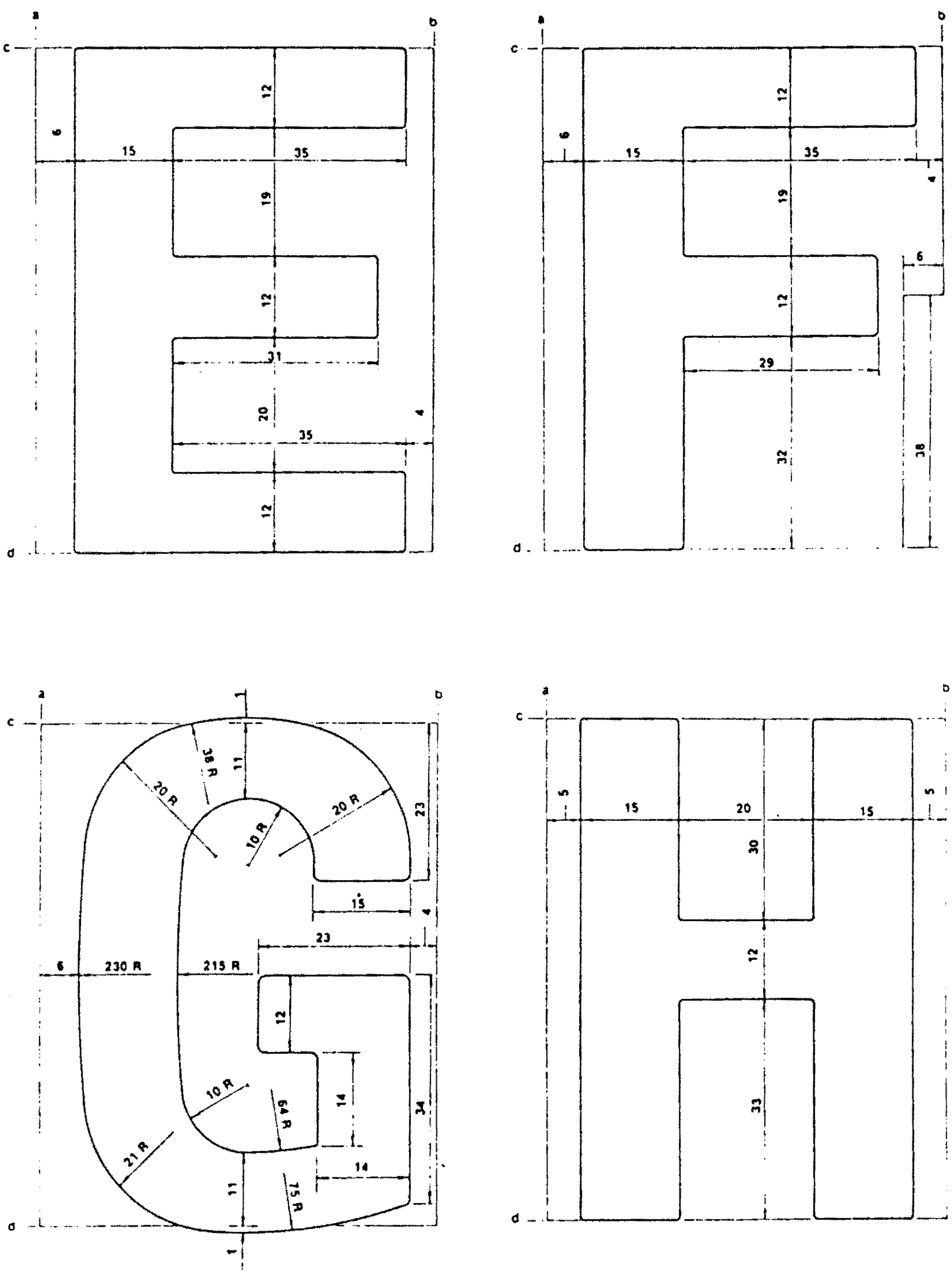


Fig. 3 (continued)

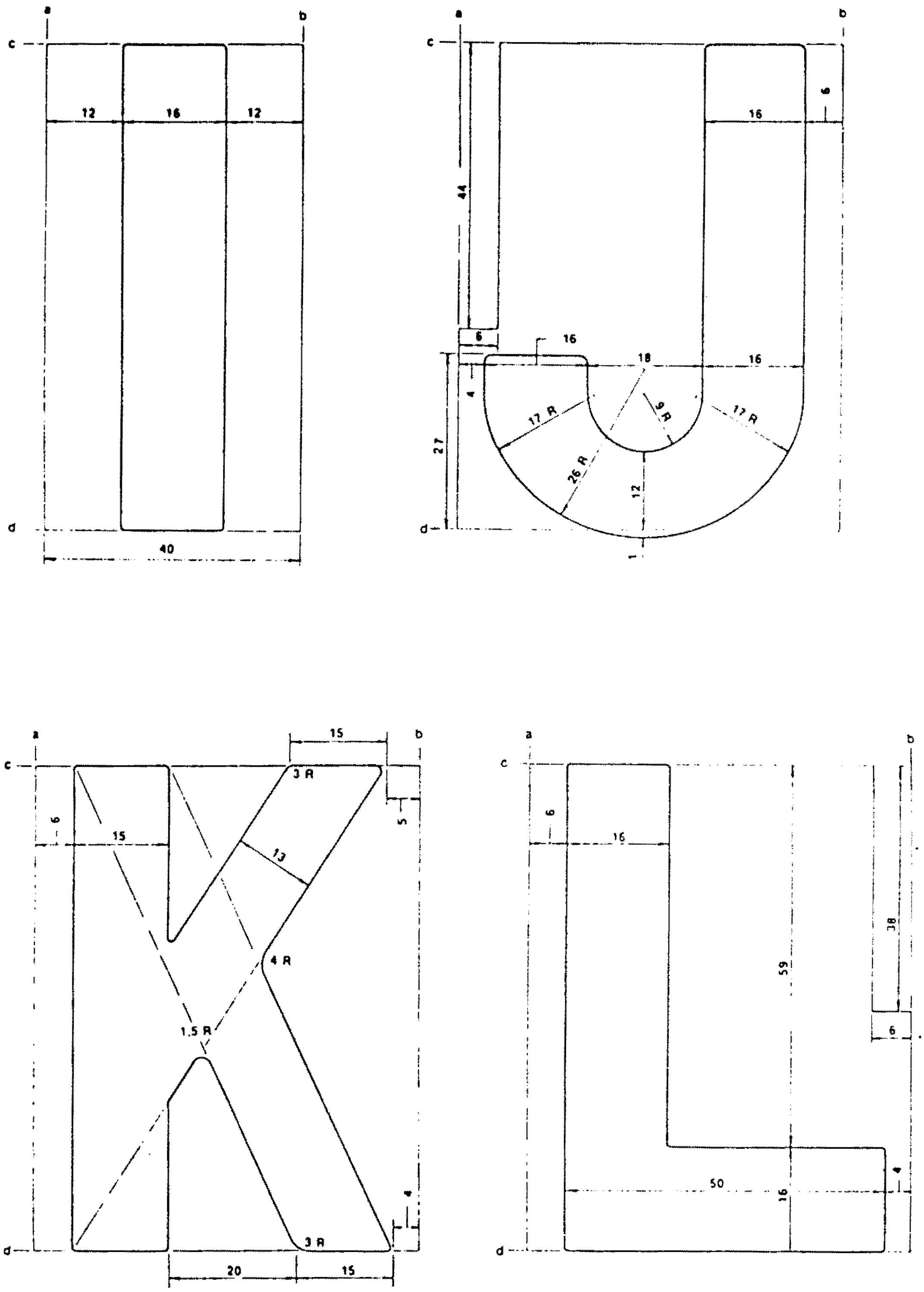
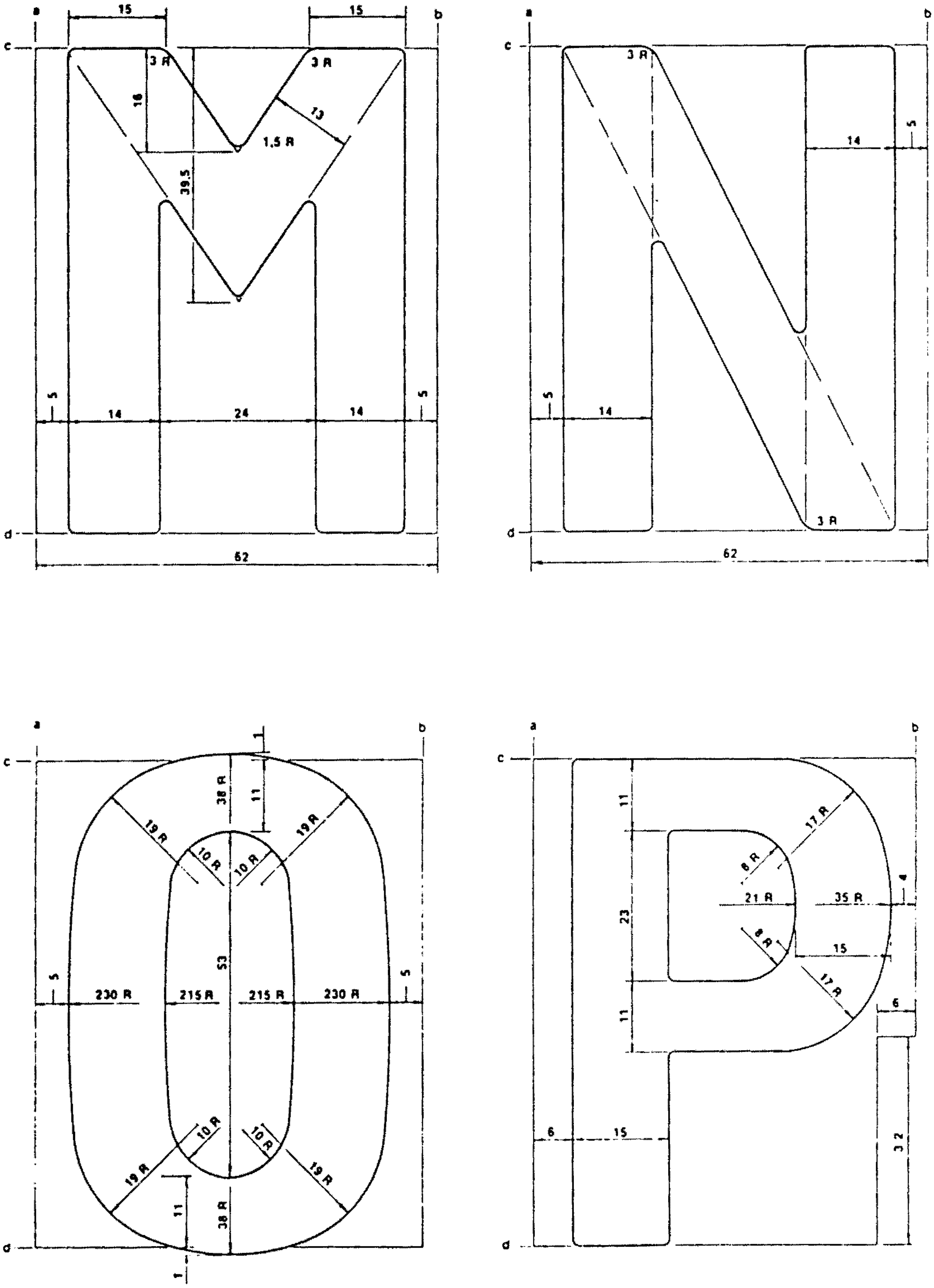


Fig. 3 (continued)

59



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60

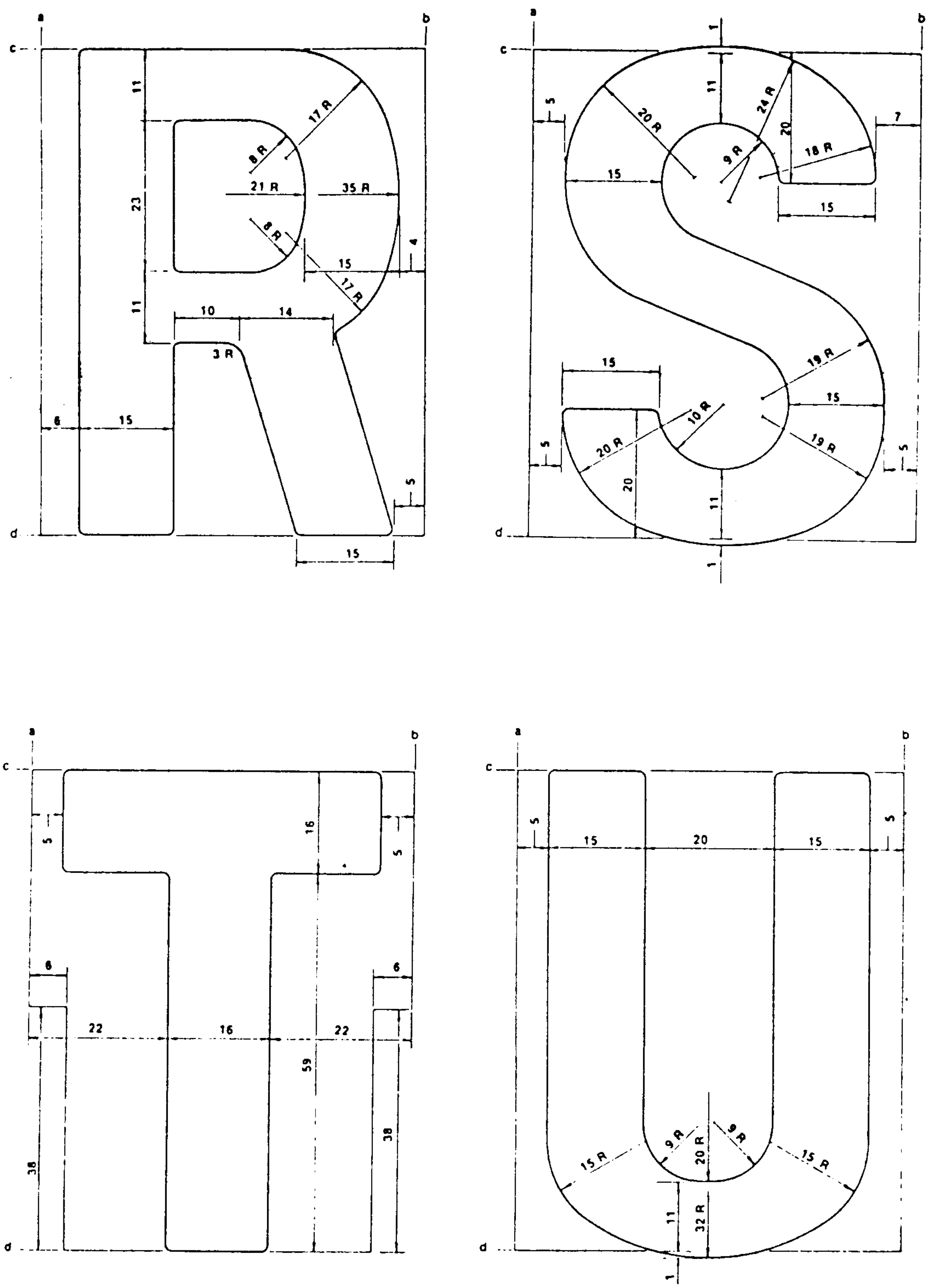


Fig. 3 (continued)

61

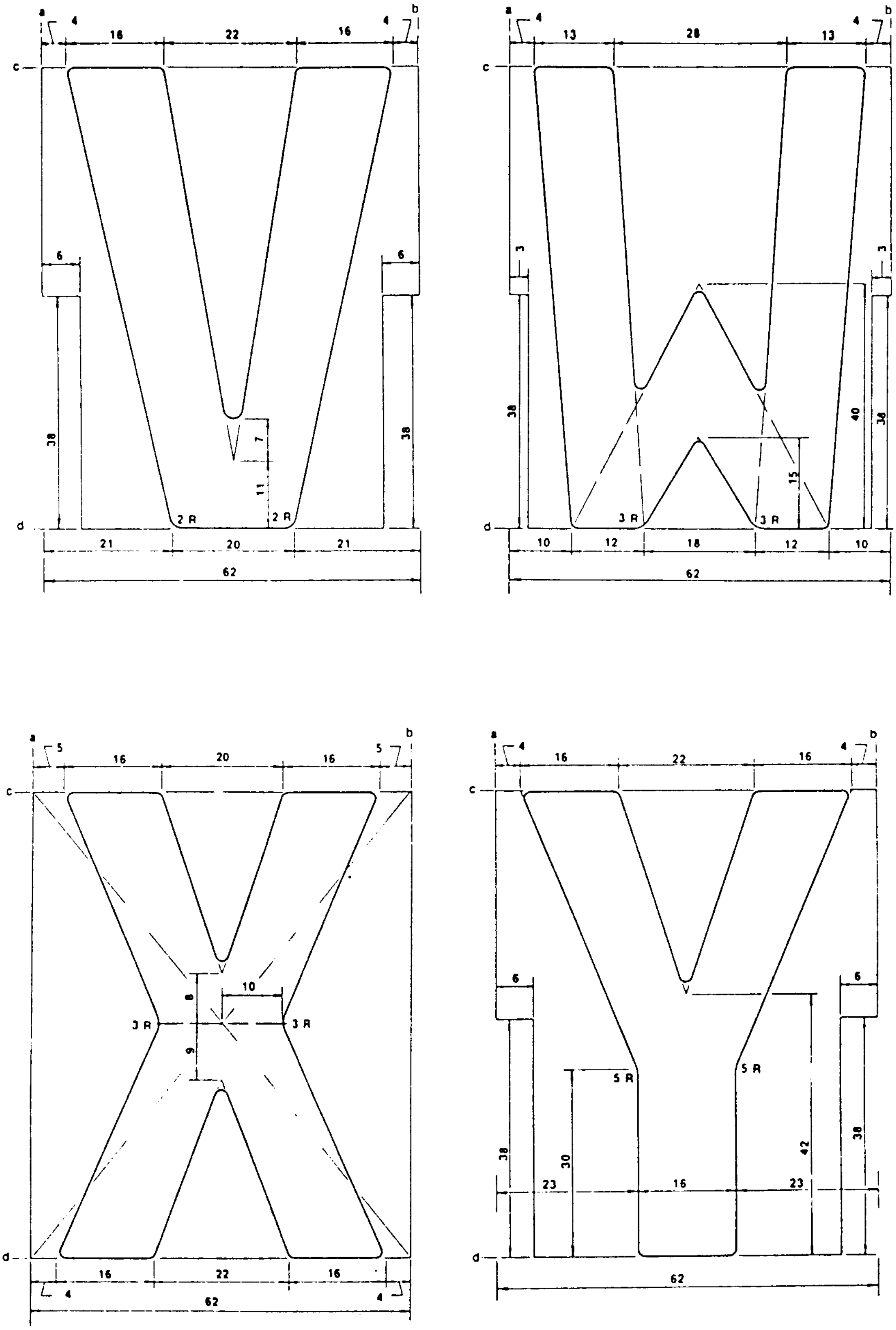


Fig. 3 (continued)

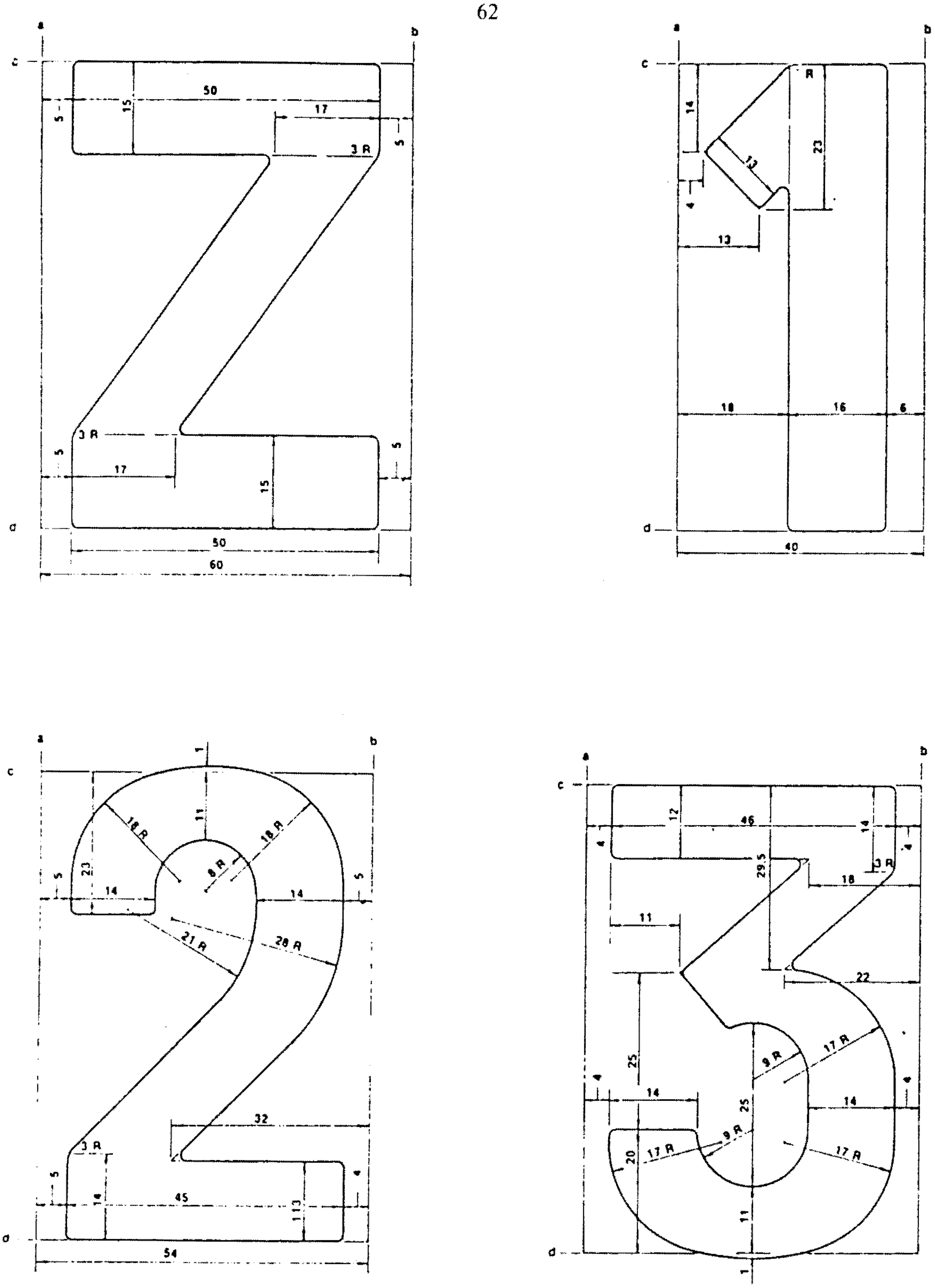


Fig. 3 (continued)

63

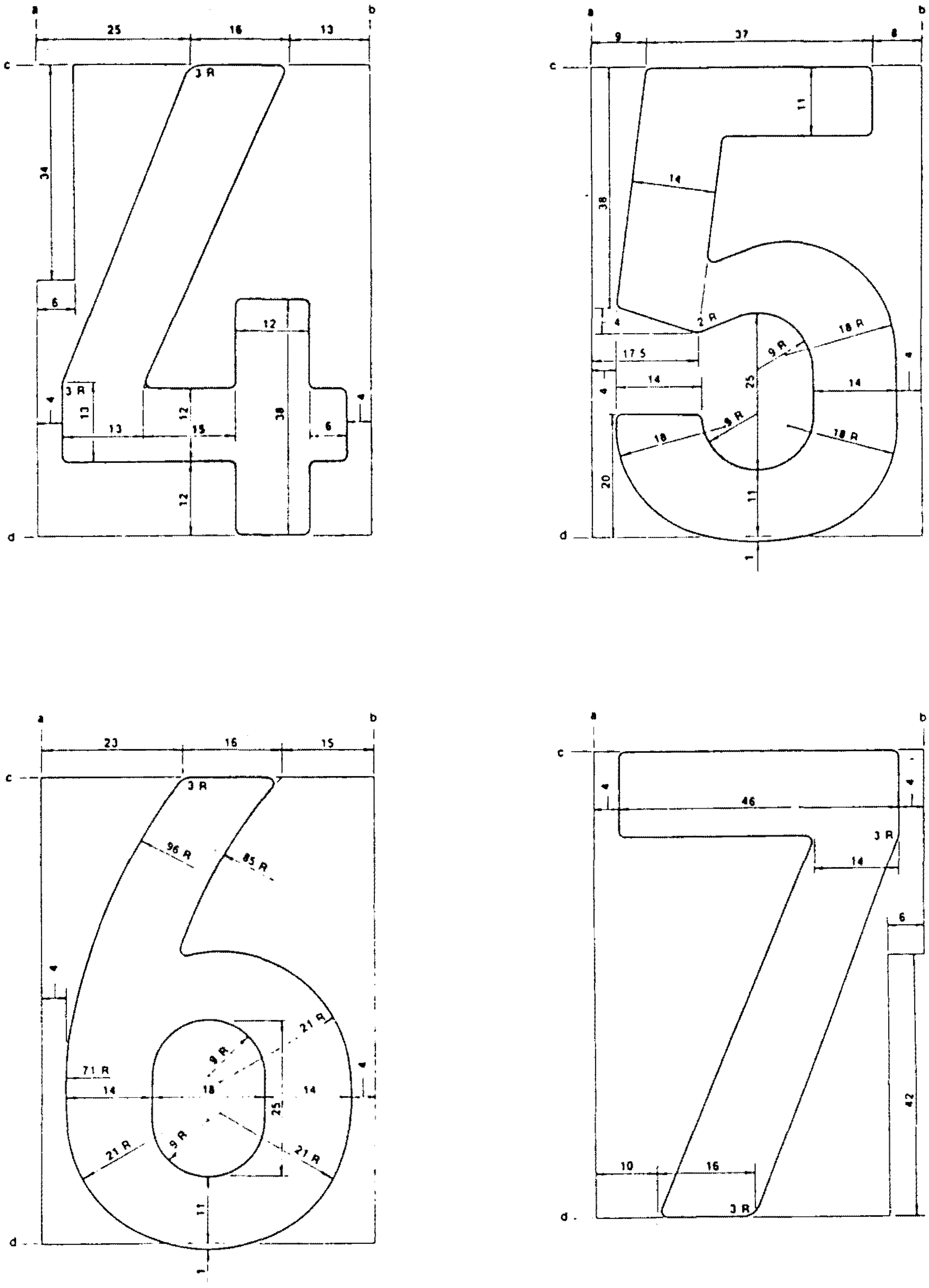


Fig. 3 (continued)

64

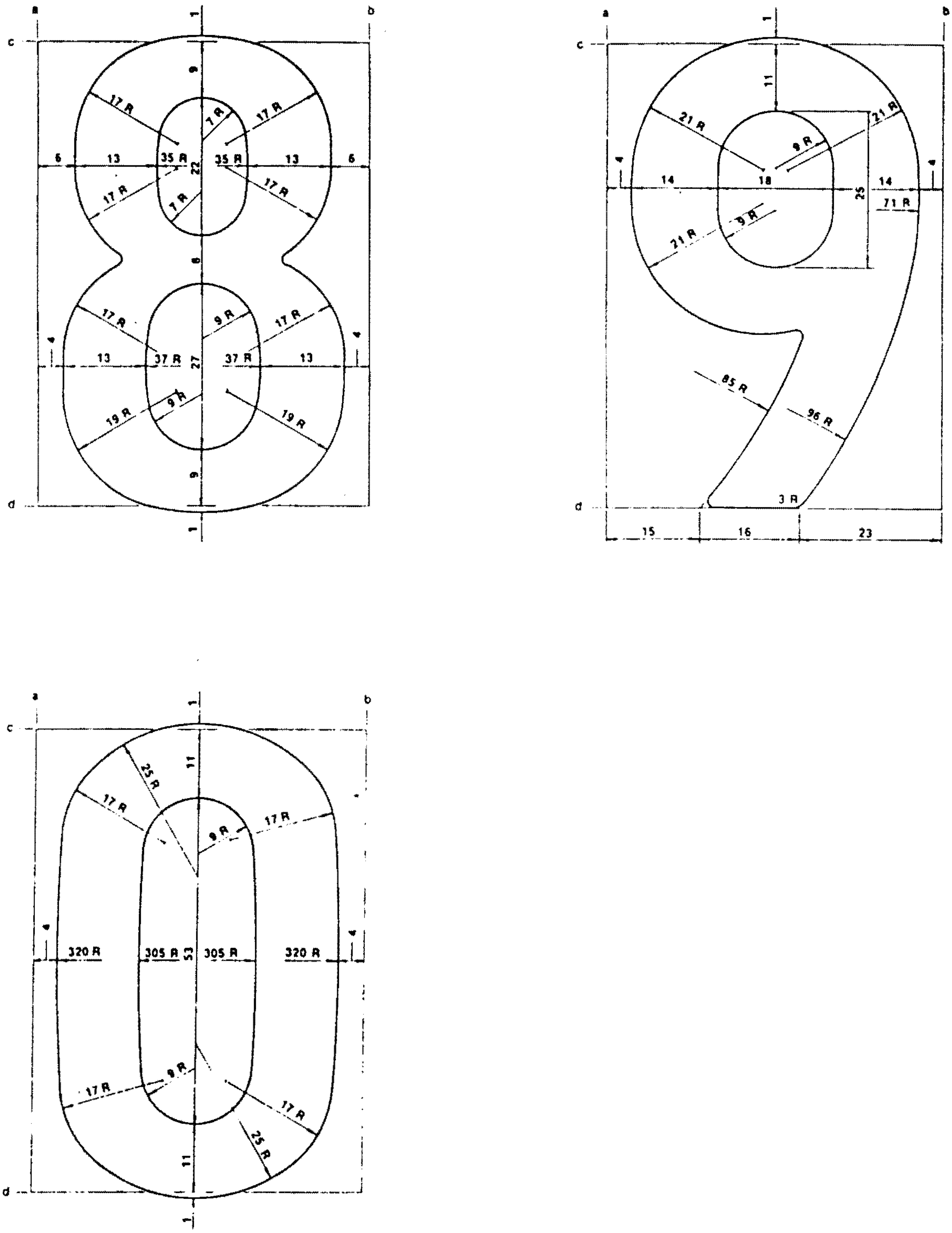
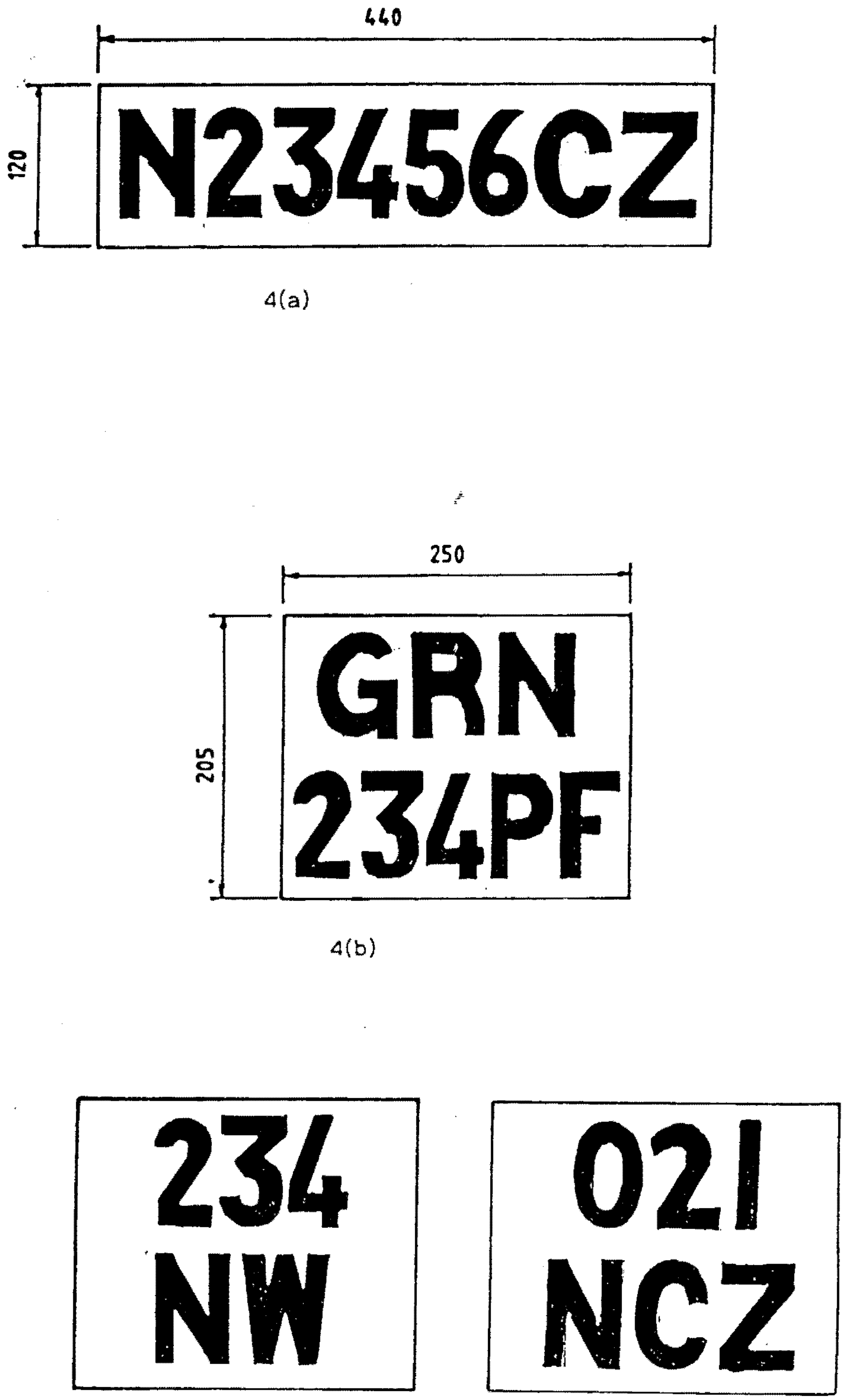


Fig. 3 (continued)

65

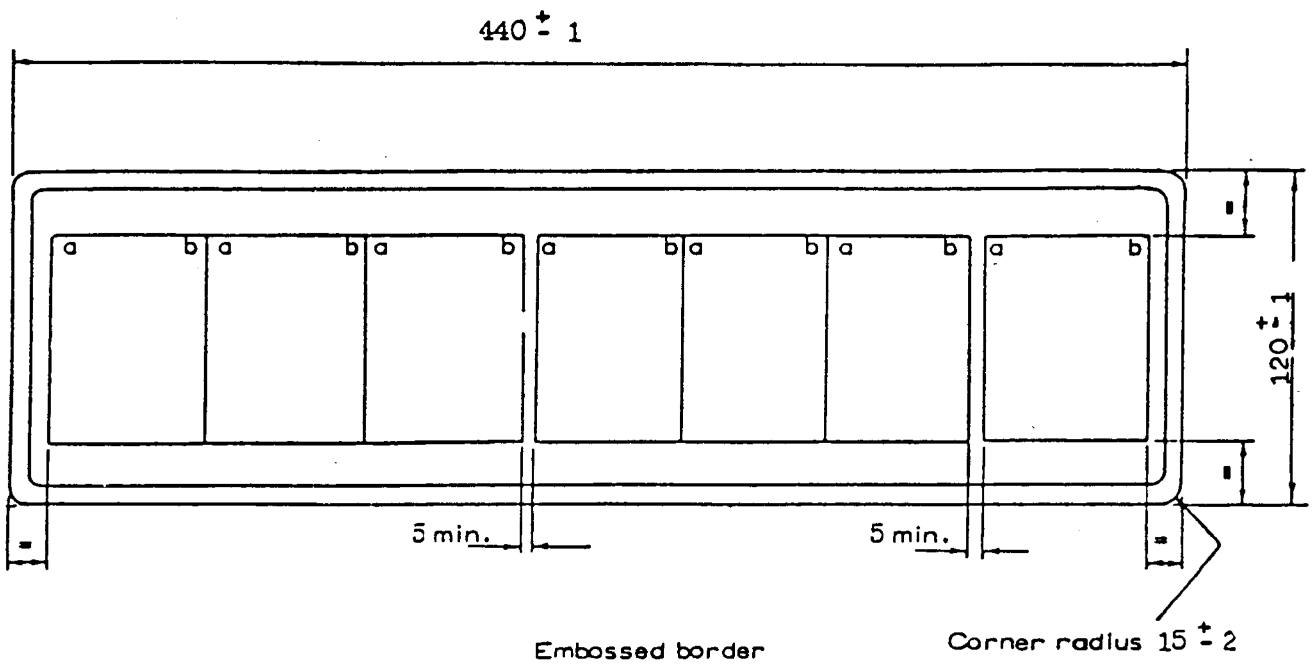


4(c)

Dimensions in millimetres 8811/1

Fig. 4 — Examples of Layout of Registration Marks with more than Seven Characters

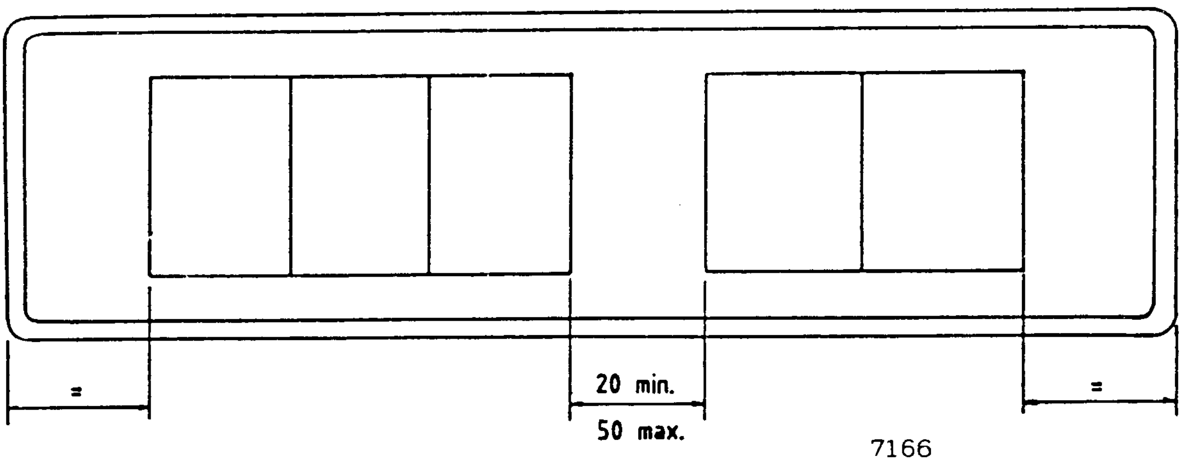
66



Various combinations of letters and numerals

NOTE : Spacing according to character arrangements

5 (a) Seven Characters in One Line (see also Fig. 1 (a) and (c))

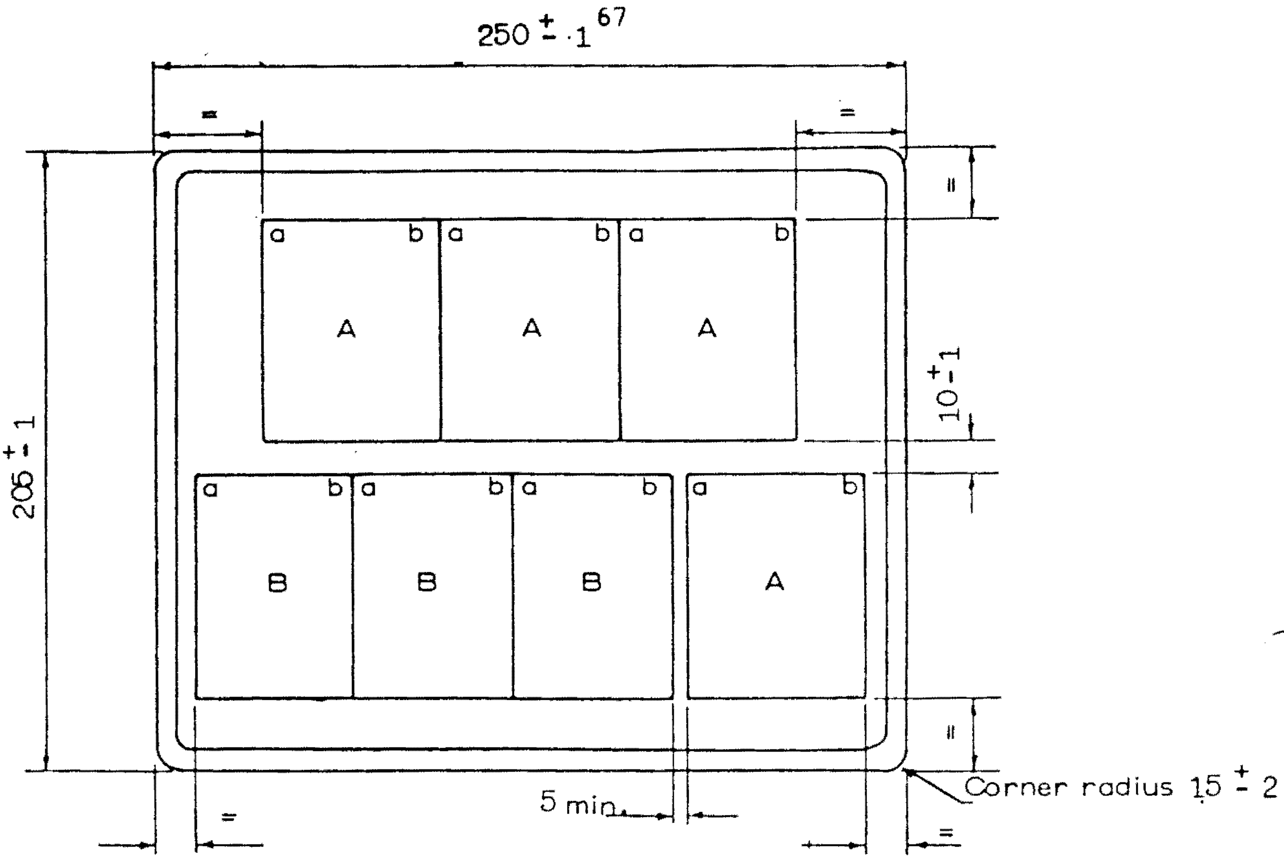


7166

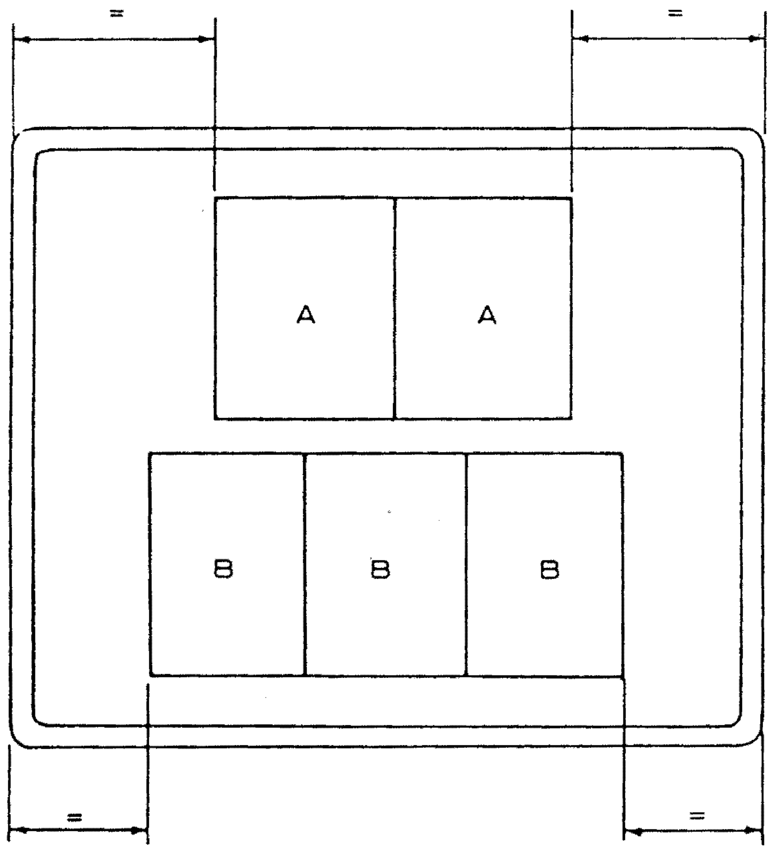
Dimensions in millimetres

5(b) Five Characters in One Line (see also Fig. 1(b)

FIG 5. - Sizes of Registration Plates and Examples of Spacing of Letters and Numerals



5(c) Seven Characters in Two Lines (see also Fig. 1 (d))



Dimensions in millimetres 7166

5 (d) Five Characters in Two Lines (see also Fig. 1(e))

Fig. 5 (continued)

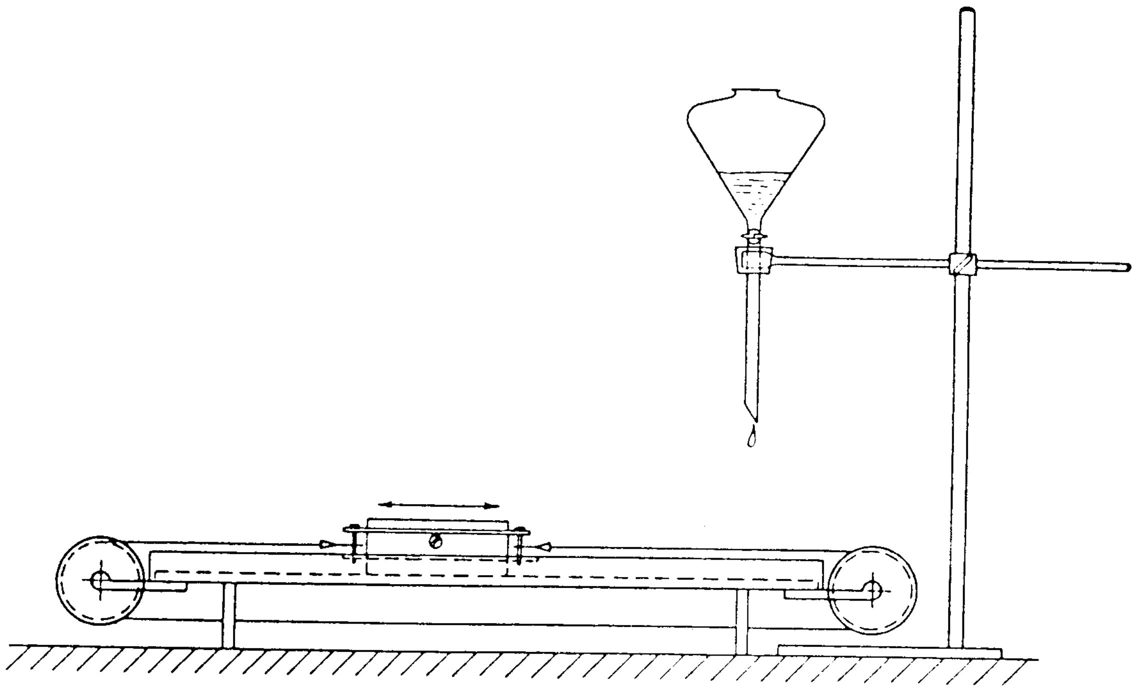


Fig. 6 - Washability Testing Apparatus

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PLASTIC BLANKS

PART III

CONTENTS

PART III

71

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART III : BLANKS (PLASTICS)

1. SCOPE

1.1 This part of the specification covers requirements for plastics blanks for use in the production of registration plates, covered by Part IV of the specification.

NOTE:

The standards referred to in this part of the specification are listed in Part I and IV

2. DEFINITIONS

2.1 For the purposes of this part of the specification the definitions given in Part I of the specification (other than the definition of "Blank") and the following definition shall apply:

Blank

A flat plastics plate.

3. REQUIREMENTS

3.1 FORMING

Each blank shall be formed by an injection moulding process.

3.2 MATERIAL

A blank shall be of one of the following materials:

a) Methyl methacrylate polymer;

b) impact modified methyl methacrylate polymer;

c) a co-polymer of methyl methacrylate containing at least 85% by mass of material derived from a methyl methacrylate;

d) polycarbonate

In addition, the material shall be such that the blank is UV-stable, transparent, has a surface specular gloss at 60° of at least 80, and complies with the performance requirements of 3.5.

3.3 SHAPE AND DIMENSIONS

The shape and overall dimensions of a blank shall comply with the requirements given in Subsection 3.3 of Part I of the specification. The thickness of the blank shall be not less than 3 mm and not more than 4 mm. The edges of one face of each blank shall be rounded or bevelled at approximately 45°, over at least half the thickness of the blank (see Fig. 1).

3.4 WORKMANSHIP

A blank shall be free from bubbles, creases, crevices and sharp or jagged edges, and shall be of such flatness that when the face of the blank is laid on a truly flat surface, no part of this face is more than 3 mm from the surface.

3.5 PERFORMANCE

3.5.1 Resistance to Weathering

When tested in accordance with 5.4, the blank shall show no signs of cracking, dulling or change of colour.

3.5.2 Resistance to Impact

When tested in accordance with 5.5, the blank shall show no sign of cracking.

3.5.3 Tensile Strenght at Yield

When a blank is tested in accordance with 5.6, the stress corresponding to the yield point of a test specimen shall be at least 35 MPa in the case of a methacrylate material and at least 55 MPa in the case of polycarbonate.

3.5.4 Softening Point

When a blank is tested in accordance with 5.7, the softening point shall be at least 80° C in the case of a methyl methacrylate material and at least 140° C in the case of polycarbonate.

3.5.5 Resistance to Fuel Mixture

When a blank is tested in accordance with 5.8, there shall be no dulling of the material and no visible surface cracking, and any change in hardness of the treated surface shall not exceed 10%.

3.5.6 Resistance to Abrasion

When a blank is tested in accordance with 5.9, the specular gloss measured at the end of the test shall be at least 50% of the value measured at the start of the test.

4. PACKING AND MARKING

4.1 PACKING

The blanks shall be so packed as to ensure that they are not damaged during transportation and storage.

4.2 MARKING

Each blank shall bear, on the front face and forming part of the moulding, the manufacturer's name or trade name or trade mark in legible and indelible marking. The marking shall be located adjacent to the top right-hand corner of the blank and shall occupy a space of approximately 5 mm in height and 25 mm in length.

5. INSPECTION AND METHODS OF TEST

5.1 INSPECTION

Visually examine and measure each blank in the sample for compliance with all the relevant requirements of the specification for which tests to assess compliance are not given in 5.4-5.9 (inclusive).

5.2 TEST SPECIMENS

Prepare the following test specimens :

NOTE: The test specimens given in (a)-(e) below may be prepared from a single blank.

a) Resistance to weathering

A test specimen of length at least 150 mm and of width at least 70 mm and having not more than one cut edge.

b) Resistance to impact

A test specimen of any convenient size.

c) Tensile strength

Three test specimens of the size and shape given in Fig. 2.

d) Softening point

Three test specimens, each of size approximately 10 mm square and of thickness not less than 2,5 mm and not more than 3 mm. (The specified thickness may be obtained by machining the material on one side only.)

e) Resistance to fuel mixture

A test specimen of any convenient size provided that it is big enough to include a surface area of approximately 100 cm^2.

f) Resistance to abrasion

A test specimen of length approximately 440 mm and of width approximately 120 mm.

NOTE : In the case of blanks of size 250 mm x 250 mm, the test specimen consists of two pieces.

5.3 CONDITIONING OF SPECIMENS

Prior to testing, condition all specimens (except specimens for weathering) for a period of at least 16 h at a temperature of 23 ± 2° C and a relative humidity of 50 ± 5%.

5.4 RESISTANCE TO WEATHERING

Use the method given in Subsection 6.3 of Part I of the specification. Check for compliance with the requirements of 3.5.1.

5.5 RESISTANCE TO IMPACT

Use the method given in Subsection 6.4 of Part I of the specification, except that the striker is raised to a height that will allow it to fall on any point on the face of the specimen (see 5.2(b)) and with an energy of 8 ± 0,25 J.

Check for compliance with the requirements of 3.5.2.

5.6 TENSILE STRENGTH AT YIELD

5.6.1 Apparatus

A tensile testing machine having a fixed jaw and a movable jaw capable of a rate of separation of 300 ± 5 mm/min, and fitted with a load indicator capable of showing the tensile load carried by the test specimen and of indicating this load to an accuracy of 1% or better.

5.6.2 Procedure

Place the test specimen (see 5.2(c)) in the jaws of the tensile testing machine. Start the machine and continue applying stress to the test specimen at least until the yield point of the specimen is reached. Record the force at which this point is reached and stop the machine.

Repeat the above procedure with the other two test specimens. Use the following formula to calculate the tensile strength of the specimen:

$$\text{Tensile strength, MPa} = \frac{\text{Load applied at yield, MN}}{\text{Average cross-sectional area, m}^2}$$

Determine the yield stress of the material for the blank by calculating the arithmetic mean of the tensile strength of the three test specimens, and check for compliance with the requirements of 3.5.3.

5.7 SOFTENING POINT

5.7.1 Apparatus

a) Softening point apparatus

A Vicat softening point temperature apparatus having the following components (see also Fig. 3):

1) Rod

A rod made of an alloy having a low thermal conductivity (to reduce its thermal expansion over the range of temperatures used in the test) and provided with a carrying plate. The rod is so held in a rigid metal frame that it can move vertically freely.

2) Indenting tip

An indenting tip, made of hardened steel, in the form of a cylinder of length approximately 3 mm, having a cross-sectional area of 1,00 ± 0,15 m^2 and fixed to the bottom of the rod. The lower surface of the tip is plane, perpendicular to the axis of the rod and free from burrs.

3) Gauge

A micrometer dial gauge (or other equivalent measuring instrument) graduated in divisions of 0,01 mm.

4) Masspieces

Where necessary, enough masspieces such that, when they are placed on the carrying plate, the combined mass of the rod, indenting tip, carrying plate and masspieces exerts a force of 50 ± 0,5 N on the test specimen. (The combined mass will be approximately 5 kg.)

b) Bath

A bath containing a suitable heating liquid into which the apparatus (see Fig. 3) is placed, and of such size that a test specimen mounted in the apparatus is at least 35 mm below the surface of the liquid. The bath is fitted with a stirrer and a heating control of such design as to allow the temperature of the liquid to be raised uniformly at a rate of 50 ± 5 °C/h.

c) Thermometer

A thermometer suitable for measuring the temperature of the liquid in the bath to within 0,5 ° C.

5.7.2 Procedure

Place the specimen (see 5.2(d)) with, when relevant, the non-machined surface uppermost and horizontally under and in contact with the indenting tip, ensuring that the distance of the indenting tip from the edges of the test specimen is at no point less than 3 mm. Ensure that the surface of the test specimen that is in contact with the base of the apparatus, is flat. Immerse the assembly (see Fig. 3) in the bath and hold the temperature of the liquid to at least 50 ° C below the expected softening temperature of the test specimen. Ensure that the bulb of the thermometer is at the same level as, and as close as possible to, the test specimen.

After approximately 5 min, set the micrometer dial gauge to zero and ensure, by adding masspieces to the carrying plate if necessary, that the force applied to the test specimen is 50 ± 0,5 N. Increase the temperature of the bath at a uniform rate of 50 ± 5 ° C/h and ensure that the liquid is continuously stirred. When the identing tip has penetrated the surface of the test specimen to a depth of 1,0 ± 0,1 mm, record the temperature of the bath.

Repeat the above procedure on the other two test specimens and determine the softening point of the material by calculating the arithmetic mean of the temperatures recorded for the three test specimens. Check for compliance with the requirements of 3.5.4.

NOTE :

If the results of the individual tests differ by more than 2 ° C, discard the results and repeat the test on further sets of three test specimens until the results obtained for the three test specimens do not differ from one another by more than 2 ° C.

5.8 RESISTANCE TO FUEL MIXTURE

5.8.1 Procedure

a) Select an area of approximately 100 cm^2 on the surface of the specimen (see 5.2(e)).

b) Measure and record, on the Rockwell "R" scale, the surface hardness of this area. (Typical hardness values as measured on the Rockwell "R" scale are 105-120 in the case of methacrylate and 115-125 in the case of polycarbonate.)

c) Apply to this area approximately 1 ml of a fuel mixture consisting of the following:

Denatured Methanol 2 parts by volume
Benzene................................ 1 part by volume
Petroleum ether (boiling range 60-120 °C 7 parts by volume

d) Allow the mixture to evaporate completely in a draught-free area.

e) Immediately measure and record, on the Rockwell "R" scale, the surface hardness of the treated surface. Compare this reading with the reading taken in (b) above, and check for compliance with the requirements of 3.5.5.

5.9 RESISTANCE TO ABRASION

5.9.1 Apparatus

a) Specular glossmeter (60 °)

A 60 ° glossmeter consisting of an incandescent light source furnishing an incident beam, means for locating the surface of the specimen, and a receptor located to receive the required pyramid of rays reflected by the specimen, the receptor consisting of a photosensitive device responding to visible radiation.

b) Abrader

An abrader (see Fig. 4) consisting of a boat, of approximate size 90 mm x 55 mm at its base, of total mass 450 ± 5 g and equipped with suitable attachments for fixing abrasive paper (see (c) below) to the bottom of the boat.

Wires fastened to a vertical peg at each end of the boat are so actuated as to move the boat back and forth over the test specimen at a constant speed of 35-40 oscillations (70-80 strokes) per minute. The length of each stroke is approximately 330 mm and the wires moving the boat do not exert a vertical force component. The apparatus is mounted on a horizontal table to which the specimen can be firmly clamped. Provision is made for a constant supply of water to drip onto the specimen and for a suitable means of collecting excess water.

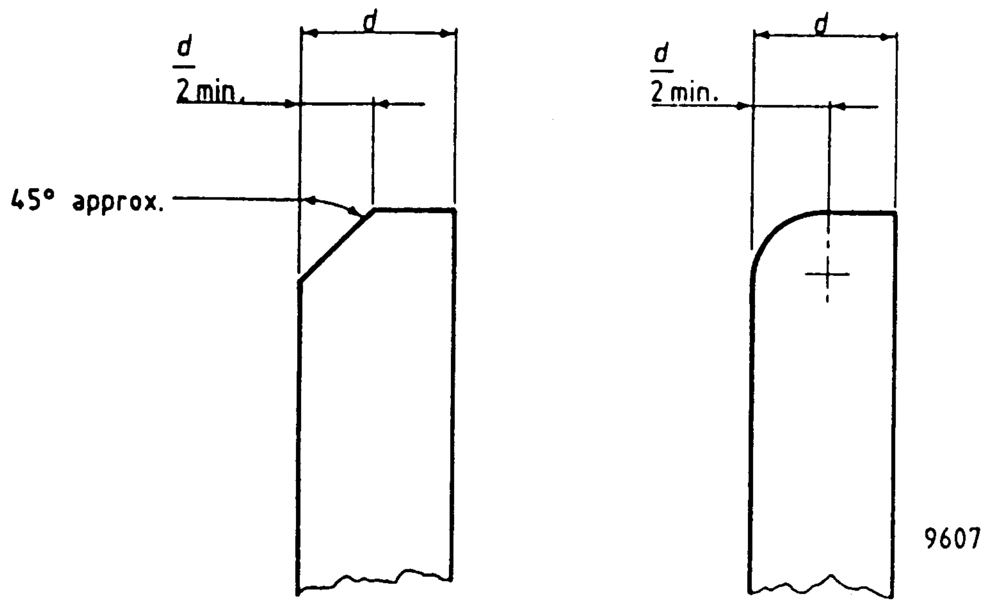
c) Abrasive paper

Pieces of No 400 waterproof abrasive paper.

5.9.2 Procedure

Measure and record the 60 ° specular gloss of the front surface of the specimen (see 5.2(f)). Fix the abrasive paper to the boat of the abrader. Clamp the specimen, with its front surface uppermost, in position on the table and thoroughly wet the surface of the specimen. Start the abrader and, during the abrading of the specimen, use enough water to keep the surface of the specimen wet. After the abrader has completed 15 oscillations, stop the abrader, remove the specimen and, with a clean cloth, wipe clean the abraded surface. Leave the specimen to dry for a period of at least 30 min at room temperature and then measure and record the 60 ° specular gloss of the front surface. Check for compliance with the requirements of 3.5.6.

84



1(a) Bevelled Edge

1(b) Rounded Edge

Fig. 1 - Examples of Shaped Edge

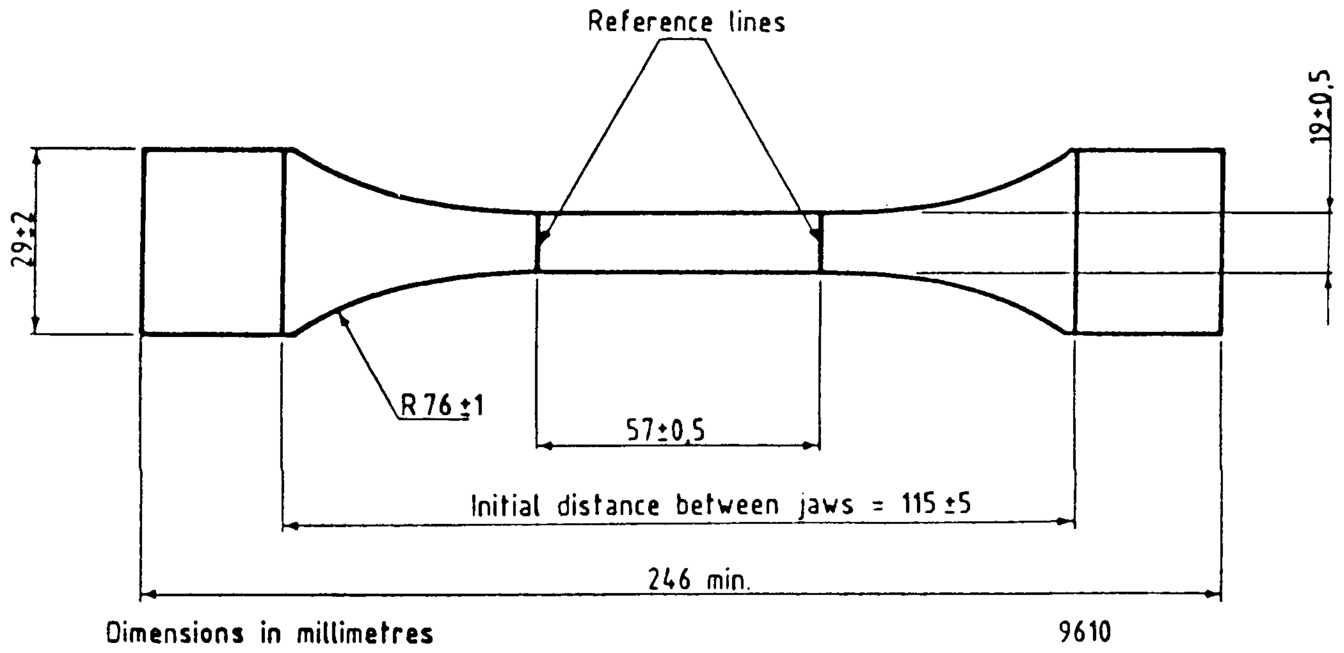


Fig. 2 - Tensile Test Specimen

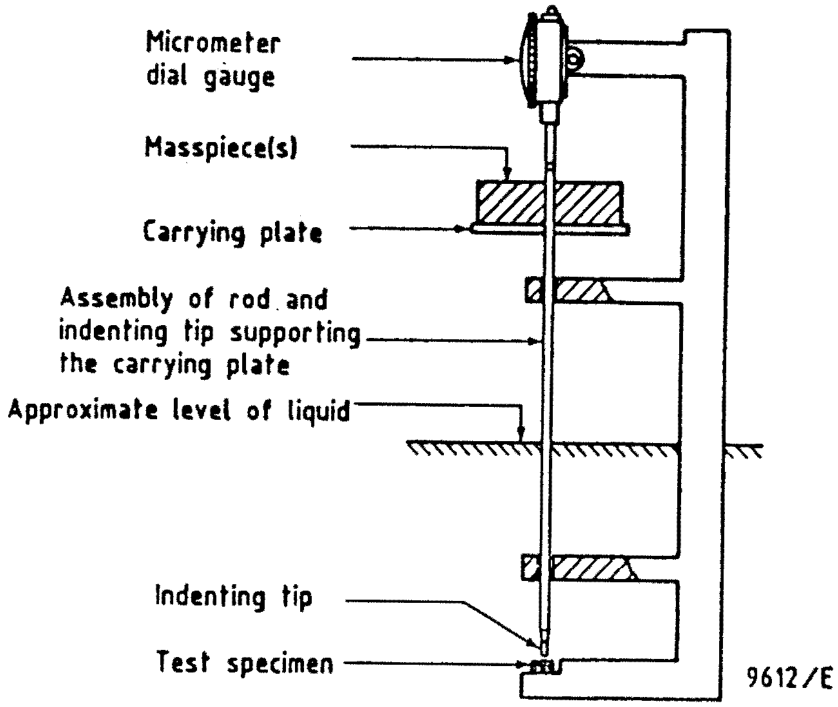


Fig. 3 - Schematic Arrangement of Vicat Softening Point Temperature Apparatus

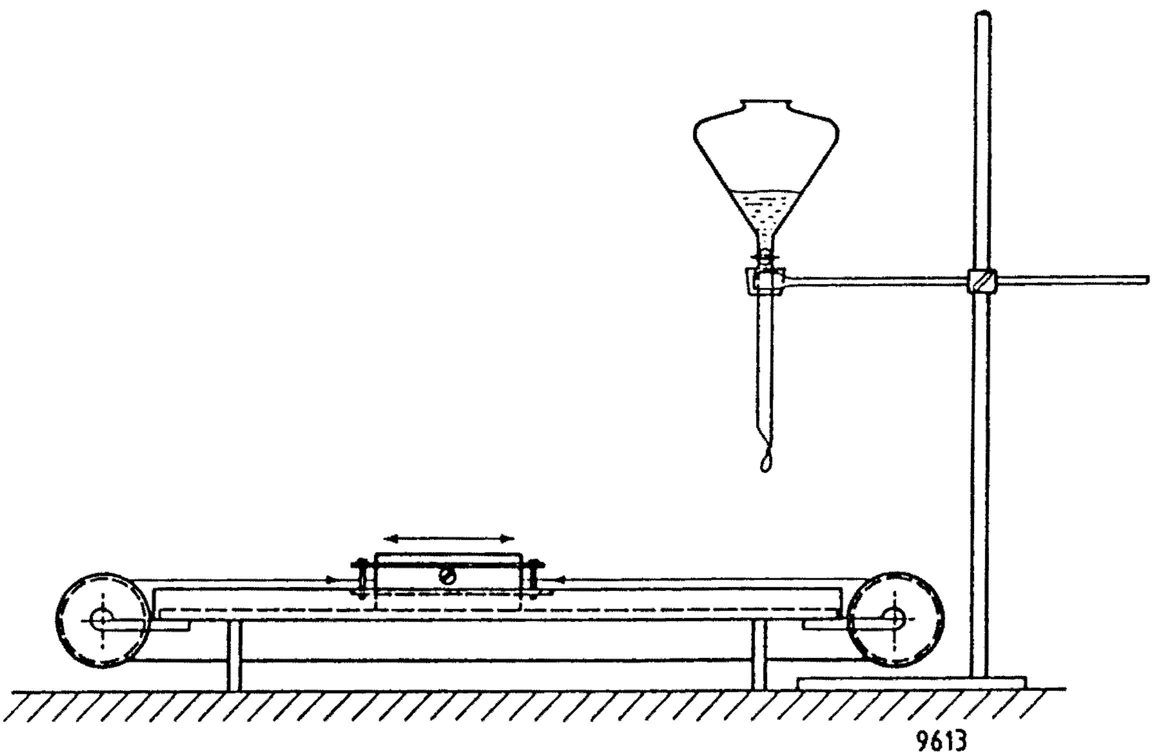


Fig. 4 - Abrader

86

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART IV

PLASTIC PLATES

CONTENTS

PART IV

89

STANDARD SPECIFICATION

FOR

RETRO-REFLECTIVE REGISTRATION PLATES

FOR MOTOR VEHICLES

PART IV : REGISTRATION PLATES (PLASTICS)

1. SCOPE

1.1 This part of the specification covers plastics registration plates produced by applying a registration mark and border to a blank (see Part III of the specification) and intended for use on motor vehicles (including motor cycles and motor tricycles) and trailers.

NOTE

The standards referred to in this part of the specification are listed in Part I, II and III.

2. DEFINITIONS

2.1 For the purposes of this part of the specification the definitions for "Registration mark or registration number" and "Registration plate (Plate)" given in Part I of the specification, the definition for "Blank" given in Part III of the specification and the following definition shall apply:

Retro-reflective surface

A surface from which light is reflected in directions close to the directions close to the direction of incidence within a wide range of angles of incidence at the surface.

3. REQUIREMENTS

3.1 MATERIALS

3.1.1 Blanks

The retro-reflective material, registration mark, border and protective cover material on a registration plate shall have been applied to a blank that complies with the requirements of Part III of the specification.

3.1.2 Retro-reflective Material

The colour of the retro-reflective material for plates shall be red, blue, green, yellow or white. The retro-reflective material shall be such that, when the material is applied to the surface of the plastics blank in accordance with 3.4, the colour, luminance factor and coefficients of retro-reflection of the plate comply with the relevant requirements of Subsection 3.2.2 and 3.2.3 of Part I of the specification.

3.1.3 Registration Mark and Border

The registration mark and border of a plate shall be of

a) matt black self-adhesive polyester sheeting, polymer film transfer ink, or silk screening ink, of thickness not exceeding 25μm; or

b) for the registration mark only, matt black, fully pre-shrunk polyethylene sheeting that contains an ultraviolet inhibitor and is of thickness not exceeding 80μm.

3.1.4 Protective Cover

Protective covers for plates shall be of a material that is waterproof, fully pre-shrunk, flexible and of thickness at least 20 μm.

3.2 REGISTRATION MARK

The shape, dimensions and spacing of the characters (letters and numerals) of a registration mark shall comply with the appropriate requirements of Subsections 3.1.3 and 3.1.4 of Part II of the specification except that, in the case of registration marks referred to in Subsection 3.1.3(b) of Part II of the specification, the shape and dimensions of the characters shall, subject to a tolerance of ± 0,5 mm, be as shown in Fig. 1.

3.3 BORDER

The border of a plate shall be as shown in Fig. 2(a) or 2(b) and shall extend around the four edges of the plate.

3.4 APPLICATION (See Fig. 3)

a) The registration mark and border shall interpose the retro-reflective surface of the retro-reflective material and the rear surface of the blank.

b) The retro-reflective material shall be so applied that the retro-reflective surface is in contact with and completely covers the registration mark and border, and the remainder of the rear surface of the blank.

c) A protective cover shall be applied to the whole of the rear surface of the retro-reflective material.

d) If an adhesive is used to bond the rear surface of the blank to the front surface of the retro-reflective material, the adhesive shall be colourless.

3.5 WORKMANSHIP

The retro-reflective material, registration mark and border of a plate shall be free from creases, chips, blisters, discoloration and spots. The registration mark shall be clearly defined.

3.6 PERFORMANCE

3.6.1 Resistance to Weathering

When a plate is tested in accordance with 5.4,

a) the chromaticity co-ordinates of the retro-reflective parts of the plate shall still be within the area defined by the chromaticity co-ordinates given in Subsection 3.2.2.1 and 3.2.3 of Part I of the specification;

b) the reflected luminous intensity, at an observation angle of 0,2 ° and an angle of incidence of 4 °, shall be at least 50% of the appropriate corresponding initial value given in Subsection 3.2.2.2 and 3.2.3.1 of Part I of the specification;

c) the retro-reflective material, registration mark, border and protective cover shall show no sign of cracking, blistering or loss of adhesion;

d) when relevant, the adhesive (see 3.4(d)) shall remain colourless; and

e) the registration mark shall show no loss of legibility.

3.6.2 Resistance to Salt Fog

When tested in accordance with 5.5, the plate shall comply with the requirements given in 3.6.1(c), (d) and (e).

3.6.3 Resistance to Scratching, Impact and Abrasion

When a plate is tested in accordance with 5.6, 5.7 and 5.8, in each case there shall be no sign of penetration of the protective cover.

3.6.4 Resistance to Bending

When a plate is tested in accordance with 5.9, there shall, after each bending operation, be no sign of cracking of the plastics blank or of cracking or loss of adhesion of the retro-reflective material, protective cover, registration mark or border.

3.6.5 Strength of Adhesion

When a plate is tested in accordance with 5.10, the strength of the adhesion of the retro-reflective material and the protective cover shall be at least 1 N/mm of width.

4. PACKING, MARKING AND LABELLING

4.1 PACKING

Plates shall be so packed as to ensure that they are not damaged during transportation and storage.

4.2 MARKING

The surface of the plate containing the registration mark shall bear, in legible and indelible marking, and of the same material as that used for the registration mark, the manufacturer's name or trade name or trade mark in a space approximately 5 mm in height and 25 mm in length.

4.3 LABELLING

The labelling of plates shall comply with the requirements of Subsections 4.3(a) and 4.3(c) of Part II of the specification.

5. INSPECTION AND METHODS OF TEST

5.1 INSPECTION

Visually examine and measure each plate in the sample for compliance with all the relevant requirements of the specification, for which tests to assess compliance are not given in 5.4-5.10 (inclusive).

5.2 TEST SPECIMENS

5.2.1 Specimens for Tests other than Strength of Adhesion

NOTE:

At least two registration plates are required in order to prepare all the test specimens given in (a)-(f) below.

From single registration plates, cut the following test specimens:

a) Resistance to weathering

A test specimen of length at least 150 mm and of width at least 70 mm, and containing at least two characters.

b) Resistance to Salt Fog

A test specimen of length at least 150 mm and of width at least 100 mm, and containing at least two characters.

c) Resistance to scratching

A test specimen of length approximately 100 mm and of width approximately 55 mm.

d) Resistance to impact

A test specimen of any convenient size.

e) Resistance to abrasion

A test specimen of length approximately 150 mm and of width approximately 120 mm.

f) Resistance to bending

A test specimen of length at least 250 mm and of width between 100 mm and 120 mm and having on it at least one character of a registration mark and a section of a border.

5.2.2 Specimens for Strength of Adhesion Test

NOTE

Sufficient blanks, retro-reflective material and protective cover material of the type used (in each case) in the manufacture of the registration plates under test, are required to prepare the test specimens given below.

Prepare the test specimens as follows:

a) Laminated retro-reflective and protective cover material

1) From the blanks cut four test panels, each of size approximately 120 mm x 70 mm.

97

2) From the laminated retro-reflective and protective cover material cut 12 test strips each of size approximately 300 mm x 15 mm.

3) To the surface of each of the four test panels (see (1) above), starting approximately 20 mm from the one end of the panel, and in the direction of the length of the test panel, apply, in the manner used by the manufacturer, three test strips (see (2) above) adjacent to one another.

b) Unlaminated retro-reflective and protective cover material

1) From the blanks cut eight test panels, each of size approximately 120 mm x 70 mm.

2) From both the retro-reflective material and the protective cover material cut 12 test strips , each of size approximately 300 mm x 15 mm.

3) To the surface of each of four of the test panels (see (1) above) apply three test strips (see (2) above) of the retro-reflective material as in (a)(3) above.

4) Cover one surface of each of the four remaining test panels with retro-reflective material, then apply three test strips of protective cover material (see (2) above) to the retro-reflective material on each of the panels, as in (a)(3) above.

5.3 CONDITIONING OF SPECIMENS

5.3.1 In the case of all specimens for the test given in 5.9, and specimens for the tests given in 5.6, 5.7 and 5.8 that have been prepared from plates having protective covers made from materials other than plastics, condition the specimens prior to testing for a period of at least 16 h at a temperature of 23 ± 2 °C and a relative humidity of 50 ± 5%.

5.3.2 In the case of specimens for the test given in 5.10, condition half of the specimens as in 5.3.1 above, and subject the remaining half to the test for resistance to weathering given in 5.4. In addition, ensure that a period of at least 72 h has elapsed between the time that the retro-reflective material or the protective cover material or both (as appropriate) was applied to the blank, and the commencement of the test.

5.4 RESISTANCE TO WEATHERING

Use the method given in Subsection 6.3 of Part I of the specification. Check for compliance with the requirements of 3.6.1.

5.5 RESISTANCE TO SALT FOG

Use the method given in Subsection 6.6 of Part I of the specification. Check for compliance with the requirements of 3.6.2.

5.6 RESISTANCE TO SCRATCHING

Use the method given in Subsection 6.5 of Part I of the specification to test the protective cover of the specimen (see 5.2.1(c)), except that the electric current supply and ammeter are not used. Visually examine any scratch marks, and check for compliance with the requirements of 3.6.3.

5.7 RESISTANCE TO IMPACT

Use the method given in Subsection 6.4 of Part I of the specification to test the protective cover of the specimen (see 5.2.1(d)), except that the striker is raised to a height that will allow it to fall with an energy of $3^{+0,25}_{-0}$J. Check for compliance with the requirements of 3.6.3.

5.8 RESISTANCE TO ABRASION

5.8.1 Apparatus

a) Tube and funnel

A glass guide tube of length approximately 915 mm and of inside diameter approximately 20 mm, fitted with a funnel at the upper end and holding approximately 2 l of sand. The guide tube is supported in a vertical position and a support is provided for holding the test specimen (see Fig. 4).

b) Sand

Sand of particle size such that at least 80% passes through a sieve of nominal aperture size 850 m and not more than 5% passes through a sleve of nominal aperture size 600 m.

5.8.2 Procedure

Set up the guide tube in a vertical position. Place the test specimen (see 5.2.1(e)) approximately 25 mm below the orifice of the tube, with the protective cover of the specimen facing the tube and at an angle of approximately 45 ° to the vertical (see Fig. 4). So introduce sand into the funnel that it falls onto the protective cover of the test specimen, and continue until 20 $^{+0,5}_{-0}$ l of sand has fallen. Stop the test and check for compliance with the requirements of 3.6.3.

It is recommended that a quantity of this sand be used not more than 50 times.

5.9 RESISTANCE TO BENDING

Use the method given in Subsection 6.7 of Part I of the specification, except that the rear surface of the test specimen (see 5.2.1(f)) is placed against a mandrel of diameter 75 ± 1 mm. Check for compliance with the requirements of 3.6.4.

5.10 STRENGTH OF ADHESION

5.10.1 Apparatus

A tensile testing machine having a fixed jaw and a movable jaw capable of a rate of separation of 300 ± 5 mm/min, and fitted with a load indicator capable of showing the tensile load carried by the test specimen and of indicating this load to an accuracy of 1% or better.

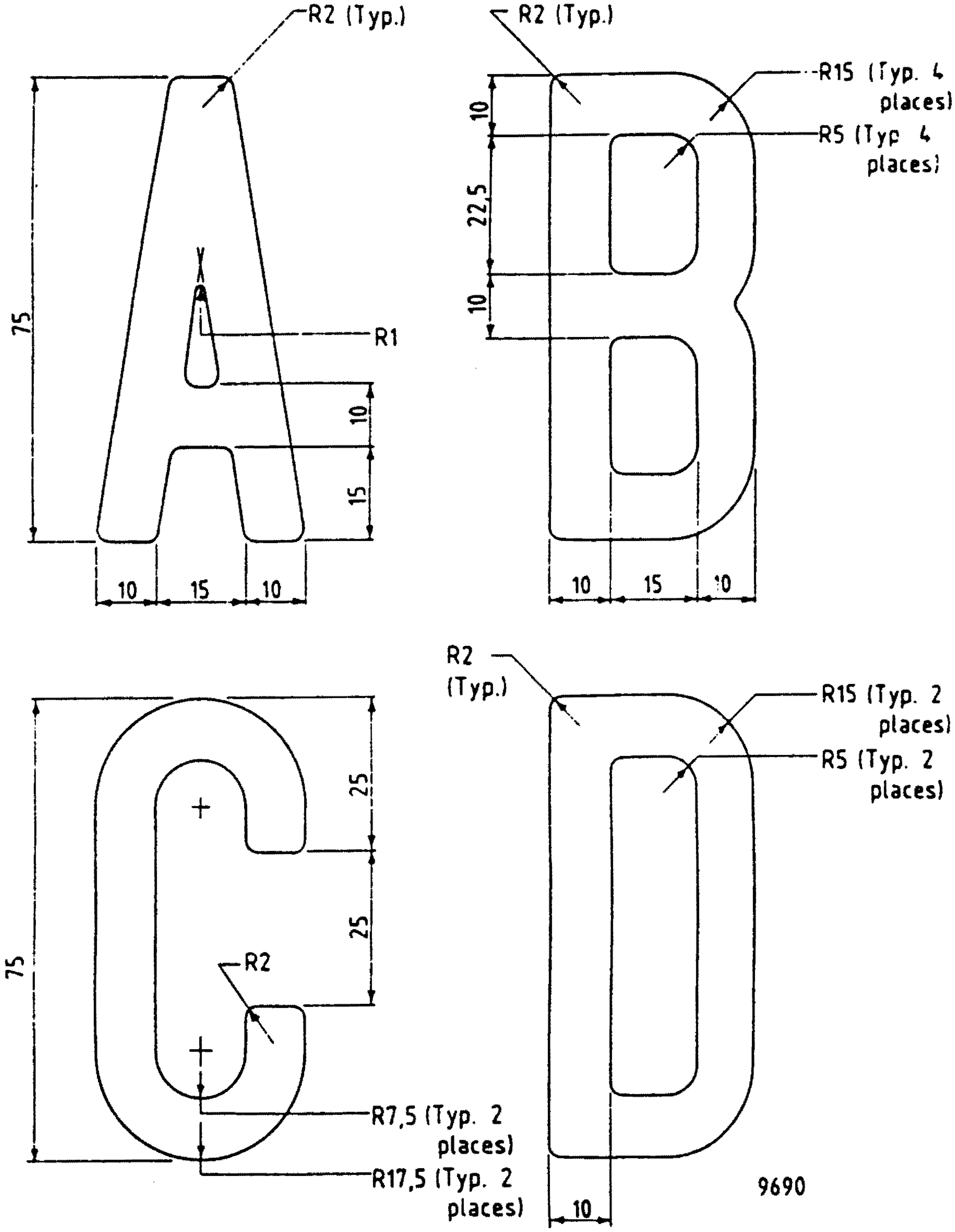
5.10.2 Procedure

Double back the free end of one of the test strips at one end of the test specimen (see 5.2.2) and strip it from the panel for a distance of approximately 25 mm. Grip that end of the test specimen in the movable jaw of the tensile testing machine, and grip the free end of the strip in the fixed jaw, ensuring that the pull on the strip will be applied slightly offset from, but parallel to that part of the strip adhering to the panel. (This can be achieved by inserting suitable packing in the movable jaw of the tensile testing machine.)

Set the movable jaw in motion and record the maximum force required to remove the strip of material from the surface of the panel.

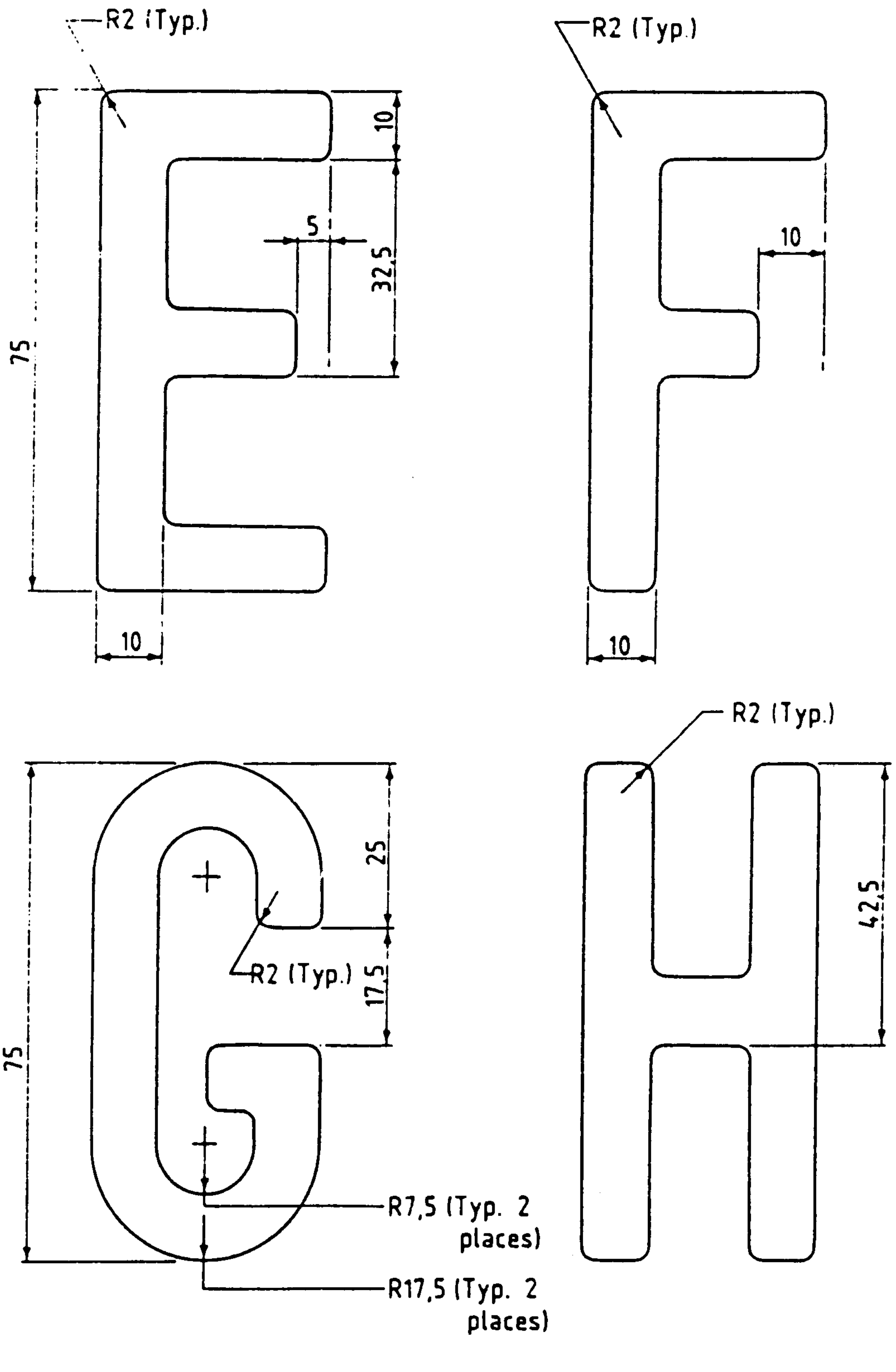
Repeat the above procedure on the other 11 or 23 strips (as appropriate) and calculate the average force per millimetre of width of the strip required to remove the strip from the test panel. Check for compliance with 3.6.5.

102



Dimensions in millimetres

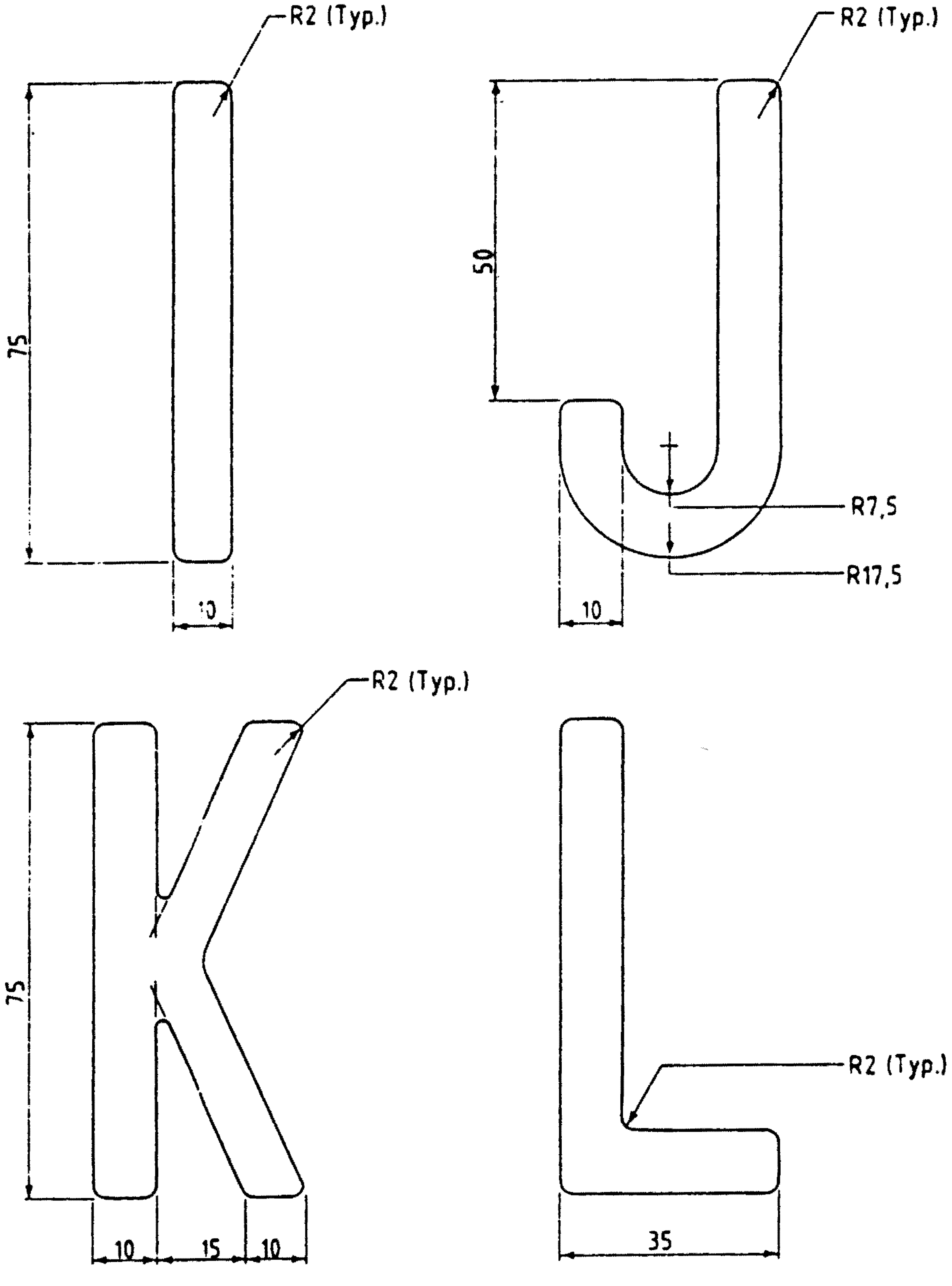
Fig. 1 - Shapes and Sizes of Letters and Numerals



9691

Fig. 1 (continued)

104



9692

Fig. 1 (continued)

105

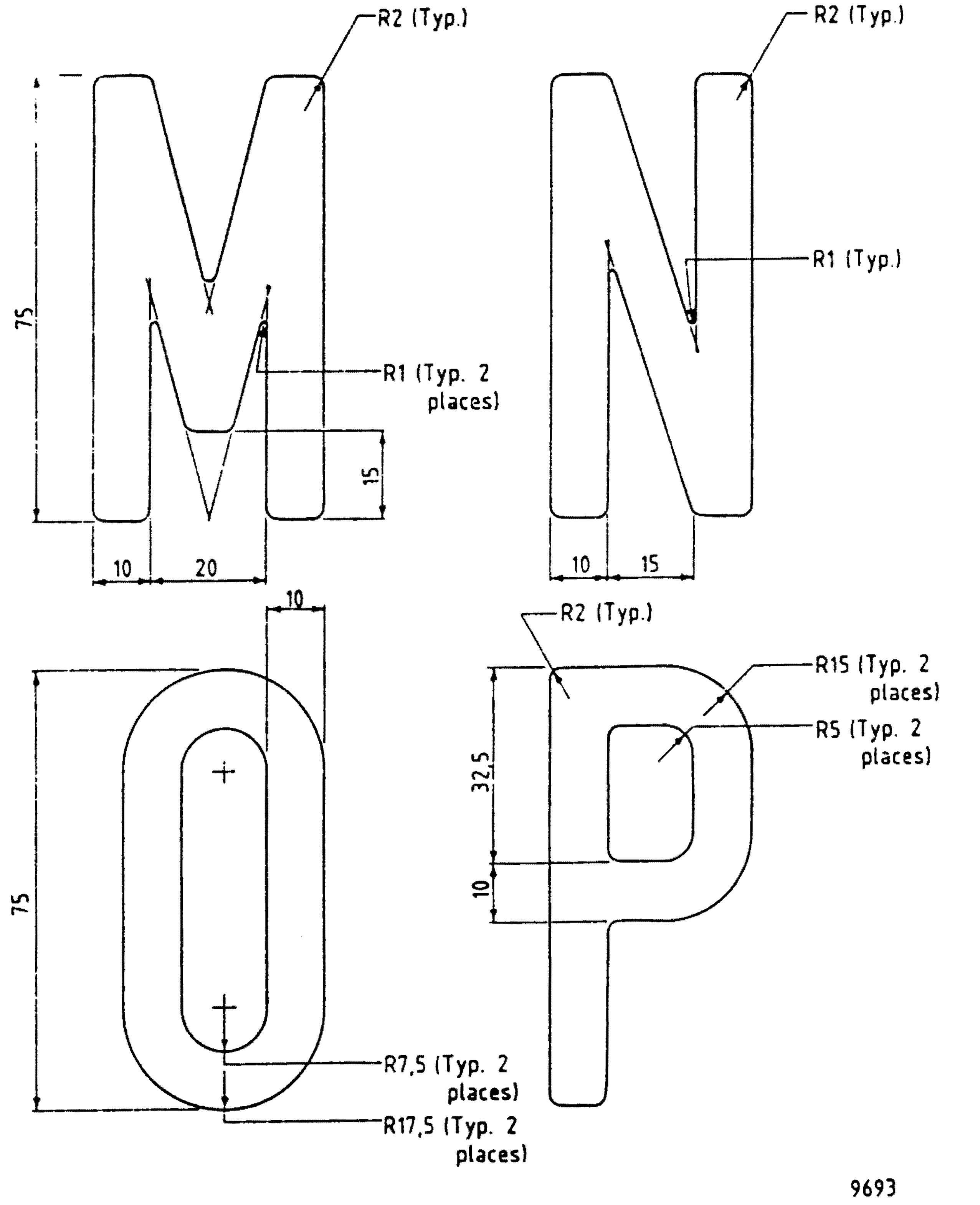


Fig. 1 (continued)

106

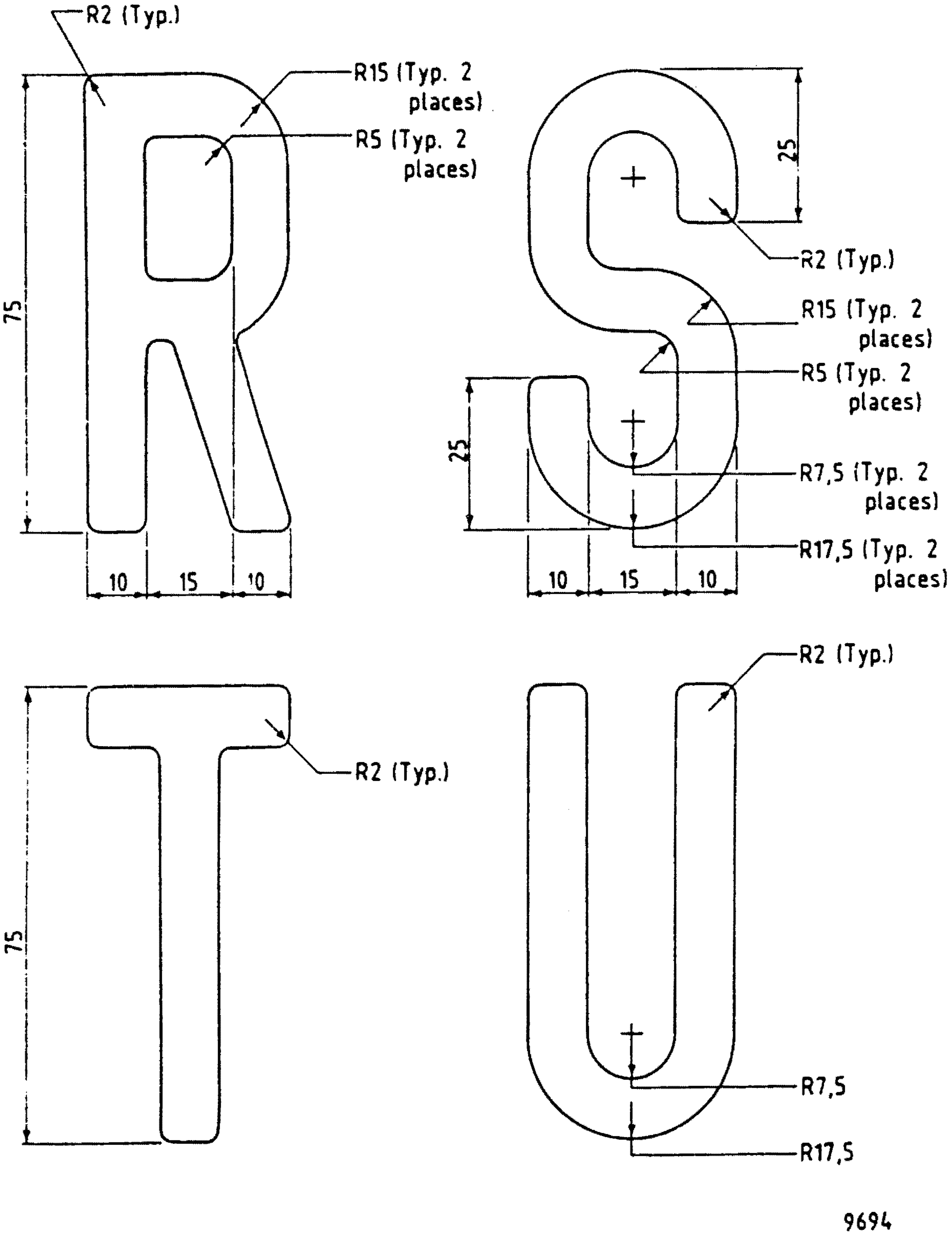


Fig. 1 (continued)

107

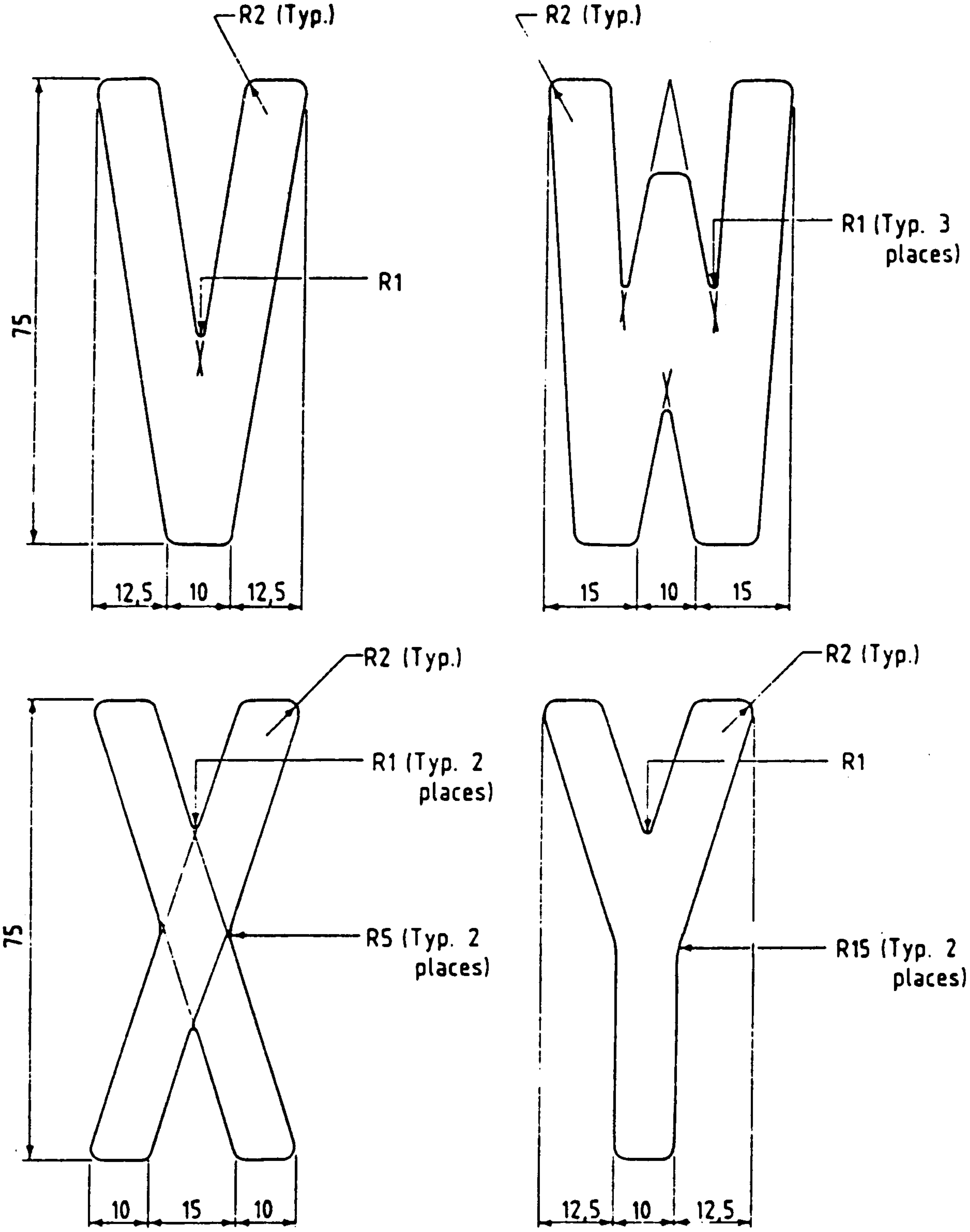


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Fig. 1 (continued)

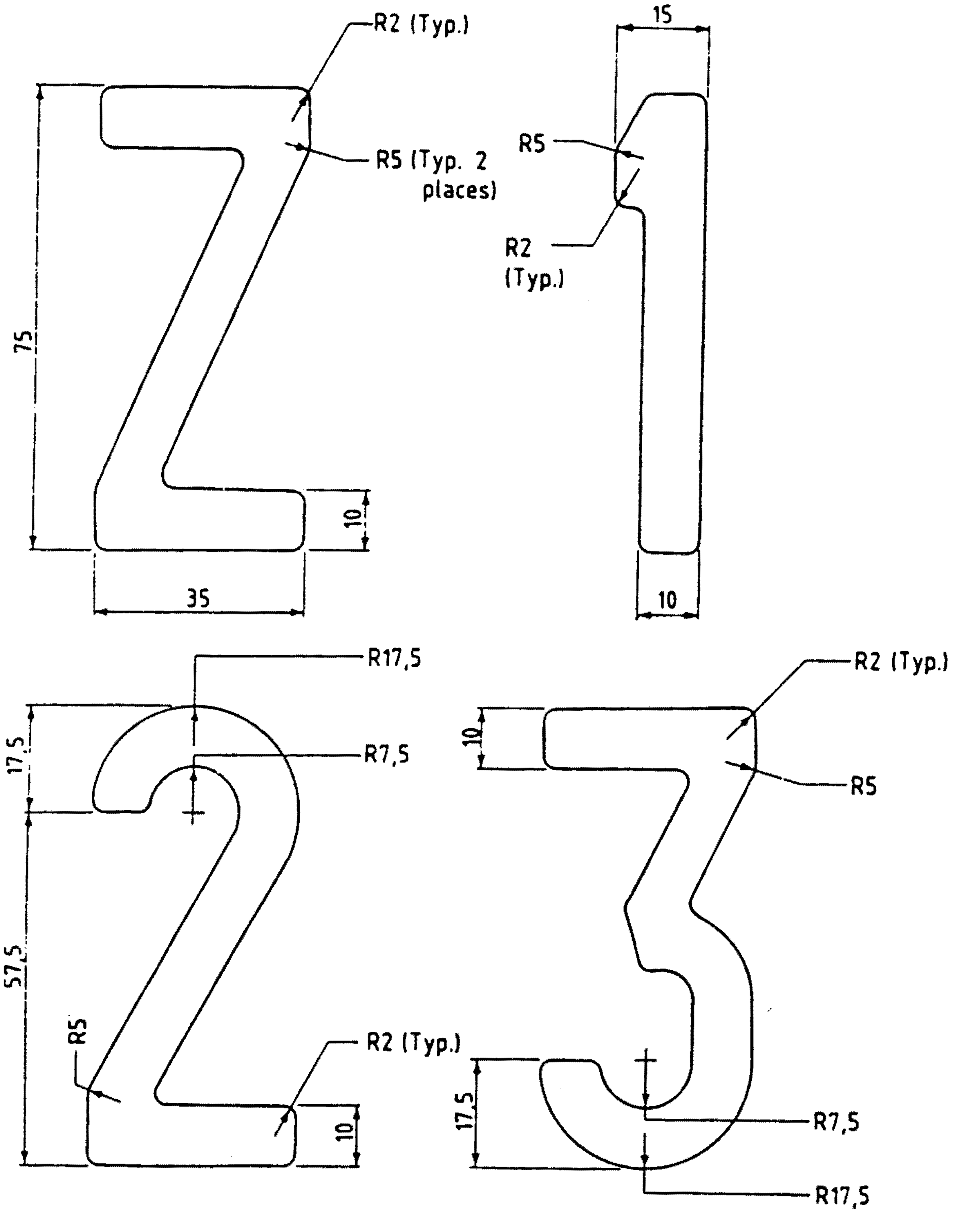

Fig. 1 (continued)

109

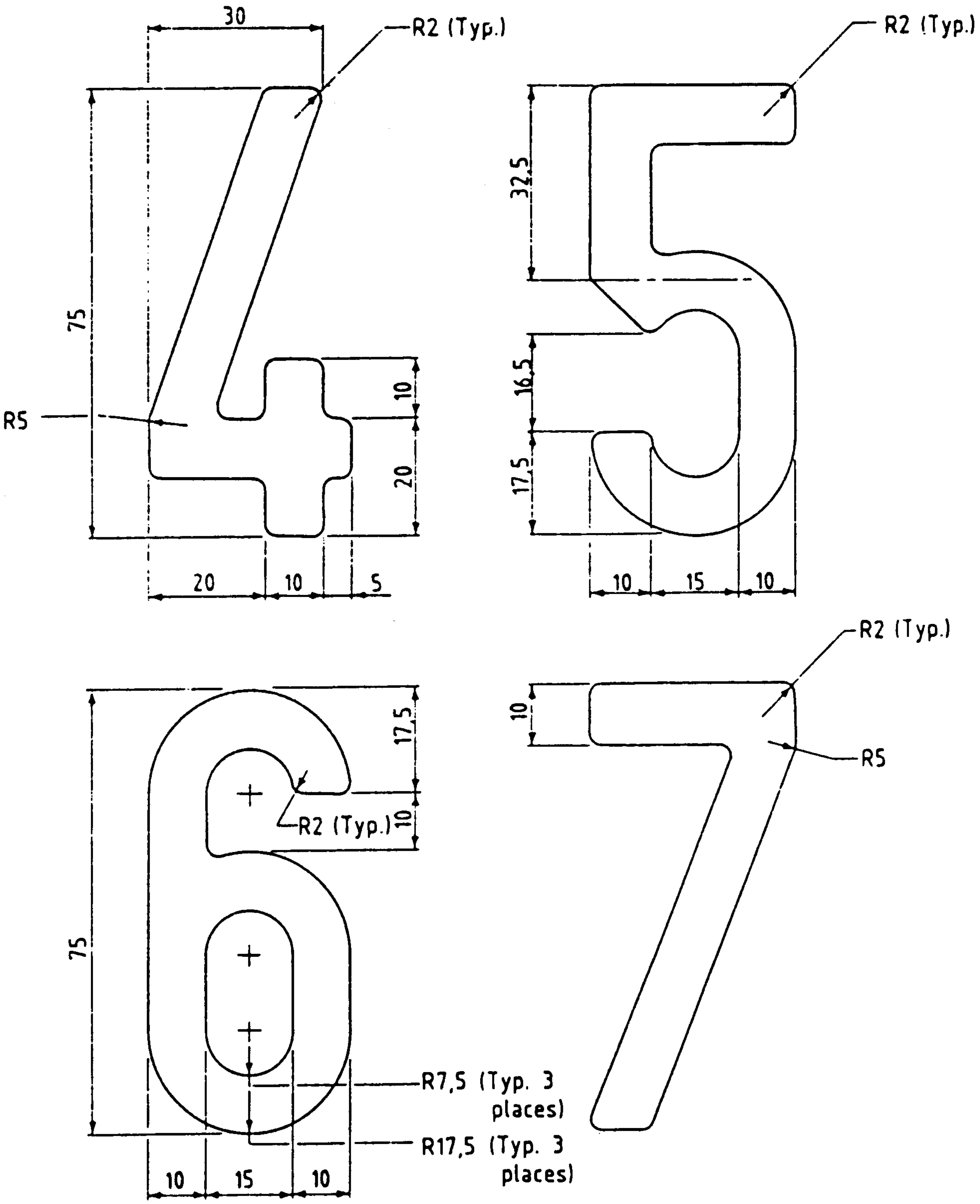

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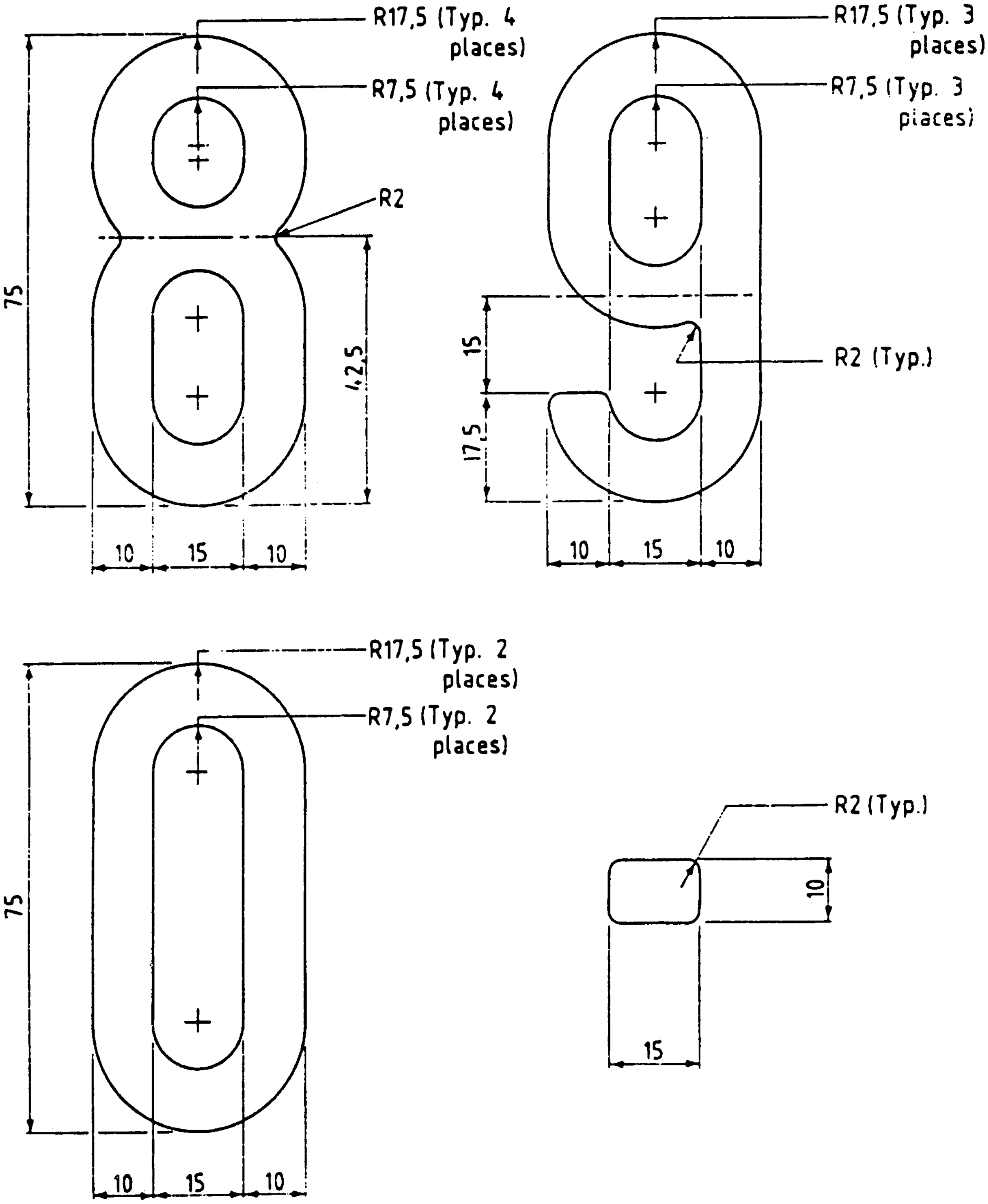
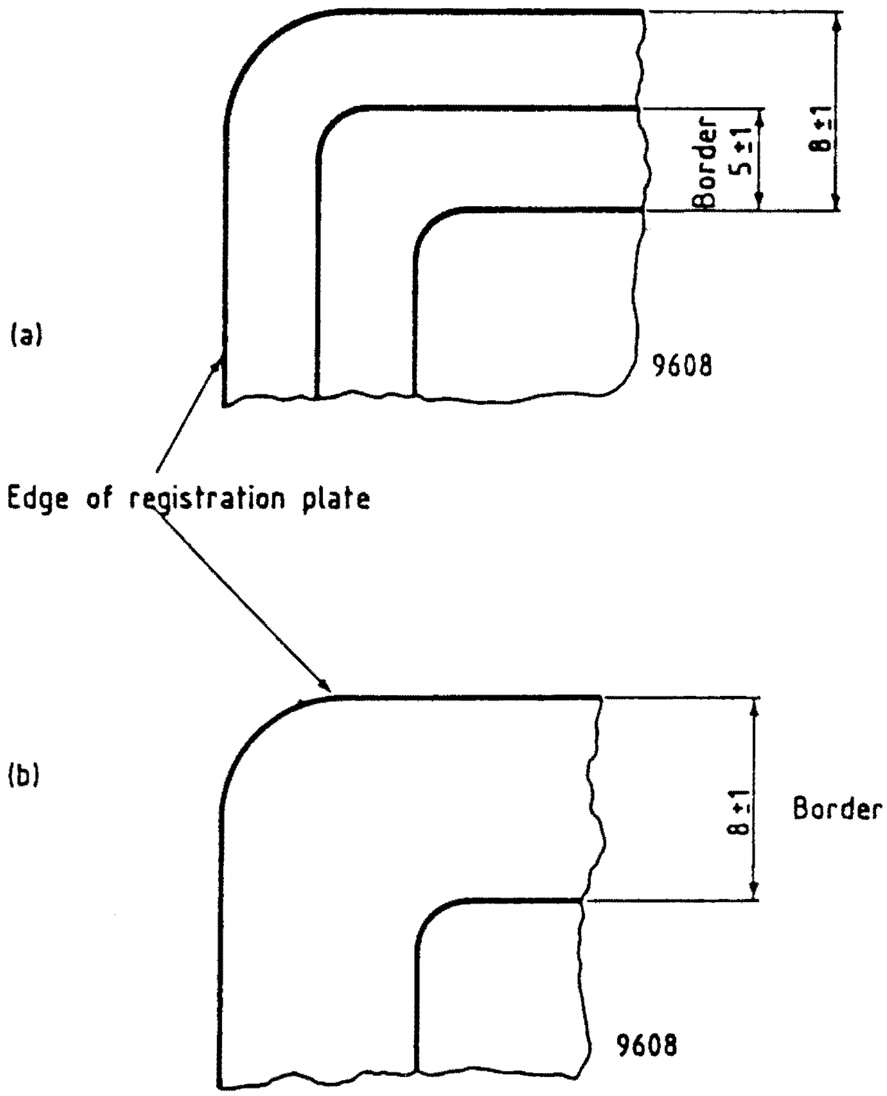
Fig. 1 (continued)



9698

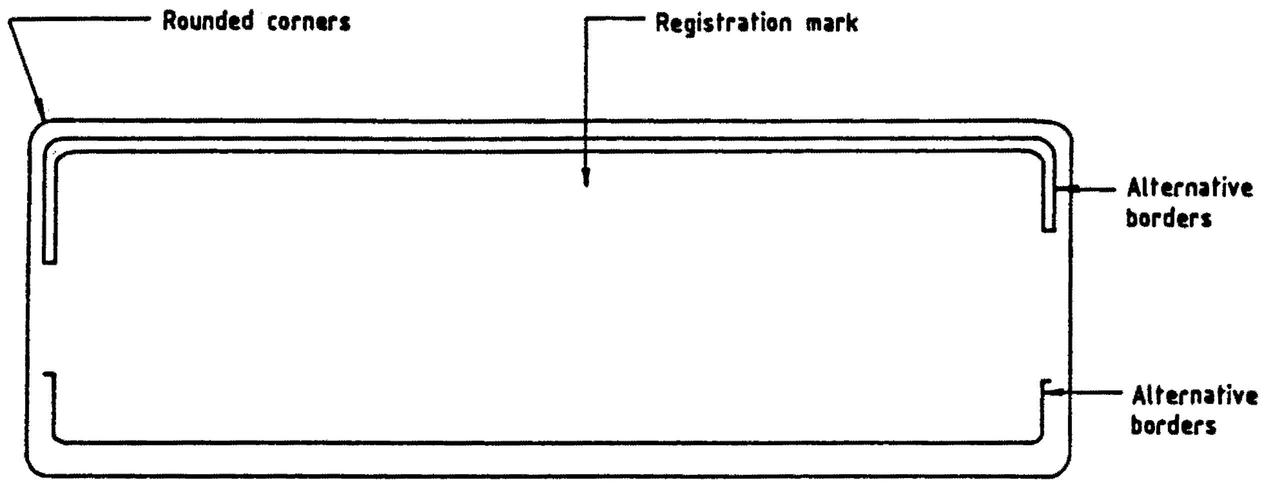
Fig 1 (continued)

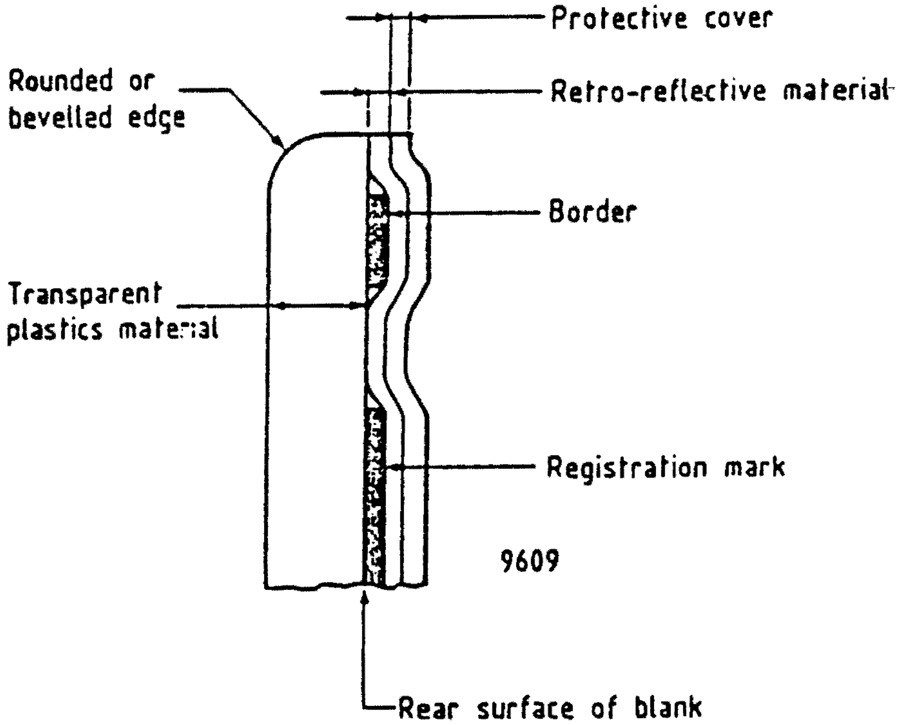


Dimensions in millimetres

Fig. 2 - Borders for Registration Plates

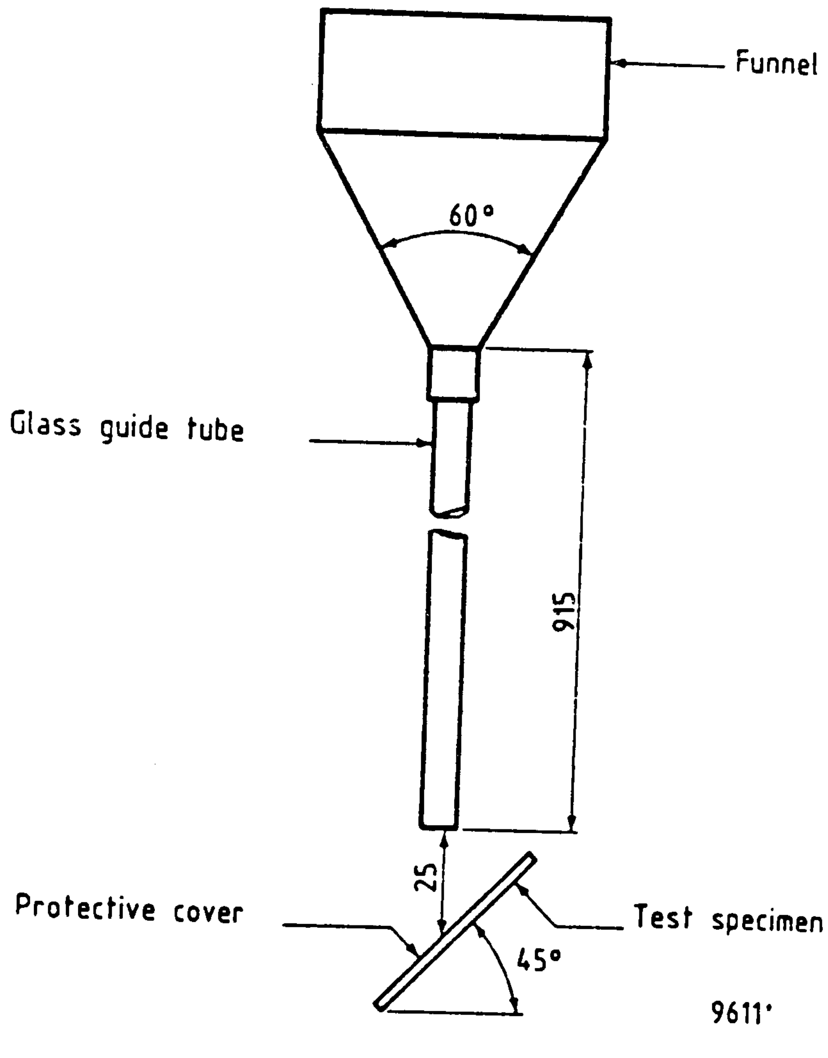
112





Enlarged side view detail

Fig. 3 - Details of Registration Plate



All dimensions and angles are approximate
Dimensions in millimetres

Fig. 4 - Apparatus for Abrasion Test

PART V

COLORIMETRY

OFFICIAL RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON ILLUMINATION

Table of Contents:

COLORIMETRY

OFFICIAL RECOMMENDATIONS OF THE COMMISSION INTERNATIONALE DE L'ECLAIRAGE (CIE)

Preface

By general consent in all countries the specification of basic standards for use in colorimetry is the province of the Commission Internationale de l'Eclairage (CIE). The first major recommendations regarding colorimetric standards were made by the CIE in 1931, and these formed the basis of modern colorimetry. The original recommendations of 1931 were reviewed from time to time by the permanent CIE Colorimetry Committee and changes were made when these were considered necessary. New recommendations were added to supplement the existing ones or to broaden the scope of colorimetry in accordance with developments in practice and science.

The deliberations and recommendations made by the CIE Colorimetry Committee are recorded in the Proceedings of the various Sessions of the CIE. Unfortunately the distribution of these Proceedings has always been rather limited and ready access to them often proves difficult. In addition, much of the material published in the Proceedings is obsolete or inconsistent with current colorimetric practice. The recommendations, though much smaller in quantity than the general deliberations of the Committee, also present an incoherent picture. Many recommendations are merely proposals to study or work on certain topics that were considered important at the time.

In view of these circumstances the CIE Colorimetry Committee decided to prepare a special Document on Colorimetry that would be a consistent and comprehensive account of the present basic colorimetric standards according to the CIE. This document is not intended to be a text book on colorimetry but rather a source of reference to the basic standards that govern modern colorimetry.

The document has taken several years of preparation during which time a total of four successive drafts were submitted by the Chairman to the experts, corresponding members, and consultants of the CIE Colorimetry Committee. At its meeting in June 1969 in Stockholm the Colorimetry Committee agreed unanimously to submit the fourth draft (with minor revisions) of the document to the CIE Action Committee for formal approval by the member bodies of the CIE. Formal approval was given in 1970.

All those experts, corresponding members, and consultants of the CIE Colorimetry Committee (E-1.3.1) who have been on the Committee's roster during the period (1964 to 1969) of preparing the document are listed below. The final English version has been translated into French by G. Bertrand (expert member from France) and into German by M. Richter (expert member from Germany).

Gunter Wyszecki,
Chairman,
CIE Expert Committee E-1.3.1
(Colorimetry).

National Research Council of Canada
Ottawa 7, Ontario Canada.

116

COLORIMETRY

OFFICIAL RECOMMENDATIONS OF THE COMMISSION INTERNATIONALE DE L'ECLAIRAGE (CIE)

The document is divided into two parts, (i) an introduction describing in general terms and in chronological order the more important activities and recommendations put forward by the CIE Colorimetry Committee, and (ii) the wording of all those recommendations regarding colorimetry now in force.

Introduction

At the 6th Session of the CIE held at Geneva in 1924 it was decided to set up a Study Group on Colorimetry[1]). This decision was taken in recognition of the fact that the measurement of color had become an important factor in several industries and scientific laboratories but none of the systems of color specification that existed at that time could be considered satisfactory for general practice. Useful discussions on the problem, however, did not begin before 1928, the year of the 7th Session of the CIE held at Saranac Inn, N.Y.[2]). At that time a working program was proposed to establish suitable basic standards which would put colorimetric practice on a unified basis. In particular, it was agreed that efforts should be made to reach agreements on a) colorimetric nomenclature, b) a standard daylight for colorimetry, and c) the 'sensation curves' of the average human observer with normal color vision. The National Committee of Great Britain was asked to undertake the duties of the CIE Secretariat on the subject of colorimetry.

At the 8th Session of the CIE held at Cambridge, England, in 1931, the first major recommendations were made which laid the basis for modern colorimetry[3]). There was a total of five recommendations. Recommendations 1, 4 and 5 established the CIE 1931 standard observer and colorimetric coordinate system, recommendation 2 specified three standard sources (A, B, and C), and recommendation 3 standardized the illuminating and viewing conditions for measuring reflecting surfaces and the standard of reflectance in the form of a magnesium-oxide surface.

The CIE 1931 standard colorimetric observer was defined by two different but equivalent sets of color-matching functions (spectral tristimulus values) based on the photopic lumious efficiency function $V(\lambda)$, already adopted by the CIE in 1924, and on experimental work carried out by Guild[4]) and Wright[5]). The first set of color-matching functions, $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$, is expressed in terms of spectral stimuli of wavelengths 700.0 nm (R), 546.1 nm (G), 435.8 nm (B) as the reference stimuli with the units adjusted so that the chromaticity coordinates of the equi-energy stimulus are all equal. (The equi-energy stimulus may be defined as a stimulus whose total radiant power at all wavelengths between any two limiting wavelengths within the visible spectrum is a constant multiple of the difference between these limiting wavelengths). The luminances L_R, L_G, L_B, of unit quantities of the reference stimuli (R), (G), (B) are in the ratios 1.0000 : 4.5907 : 0.0601; their radiances are in the ratios 72.0962 : 1.3791 : 1.0000.

The second set of color-matching functions, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, was recommended for reasons of more convenient application in practical colorimetry. Its derivation from the first set was based on a proposal by Judd[6]) and involved a linear transformation. The coefficients of the transformation were chosen so as to avoid negative values of $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ at all wavelengths. The units of the new reference stimuli (X), (Y), (Z) were adjusted to make the chromaticity coordinates of the equi-energy stimulus all equal. The transformation coefficients were further adjusted so that first no part of the spectrum locus on the chromaticity diagram was very much closer to the equi-energy point than any other part; second the dominant wavelength of one (Z) of the reference stimuli corresponded closely to the wavelength of the spectral stimulus perceived under usual viewing conditions to be psychologically unitary blue, neither reddish nor greenish; and third, the luminances L_X, L_Y, L_Z, of unit quantities of the reference stimuli were equal to 0, 1, 0, respectively, resulting in a set of color-matching functions in which $\bar{y}(\lambda)$ became identical to $V(\lambda)$.

CIE standard sources A, B, C were intended to be representative of interior illumination by tungsten-filament lamps (Source A), of illumination by direct sunlight (Source B), and of illumination by average daylight (Source C). CIE source A was a gas-filled coiled tungsten-filament lamp operating at a color temperature of 2848 K

(c_2 = 1.4350 · 10^{-2} m · K) and CIE sources B and C were produced by combining source A with liquid filters whose cell construction and chemical compositions were specified in accordance with a proposal by Davis and Gibson[7]).
The directions of illumination and viewing to be used in the colorimetry of opaque objects were specified as 45 degrees and normal to the surface, respectively. This recommendation was made in accordance with general practice prevalent at that time and in full recognition of the fact that colorimetric measurements may be affected greatly by variations of the illuminating and viewing conditions.
The standard of reflectance was specified in the form of a (smoked) magnesium-oxide surface whose spectral reflectance was taken to be equal to unity at all wavelengths within the visible spectrum. Reflectance measurements of a test object against this standard were to be made under the same illuminating and viewing conditions.
In subsequent work of the CIE Colorimetry Committee new knowledge regarding colorimetry was considered continuously. The original recommendations of 1931 were reviewed from time to time and changes made when these were considered necessary. New recommendations were added to supplement the existing ones or to broaden the scope of colorimetry in accordance with the developments in practice and science.
At the 12th Session of the CIE held in Stockholm in 1951 it was decided to keep unchanged the spectral power distribution of standard source A and this necessitated changing its definition to a gas-filled coiled tungsten-filament lamp operating at a color temperature of approximately 2854 K (c_2 = 1. 4380 · 10^{-2} m · K) according to the International Temperature Scale of 1948[8]). In 1968 the Comité International des Poids et Mesures adopted a slight modification of the International Practical Temperature Scale of 1948 (amended in 1960) and the value of c_2 is now equal to 1.4388 · 10^{-2} m · K. The change leads to another increase of the color temperature of source A, to approximately 2856 K, which has been introduced in this document together with corresponding changes to all other standard illuminants and sources presently recommended by the CIE.
At the 14th Session of the CIE held at Brussels in 1959 it was decided to consider the 'perfect reflecting diffuser' for ultimate adoption as the standard of reflectance to supersede the magnesium-oxide surface[9]).
A new set of Tables was worked out for the color-matching functions of the CIE 1931 standard colorimetric observer and these are published for the first time in this document. The new Tables are essentially the same as the original 1931 Tables but contain interpolated values at one nanometer intervals and cover an extended wavelength range from 360 to 830 nm. The original values were also smoothed slightly to eliminate small irregularities. The new values have become the official values for the CIE 1931 standard colorimetric observer.
The CIE 1931 standard colorimetric observer has been of continuous concern to the CIE Colorimetry Committee because of a number of reports indicating that the standard observer data may not adequately represent the color-matching properties of the average observer with normal color vision[10]). Particularly, it was suggested that in the wavelength region 380 to 460 nm the values of $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ were too low. The origin of this discrepancy was traced to the CIE 1924 luminous efficiency function $V(\lambda)$ which Guild and Wright had used in the derivation of their color-mixture data. In 1951 Judd reviewed the problem, and on the basis of new determinations of luminous efficiency values in the short-wave region of the spectrum he calculated revised color-matching functions[11]). The CIE then recommended that the National Committees give high priority to the researches that they had started on the luminous efficiency and color-matching functions, with a view to supplying the basis for a possible revision of the standard observer. Also the merits of the various ways of expressing the revision were to be studied.
This working program was pursued in great detail culminating in the decision to retain the CIE 1931 standard observer data for colorimetry but to supplement it by new color-matching functions $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ recommended for use whenever a more accurate correlation with visual color matching of fields of large angular subtense (more than 4° at the eye of the observer) is desired[12]). Field tests on metameric matches in the areas of subtense below 4° did not show divergencies from the predictions of the CIE 1931 standard colorimetric observer data that were considered of significant magnitude to warrant its revision.
The new color-matching functions, $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$, defining the supplementary standard colorimetric observer were adopted officially in 1964; they were derived from experimental data supplied by Stiles and Burch[13]) and Speranskaya[14]) and were first published in 1959[15]). The experimental color-matching data were obtained for a 10° field by a direct method which did not involve an appeal to heterochromatic matching, but did depend on the actual measurement of the relative power distribution in the spectrum studied. The derivation of an average set of color-matching functions suitable for the purpose of practical colorimetry was carried out by Judd and was based on a coordinate system similar to that associated with the CIE 1931 standard colorimetric observer. The $\bar{y}_{10}(\lambda)$ function was evaluated in accordance with luminous efficiency values determined by Stiles and Burch for the instrumental stimuli by means of flicker comparisons in the 10° field. The units of the new reference stimuli (X_{10}), (Y_{10}), (Z_{10}) were chosen so as to make the chromaticity coordinates of the equi-energy stimulus all equal. The large-field color-matching data as defined by the CIE 1964 supplementary standard colorimetric

observer are intended to apply to matches where the luminance and the relative spectral power distributions of the matched stimuli are such that no participation of the rod receptors of the visual mechanism is to be expected. This condition of observation is important as 'rod intrusion' may upset the predictions of the standard observer.

Field tests have been conducted with the large-field color-matching functions, $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$, and the Colorimetry Committee considered the results of these tests as being sufficiently conclusive to warrant the formal adoption of the new data.

In recent years the problem of standard daylight illuminants has been given special attention by the Colorimetry Committee. Extensive new data on natural daylight were made available by various investigators and the Committee decided in 1963 that sufficient evidence was then available to supplement the existing CIE standard illuminants by new illuminants more adequately representing phases of natural daylight[12]). These illuminants were to be defined by relative power distributions over the spectral region 300 to 830 nm. The spectral region covered the near ultraviolet because of the increasing demand for more accurate colorimetry of fluorescent materials. The CIE standard sources B and C do not adequately represent sunlight or daylight, particularly in the ultraviolet region.

The new recommendation on standard illuminants specifies a standard illuminant D_{65} with a correlated color temperature of approximately 6500 K and states that for general use in colorimetry illuminants A and D_{65} should suffice. It is further recommended that whenever daylight other than that defined by the new standard D_{65} is desired a standardized set of formulae and tables be used to calculate the appropriate spectral power distribution corresponding to any given correlated color temperature from 4000 K to 25000 K. This recommendation was based on a report prepared by Judd, MacAdam, and Wyszecki, with the collaboration of Budde, Condit, Henderson and Simonds[16]).

Another important problem the Colorimetry Committee has dealt with over several years is that concerning a coordinate system providing a three-dimensional spacing perceptually more uniform than that provided by the (XYZ)-system. There is a growing demand for such a system and many different proposals have been forwarded over the years by different investigators. The committee considered a number of the existing systems and at the 14th Session of the CIE held at Brussels in 1959 a proposal was made to adopt the MacAdam uniform-chromaticity scale diagram of 1937[17]) as a standard UCS diagram. The proposal was approved officially by the CIE in 1960 and the diagram is now known as the CIE 1960 UCS diagram. An extension of the UCS diagram to three dimensions was proposed to the Committee by Wyszecki[18]) and this formed the basis for a CIE recommendation known as the CIE 1964 (U^*, V^*, W^*) system[12]), referred to in the CIE Vocabulary as the CIE 1964 Uniform Color Space. (The symbols U^*, V^*, W^* were used to distinguish these variables from the tristimulus values U, V, W, to which they are related by non-linear equations). In this system a measure ΔE of the perceptual size of the difference between two given colors is obtained by the square root of the sum of the squares of the differences between corresponding coordinates U^*, V^*, W^*, of the two colors. The CIE recommendation was put forward in an attempt to unify the currently very diverse practice of calculation of color differences. The CIE colorimetry committee is continuing its work on color-difference formulae. At a meeting in June 1967 in Washington a detailed working program was adopted that involves the study of not only the formula recommended provisionally in 1964 but also three other formulae currently under consideration as improvements of the CIE 1964 color-difference formula[19]).

The CIE Colorimetry Committee has concerned itself with several other colorimetric problems not specifically mentioned in this introductory note. Some of these problems have been resolved and have resulted in official recommendations and these are included in the main part of this document. Other problems were of the nature of 'further study' and either did not result in official recommendations or are still being studied. These activities are not recorded in this document but can be found in the Proceedings of the various Sessions of the CIE. Neither does this document include any recommendations regarding colorimetric nomenclature and methods of assessing the color rendering properties of light sources. Both subjects used to be within the terms of reference of the Colorimetry Committee but for several years now have been subjects of separate committees[20,21]) which have prepared (or will prepare) separate documents.

119

OFFICIAL RECOMMENDATIONS

The wording of the original recommendations has been altered to be consistent with modern nomenclature, and in some cases the original recommendations have also been modified in content to bring them into line with present day thinking and practice. The versions given in this document are the official recommendations now in force and supersede all previous recommendations published in the CIE Proceedings. It is anticipated that in all subsequent CIE Proceedings an official statement will be made regarding the recommendations given in this document, and, if required, amendments will be announced at that time.

The recommendations are divided into the following four groups:

1. Recommendations concerning standard physical data,
2. Recommendations concerning standard observer data,
3. Recommendations concerning uniform color spacing,
4. Recommendations concerning miscellaneous colorimetric practices and formulae.

1. RECOMMENDATIONS CONCERNING STANDARD PHYSICAL DATA

1.1. Standard illuminants for colorimetry[1a)*)]

It is recommended that the following illuminants, defined by relative spectral power distributions given in Table 1.1.1 be used for general colorimetry:

Illuminant A: Representing light from the full radiator at absolute temperature 2856 K (approximately) according to "The International Practical Temperature Scale, 1968"[1b)].

Note: Table 1.1.5 gives the relative spectral power distribution of illuminant A from 300 to 830 nm at 1 nm intervals and with six significant figures.

Illuminant B: Representing direct sunlight with a correlated color temperature of approximately 4874 K[1c)].

Illuminant C: Representing average daylight with a correlated color temperature of approximately 6774 K[1c)].

Illuminant D_{65}: Representing a phase of daylight with a correlated color temperature of approximately 6504 K[1c)].

Note: Illuminant D_{65} supplements the illuminants A, B and C. For general use in colorimetry illuminants A and D_{65} should suffice[1d)].

Other Illuminants D:

It is recommended that whenever a phase of daylight other than that defined by the standard D_{65} is desired the following rules be observed to define it[1e)]:

a) *Chromaticity.* The 1931 (x, y) chromaticity coordinates of the daylight (D) to be defined must satisfy the following relation:

$$y_D = -3.000\, x_D^2 + 2.870\, x_D - 0.275$$

with x_D being within the range 0.250 to 0.380. The correlated color temperature T_c ($c_2 = 1.4388 \cdot 10^{-2}$ m · K) of daylight D is related to x_D by the following formulae based on normals to the Planckian locus on the CIE 1960 UCS diagram.

*) Superscripts refer to Explanatory Comments on the Official Recommendations given on pages 23 to 26.

(i) for correlated color temperatures from approximately 4000 K to 7000 K:

$$x_D = -4.6070 \frac{10^9}{T_c^3} + 2.9678 \frac{10^6}{T_c^2} + 0.09911 \frac{10^3}{T_c} + 0.244063$$

(ii) for correlated color temperatures from 7000 K to approximately 25000 K:

$$x_D = -2.0064 \frac{10^9}{T_c^3} + 1.9018 \frac{10^6}{T_c^2} + 0.24748 \frac{10^3}{T_c} + 0.237040$$

b) *Relative spectral power distribution.* The relative spectral power distribution $S(\lambda)$ of daylight D is to be computed from

$$S(\lambda) = S_0(\lambda) + M_1 S_1(\lambda) + M_2 S_2(\lambda)$$

where $S_0(\lambda)$, $S_1(\lambda)$, $S_2(\lambda)$ are functions of wavelength, λ, given in Table 1.1.2, and M_1, M_2 are factors whose values are related to the chromaticity coordinates x_D, y_D as follows:

$$M_1 = \frac{-1.3515 - 1.7703\, x_D + 5.9114\, y_D}{0.0241 + 0.2562\, x_D - 0.7341\, y_D}$$

$$M_2 = \frac{0.0300 - 31.4424\, x_D + 30.0717\, y_D}{0.0241 + 0.2562\, x_D - 0.7341\, y_D}$$

c) *Calculations*[1 f]. To facilitate the practical use of this recommendation values of x_D, y_D, M_1, and M_2 for correlated color temperatures in the range 4000 to 25000 K are given in Table 1.1.3. Although the formulae of this recommendation enable the relative spectral power distribution for any correlated color temperature to be calculated, and the values given in Table 1.1.3 facilitate their calculations for a wide range of correlated color temperature, it is recommended that in the interests of standardization, D_{65} be used whenever possible; when D_{65} cannot be used, it is recommended that one of the two relative spectral power distributions given in Table 1.1.4 (D_{55} and D_{75}) having correlated color temperatures of approximately 5503 K and 7504 K, be used whenever possible.

Note 1:
Seasonal variations in the spectral power distribution of daylight are known to occur, particularly in the ultraviolet region, but this recommendation should be used pending the availability of further information on these variations.

Note 2:
The spectral power distributions of daylight D produced by this recommendation are based on experimental observations over the range 330 to 700 nm, and on extrapolation in the ranges 300 to 330 and 700 to 830 nm. The extrapolated values are believed to be accurate enough for normal colorimetric purposes, but should not be used for other purposes if high accuracy in these regions is necessary.

Note 3:
The relative spectral power distributions of daylight D are given in these recommendations at every 10 nm and represent values averaged over the wavelength ranges from −5 to +5 nm from the nominal values. If for the purpose of colorimetric computation values are required at closer intervals they should be interpolated from the 10 nm values linearly.
Table 1.1.5 gives the relative spectral power distribution of D_{65} at intervals of 1 nm and with six significant figures. The values of Table 1.1.5 have been calculated by following the procedure stated in paragraphs a) and b) above and then interpolating linearly.

In calculating S(λ) the factors M_1 and M_2 were used with three decimal figures as given in Table 1.1.3. When the values of Table 1.1.5 are rounded to one decimal figure the values of Table 1.1.1 are obtained.

Note 4:
When samples exhibiting fluorescence excited by ultraviolet radiation are involved, one of the illuminants defined in these recommendations should be used to represent daylight instead of standard illuminants B and C which have insufficient ultraviolet contents.

Note 5:
The chromaticity coordinates of the illuminants A, B, C, D_{55}, D_{65}, D_{75}, calculated from the values of S(λ) given in Tables 1.1.1, 1.1.4 and 1.1.5, are given in Table 1.1.6.

1.2 Artificial sources representative of standard illuminants[1a)]

It is recommended that the following artificial sources be used if it is desired to realize the standard illuminants defined in Section 1.1 for actual laboratory inspection.

Source A:

Illuminant A is to be realized by a gas-filled coiled-tungsten filament lamp operating at a correlated color temperature of 2856 K ($c_2 = 1.4388 \cdot 10^{-2}$ m · K). A lamp with a fused-quartz envelope or window is recommended if the spectral power distribution of the ultraviolet radiation of illuminant A is to be realized more accurately.

Source B:

Illuminant B is to be realized by source A, combined with a filter consisting of a layer, one centimeter thick of each of two solutions B_1 and B_2, contained in a double cell made of colorless optical glass. The solutions are to be made up as follows:

Solution B_1:

Copper Sulphate ($CuSO_4 \cdot 5H_2O$)	2.452 g
Mannite [$C_6H_8(OH)_6$]	2.452 g
Pyridine (C_5H_5N)	30.0 ml
Distilled water to make	1000.0 ml

Solution B_2:

Cobalt Ammonium Sulphate [$CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$]	21.71 g
Copper Sulphate ($CuSO_4 \cdot 5H_2O$)	16.11 g
Sulphuric Acid (density 1.835 g · ml^{-1})	10.0 ml
Distilled water to make	1000.0 ml

Source C:

Illuminant C is to be realized by source A, combined with a filter consisting of a layer, one centimeter thick of each of two solutions C_1 and C_2, contained in a double cell made of colorless optical glass. The solutions are to be made up as follows:

Solution C_1:

Copper Sulphate ($CuSO_4 \cdot 5H_2O$)	3.412 g
Mannite [$C_6H_8(OH)_6$]	3.412 g
Pyridine (C_5H_5N)	30.0 ml
Distilled water to make	1000.0 ml

Solution C_2: 122

Cobalt Ammonium Sulphate $[CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O)]$	30.58	g
Copper Sulphate ($CuSO_4 \cdot 5H_2O$)	22.52	g
Sulphuric Acid (density 1.835 g · ml^{-1})	10.0	ml
Distilled water to make	1000.0	ml

Source D_{65}:

At present no artificial source is recommended to realize illuminant D_{65} or any other illuminant D of different correlated color temperature. It is hoped that new developments in light sources and filters will soon offer a sufficient basis for a CIE recommendation.

Note 1:
The artificial sources defined above and recommended as representative sources for standard illuminants are to be named 'CIE standard sources for colorimetry'.

Note 2:
Whenever the highest accuracy of the spectral power distribution of a standard source is required, it is advisable to make a spectroradiometric calibration of the actual source used, because the relative spectral powers of the source may not exactly coincide at all wavelengths with those defining the corresponding standard illuminant.

1.3 Standard of reflectance factor2)

The perfect reflecting diffuser is recommended as the reference standard. It is defined as the ideal uniform diffuser with a reflectance equal to unity. Smoked magnesium oxide is superseded from January 1, 1969.

1.4 Illuminating and viewing conditions3)

It is recommended that the colorimetric specification of opaque specimens be given so as to correspond to one of the following illuminating and viewing conditions:

a) 45°/normal (abbreviation, 45/0):
The specimen is illuminated by one or more beams whose axes are at an angle of 45° ± 5° from the normal to the specimen surface. The angle between the direction of viewing and the normal to the specimen should not exceed 10°. The angle between the axis and any ray of an illuminating beam should not exceed 5°. The same restriction should be observed in the viewing beam.

b) Normal/45° (abbreviation, 0/45):
The specimen is illuminated by a beam whose axis is at an angle not exceeding 10 degrees from the normal to the specimen. The specimen is viewed at an angle of 45° ± 5° from the normal. The angle between the axis and any ray of the illuminating beam should not exceed 5°. The same restriction should be observed in the viewing beam.

c) Diffuse/normal (abbreviation, d/0):
The specimen is illuminated diffusely by an integrating sphere. The angle between the normal to the specimen and the axis of the viewing beam should not exceed 10°. The integrating sphere may be of any diameter provided the total area of the ports does not exceed 10 percent of the internal reflecting sphere area. The angle between the axis and any ray of the viewing beam should not exceed 5°.

d) Normal/diffuse (abbreviation, 0/d):
The specimen is illuminated by a beam whose axis is at an angle not exceeding 10° from the normal to the specimen. The reflected flux is collected by means of an integrating sphere. The angle between the axis and any ray of the illuminating beam should not exceed 5°. The integrating sphere may be of any diameter provided the total area of the ports does not exceed 10 percent of the internal reflecting sphere area.

Note 1:
For the conditions 'Diffuse/normal' and 'Normal/diffuse' the influence of the specular component of specimens with mixed reflection may be reduced by the use of a gloss trap. If a gloss trap is used details of its size, shape, and position should be given.

Note 2:
In the 'Normal/45°' and the 'Normal/diffuse' conditions specimens with mixed reflection should not be measured with strictly normal illumination.

Note 3:
The '45°/normal' condition gives the radiance factor $\beta_{45/0}$. The 'Normal/45°', condition gives the radiadance factor $\beta_{0/45}$. The 'Diffuse/normal' condition gives the radiance factor $\beta_{d/0}$. The 'Normal/diffuse' condition gives the reflectance ρ.

Note 4:
It is important that the particular illuminating and viewing conditions used be specified even if they are within the range of one of the recommended standard conditions.

2. RECOMMENDATIONS CONCERNING STANDARD OBSERVER DATA[4)]

2.1 CIE 1931 standard colorimetric observer

It is recommended that colorimetric specifications of color stimuli be based on the spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, given in Table 2.1, whenever correlation with visual color matching of fields of angular subtense between 1 and 4° at the eye of the observer is desired. The spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ as given in Table 2.1 define the CIE 1931 standard colorimetric observer.

Note 1:
$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ refer to a set of reference stimuli (X), (Y), (Z) chosen for reasons of convenience in colorimetric computations.

Note 2:
The $\bar{y}(\lambda)$ function is identical with $V(\lambda)$, the photopic luminous efficiency function defining the standard observer for photometry.

Note 3:
If the spectral tristimulus values of Table 2.1 are required at closer intervals than 1 nm intervals, a linear interpolation should be used.

Note 4:
The chromaticity coordinates $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ of the spectral stimuli are given in Table 2.1 and were derived from $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ by forming the ratios

$$x(\lambda) = \frac{\bar{x}(\lambda)}{\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda)}$$

$$y(\lambda) = \frac{\bar{y}(\lambda)}{\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda)}$$

$$z(\lambda) = \frac{\bar{z}(\lambda)}{\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda)}$$

Note 5:
The chromaticity coordinates x_E, y_E, z_E of the equi-energy stimulus derived from the sums $\Sigma\bar{x}(\lambda)$, $\Sigma\bar{y}(\lambda)$, $\Sigma\bar{z}(\lambda)$ of Table 2.1 are

$$x_E = 0.333\ 314$$

$$y_E = 0.333\ 288$$

$$z_E = 0.333\ 398$$

They differ somewhat from the original 1931 data due to the smoothing and extrapolation of the spectral tristimulus values (see also Section 2.3, Note 1). The original data are as follows:

$$x_E = 0.333\ 332$$

$$y_E = 0.333\ 333$$

$$z_E = 0.333\ 335$$

2.2 **CIE 1964 supplementary standard colorimetric observer**

It is recommended that colorimetric specifications of color stimuli be based on the spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$, given in Table 2.2, whenever correlation with visual color matching of fields of angular subtense more than 4° at the eye of the observer is desired. The spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ as given in Table 2.2 define the CIE 1964 supplementary standard colorimetric observer.

Note 1:
$\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ refer to a set of reference stimuli (X_{10}), (Y_{10}), (Z_{10}) chosen for reasons of convenience in colorimetric computations.

Note 2:
If the spectral tristimulus values of Table 2.2 are required at closer intervals than 1 nm intervals, a linear interpolation should be used.

Note 3:
The chromaticity coordinates $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$ of the spectral stimuli are given in Table 2.2 and were derived from $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ by forming the ratios

$$x_{10}(\lambda) = \frac{\bar{x}_{10}(\lambda)}{\bar{x}_{10}(\lambda) + \bar{y}_{10}(\lambda) + \bar{z}_{10}(\lambda)}$$

$$y_{10}(\lambda) = \frac{\bar{y}_{10}(\lambda)}{\bar{x}_{10}(\lambda) + \bar{y}_{10}(\lambda) + \bar{z}_{10}(\lambda)}$$

$$z_{10}(\lambda) = \frac{\bar{z}_{10}(\lambda)}{\bar{x}_{10}(\lambda) + \bar{y}_{10}(\lambda) + \bar{z}_{10}(\lambda)}$$

Note 4:
The chromaticity coordinates $x_{10,E}$, $y_{10,E}$, $z_{10,E}$ of the equi-energy stimulus derived from the sums $\Sigma\bar{x}_{10}(\lambda)$, $\Sigma\bar{y}_{10}(\lambda)$, $\Sigma\bar{z}_{10}(\lambda)$ of Table 2.2 are

$$x_{10,E} = 0.333\ 296$$

$$y_{10,E} = 0.333\ 335$$

$$z_{10,E} = 0.333\ 369$$

2.3 Abridged Tables of spectral tristimulus values

In most colorimetric computations involving the spectral tristimulus values of either the CIE 1931 standard colorimetric observer or the CIE 1964 supplementary standard colorimetric observer, it should suffice to use rounded-off values of the respective spectral tristimulus values at 5 nanometer intervals from 380 to 780 nm. Tables 2.3.1 and 2.3.2 give the recommended abridged sets of spectral tristimulus values for both standard observers and corresponding chromaticity coordinates. In some colorimetric computations it might be sufficient to use the spectral tristimulus values at 10 nm intervals. If this is desired Tables 2.3.1 and 2.3.2 are recommended with all values at wavelengths 385, 395, ... 775 nm being ignored.
The use of abridged tables will generally reduce the accuracy of colorimetric computations to some degree and it is recommended that results obtained in this way be accompanied with a statement regarding the computational procedure followed.

Note 1:
The spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ given in Table 2.3.1 agree closely with those defined originally in 1931. Three minor changes have been introduced. At λ = 775 nm the new value of $\bar{x}(\lambda)$ is 0.0001 instead of 0.0000; at λ = 555 nm $\bar{y}(\lambda)$ is 1.0000 instead of 1.0002, and at λ = 740 nm $\bar{y}(\lambda)$ is 0.0002 instead of 0.0003. These changes are considered insignificant in most colorimetric computations.

Note 2:
The chromaticity coordinates x_E, y_E, z_E of the equi-energy stimulus derived from the sums $\Sigma x(\lambda)$, $\Sigma y(\lambda)$, $\Sigma z(\lambda)$ of Table 2.3.1 are for summations at 5 nm intervals:

$$x_E = 0.333\ 334$$

$$y_E = 0.333\ 330$$

$$z_E = 0.333\ 336,$$

and for summation at 10 nm intervals:

$$x_E = 0.333\ 381$$

$$y_E = 0.333\ 444$$

$$z_E = 0.333\ 175$$

The chromaticity coordinates $x_{10,E}$, $y_{10,E}$, $z_{10,E}$ of the equi-energy stimulus derived from the sums $\Sigma\bar{x}_{10}(\lambda)$, $\Sigma\bar{y}_{10}(\lambda)$, $\Sigma\bar{z}_{10}(\lambda)$ of Table 2.3.2 are for summation at 5 nm intervals:

$$x_{10,E} = 0.333\ 296$$

$$y_{10,E} = 0.333\ 339$$

$$z_{10,E} = 0.333\ 366,$$

and for summation at 10 nm intervals:

$$x_{10,E} = 0.333\ 336$$

$$y_{10,E} = 0.333\ 330$$

$$z_{10,E} = 0.333\ 333$$

3. RECOMMENDATIONS CONCERNING UNIFORM COLOR SPACING[5a)]

3.1 CIE 1960 UCS diagram

The use of the following chromaticity diagram is provisionally recommended whenever a projective transformation of the (x,y)-diagram yielding color spacing perceptually more nearly uniform than that of the (x,y)-diagram is desired. The chromaticity diagram is produced by plotting $u = 4X/(X + 15Y + 3Z)$ as abscissa and $v = 6Y/(X + 15Y + 3Z)$ as ordinate, in which X, Y, Z are tristimulus values.

Note 1:
The color spacing afforded by this chromaticity diagram is known to be perceptually more nearly uniform than the CIE (x,y)-chromaticity diagram for observation of specimens having negligibly different luminances ($\Delta Y \rightarrow 0$). This diagram is intended to apply to comparisons of differences between object colors of the same size and shape viewed in identical white to middle-gray surroundings by an observer photopically adapted to a field of chromaticity not too different from that of average daylight.

Note 2:
The same chromaticity diagram is produced by plotting $u = 4x/(-2x + 12y + 3)$ as abscissa and $v = 6y/(-2x + 12y + 3)$ as ordinate, where x, y are chromaticity coordinates.

Note 3:
If the angle subtended at the eye by the pairs of specimens being compared is more than 1° and less than or equal to 4°, the tristimulus values X, Y, Z (or chromaticity coordinates, x, y), calculated with respect to the CIE 1931 standard colorimetric observer should be used for the calculation of u and v. If this angular subtense is greater than 4°, the tristimulus values X_{10}, Y_{10}, Z_{10}, (or chromaticity coordinates x_{10}, y_{10}) calculated with respect to the CIE 1964 supplementary standard colorimetric observer should be used for the calculation of u_{10} and v_{10}.

Note 4:
To facilitate colorimetric calculations in terms of the CIE 1960 UCS diagram[5b)] Tables 2.3.3 and 2.3.4 have been prepared which give the spectral tristimulus values $\bar{u}(\lambda)$, $\bar{v}(\lambda)$, $\bar{w}(\lambda)$ and corresponding chromaticity coordinates $u(\lambda)$, $v(\lambda)$, $w(\lambda)$ derived from the CIE 1931 and CIE 1964 standard spectral tristimulus values defined respectively in Tables 2.1 and 2.2, by using the following transformation equations:

$$\bar{u}(\lambda) = \tfrac{2}{3}\,\bar{x}(\lambda)$$

$$\bar{v}(\lambda) = \bar{y}(\lambda)$$

$$\bar{w}(\lambda) = \tfrac{1}{2}[-\bar{x}(\lambda) + 3\bar{y}(\lambda) + \bar{z}(\lambda)]$$

and

$$u(\lambda) = \bar{u}(\lambda)/[\bar{u}(\lambda) + \bar{v}(\lambda) + \bar{w}(\lambda)]$$

$$v(\lambda) = \bar{v}(\lambda)/[\bar{u}(\lambda) + \bar{v}(\lambda) + \bar{w}(\lambda)]$$

$$w(\lambda) = \bar{w}(\lambda)/[\bar{u}(\lambda) + \bar{v}(\lambda) + \bar{w}(\lambda)]$$

The values of Table 2.3.3 are obtained by inserting in the above equations the corresponding values of $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ of Table 2.1. The values of Table 2.3.4 are obtained by replacing $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ by the corresponding values of $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ of Table 2.2.
The transformations were made by using all figures of the spectral tristimulus values of Tables 2.1 and 2.2, but the results given in Tables 2.3.3 and 2.3.4 have been rounded to four decimals both for the spectral tristimulus values and the chromaticity coordinates.

3.2 CIE 1964 uniform color space

Pending the development of an improved coordinate system, the use of the following coordinate system is recommended whenever a three-dimensional spacing perceptually more nearly uniform than that provided by the (XYZ)-system is desired. The recommended coordinate system is formed by plotting the variables U^*, V^* and W^* along orthogonal axes where U^*, V^* and W^* are defined in terms of the tristimulus values X, Y, Z as:

$$W^* = 25Y^{1/3} - 17, \quad 1 \leqslant Y \leqslant 100;$$

$$U^* = 13W^*(u - u_o);$$

$$V^* = 13W^*(v - v_o);$$

where u and v are defined as follows:

$$u = \frac{4X}{(X + 15Y + 3Z)}; \qquad v = \frac{6Y}{(X + 15Y + 3Z)}$$

and u_o, v_o are values of these variables for the nominally achromatic color placed at the origin of the (U^*, V^*)-system. (This is an extension of the CIE 1960 UCS diagram to three dimensions).

Note 1:
For object colors the choice of u_o, v_o to correspond to the illuminant is satisfactory.

Note 2:
If the angle subtended at the eye by the pairs of object colors being compared is more than 1° and less than or equal to 4°, the tristimulus values X, Y, Z calculated with respect to the CIE 1931 standard colorimetric observer should be used for the calculation of U^*, V^*, and W^*. If this angular subtense is greater than 4°, the tristimulus values X_{10}, Y_{10}, Z_{10} calculated with respect to the CIE 1964 supplementary standard colorimetric observer should be used for the calculation of U^*_{10}, V^*_{10} and W^*_{10}.

Note 3:
This system was chosen from among others of about equal merit to promote uniformity of practice.

3.3 CIE 1964 color-difference formula

It is recommended that the measure ΔE of the perceptual size of the difference between color (U^*_1, V^*_1, W^*_1) and color (U^*_2, V^*_2, W^*_2) be calculated by means of the following formula

$$\Delta E_{CIE} = [(U^*_1 - U^*_2)^2 + (V^*_1 - V^*_2)^2 + (W^*_1 - W^*_2)^2]^{1/2},$$

defining the distance in the CIE 1964 uniform color space between colors (U^*_1, V^*_1, W^*_1) and (U^*_2, V^*_2, W^*_2).

Note:
This measure ΔE_{CIE} is intended to apply to comparisons of differences between object colors of the same size and shape viewed in identical white to middle-gray surroundings by an observer photopically adapted to a field of chromaticity not too different from that of average daylight.

4. RECOMMENDATIONS CONCERNING MISCELLANEOUS COLORIMETRIC PRACTICES AND FORMULAE

4.1 Calculation of tristimulus values[6a)]

The CIE tristimulus values of a color stimulus may be obtained by multiplying the color stimulus function $\varphi(\lambda)$ by the CIE spectral tristimulus values and integrating these products over the whole spectrum:

128

$$X = k \int_\lambda \varphi(\lambda)\,\bar{x}(\lambda)\,d\lambda \qquad X_{10} = k_{10} \int_\lambda \varphi(\lambda)\,\bar{x}_{10}(\lambda)\,d\lambda$$

$$Y = k \int_\lambda \varphi(\lambda)\,\bar{y}(\lambda)\,d\lambda \qquad Y_{10} = k_{10} \int_\lambda \varphi(\lambda)\,\bar{y}_{10}(\lambda)\,d\lambda$$

$$Z = k \int_\lambda \varphi(\lambda)\,\bar{z}(\lambda)\,d\lambda \qquad Z_{10} = k_{10} \int_\lambda \varphi(\lambda)\,\bar{z}_{10}(\lambda)\,d\lambda$$

The symbols X, Y, Z refer to tristimulus values in the CIE 1931 standard colorimetric system, the symbols X_{10}, Y_{10}, Z_{10} to tristimulus values in the CIE 1964 supplementary standard colorimetric system. Similarly, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the spectral tristimulus values defining the CIE 1931 standard colorimetric observer, and $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ are the spectral tristimulus values defining the CIE 1964 supplementary standard colorimetric observer. The constants k and k_{10} are normalizing factors defined as

$$k = 100/\int_\lambda S(\lambda)\,\bar{y}(\lambda)\,d\lambda, \qquad k_{10} = 100/\int_\lambda S(\lambda)\,\bar{y}_{10}(\lambda)\,d\lambda$$

Note 1:
For object colors the color stimulus function $\varphi(\lambda)$ is the product of the spectral reflectance $\rho(\lambda)$, or the spectral radiance factor $\beta(\lambda)$, or the spectral transmittance $\tau(\lambda)$ of the object and the relative spectral power distribution $S(\lambda)$ of the illuminant irradiating the object; thus either

$$\varphi(\lambda) = \rho(\lambda)\,S(\lambda),$$
$$\text{or} \quad \varphi(\lambda) = \beta(\lambda)\,S(\lambda),$$
$$\text{or} \quad \varphi(\lambda) = \tau(\lambda)\,S(\lambda).$$

For illuminants the color stimulus function $\varphi(\lambda)$ is simply the relative spectral power distribution of the illuminant; thus $\varphi(\lambda) = S(\lambda)$.
It is recommended that whenever possible, for calculating the tristimulus values of object colors the illuminant be one of the standard illuminants (Section 1.1).

Note 2:
With k as defined above, Y becomes the luminous reflectance of the object when $\varphi(\lambda) = \rho(\lambda)\,S(\lambda)$, the luminance factor when $\varphi(\lambda) = \beta(\lambda)\,S(\lambda)$, and the luminous transmittance when $\varphi(\lambda) = \tau(\lambda)\,S(\lambda)$, in each case expressed as a percentage. The calculated value of Y_{10} has no significance with regard to standard photometric quantities. To calculate the luminous reflectance (or luminance factor, or luminous transmittance) the function $\bar{y}(\lambda)$, which is identical to $V(\lambda)$, must be used.

Note 3:
The calculation of the luminance L of a color stimulus requires that the color stimulus function $\varphi(\lambda)$ be the spectral concentration of radiance $L_{e\lambda}$. The constant factor k is then set equal to K_m, the maximum luminous efficacy, which is equal approximately to 680 lumens per watt.[6b] Thus

$$L = K_m \int_\lambda L_{e\lambda}\,\bar{y}(\lambda)\,d\lambda \qquad (\mathrm{cd \cdot m^{-2}\ or\ lm \cdot sr^{-1} \cdot m^{-2}})$$

Note 4:
In all practical calculations of tristimulus values the integration is approximated by a summation. Thus, for example,

$$X = k \sum_\lambda \varphi(\lambda)\,\bar{x}(\lambda)\,\Delta\lambda$$

$$Y = k \sum_\lambda \varphi(\lambda)\,\bar{y}(\lambda)\,\Delta\lambda$$

$$Z = k \sum_\lambda \varphi(\lambda)\,\bar{z}(\lambda)\,\Delta\lambda$$

$$\text{with} \quad k = 100/\sum_\lambda S(\lambda)\,\bar{y}(\lambda)\,\Delta\lambda.$$

The wavelength interval $\Delta\lambda$ is either 1, 5, or 10 nm and the spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are those defined in Table 2.1 or Table 2.3.1. Similar formulae are used for the calculation of X_{10}, Y_{10}, Z_{10}, in which case the spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ of Table 2.2 or Table 2.3.2 are used.

4.2 Calculation of chromaticity coordinates[6a)]

The chromaticity coordinates (x, y, z) are derived from the tristimulus values (X, Y, Z) as follows:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}.$$

Because of the relation $x + y + z = 1$ it suffices to use x, y only.

Note:
The chromaticity coordinates x_{10}, y_{10}, z_{10} are computed similarly from the tristimulus values X_{10}, Y_{10}, Z_{10}.

4.3 Equations representing relationships between color stimuli[7)]

When equations are used to represent relationships between color stimuli, symbols of vector notation should be used instead of those for numerical relationships. For these equations one of the following forms should be used:

$$\begin{aligned}(C) &\equiv X(X) + Y(Y) + Z(Z)\\ \mathfrak{C} &= X\mathfrak{X} + Y\mathfrak{Y} + Z\mathfrak{Z}\\ \mathbf{C} &= X\mathbf{X} + Y\mathbf{Y} + Z\mathbf{Z}\end{aligned}$$

where X, Y, Z are the tristimulus values of color stimulus (C), $\mathfrak{C}$ or **C**. The unit vectors of the reference stimuli are indicated either by (X), (Y), (Z), in which case the sign '≡', pronounced 'matches', should be used, or by the Gothic capital letters $\mathfrak{X}$, $\mathfrak{Y}$, $\mathfrak{Z}$, or by the boldface Roman letters **X**, **Y**, **Z**, in the two latter cases the sign '=', pronounced 'equals', should be used.

4.4 Excitation and colorimetric purity[8)]

It is recommended that excitation purity of a given color stimulus be represented by the symbol p_e, and be calculated by the one of the formulae

$$p_e = (y - y_w)/(y_d - y_w), \text{ or } p_e = (x - x_w)/(x_d - x_w),$$

for which the numerator has the greater arithmetic value.
It is recommended that colorimetric purity for a given stimulus be represented by the symbol p_c and be calculated by the formula:

$$p_c = p_e y_d / y.$$

In these expressions x, y are the chromaticity coordinates of the given stimulus with respect to the CIE 1931 standard colorimetric system; x_w, y_w are the coordinates of the achromatic stimulus, which is conventionally taken to have zero purity. For stimuli referring to self-luminous objects, x_w, y_w are the coordinates of the equi-energy stimulus (see Section 2.1, Note 5; Section 2.3, Note 2). For stimuli referring to object colors, x_w, y_w are the coordinates of the light used to illuminate the object. The chromaticity coordinates x_d, y_d specify in the chromaticity diagram the point on the spectrum locus, or on the boundary joining its extremes (purple line), representing the stimulus required to be mixed with the achromatic stimulus to match the stimulus considered.

Note:
Similar formulae are used when excitation purity and colorimetric purity are calculated with respect to the CIE 1964 supplementary standard colorimetric system.

4.5 **Determination of chromaticity coordinates of fluorescent lamps**[9)]

It is recommended that international comparisons of chromaticity coordinates (x, y) of fluorescent lamps shall be based upon measurements of spectral power distributions reduced by computation in accordance with recommendations 4.1 and 4.2.

Note 1:
By current practice this method is applied chiefly to fluorescent lamps used as standards. Individual lamps in any international comparison may, if desired, be evaluated in terms of standards of the same spectral type by means of either physical or visual colorimeters. If physical colorimeters are used, they should be carefully adjusted to the CIE 1931 standard colorimetric observer by spectrum templates or by filters. Visual colorimeters with more than three matching stimuli should be preferred to those having only three matching stimuli.

131

EXPLANATORY COMMENTS ON THE OFFICIAL RECOMMENDATIONS

1(a) This recommendation deviates from the original regarding 'CIE standard sources A, B, C' (CIE Proc. 8th Session, Cambridge 1931; p. 19, resolution 2. Revision in CIE Proc. 12th Session, Stockholm 1951; Vol. 3, p. 63, 7- colorimetry, recommendation 1). A distinction is made between 'illuminant' and 'source'. The term 'source' refers to a physical emitter of light, such as a lamp or the sun and sky. The term 'illuminant' refers to a specific spectral power distribution, not necessarily provided directly by a source, and not necessarily realizable by a source. The present recommendation first defines 'standard illuminants' by relative spectral power distributions and then 'standard sources'. The definition of the standard sources is considered secondary as it is conceivable that new developments in lamps and filters will bring about improved standard sources that represent the standard illuminants more accurately and are more suitable for laboratory use. Presently no recommendation has been made for a standard source representing standard illuminant D_{65}. The original recommendations regarding standard illuminant D_{65} (originally called D_{6500}) and other standard illuminants D representing daylight of different correlated color temperatures are given in CIE Proc. 15th Session, Vienna 1963; Vol. A, p. 35, recommendations 2 and 3, and in CIE Proc. 16th Session, Washington 1967, Compte Rendu d'Activité du Comité d'Experts E-1.3.1 (colorimetry).

In 1968 the Comité International des Poids et Mesures modified the 'International Practical Temperature Scale, 1948 (amended 1960)' and the value of the radiation constant c_2 was set equal to $1.4388 \cdot 10^{-2}$ m · K. The modification affects the color temperature or correlated color temperature of the CIE illuminants and sources and the appropriate changes have been made in this document.

(b) The relative spectral power distribution of illuminant A has been calculated in accordance with Planck's radiation law which gives the spectral concentration of radiant exitance of a full radiator as a function of wavelength and temperature:

$$M_{e,\lambda}(\lambda,T) = c_1 \lambda^{-5} (e^{c_2/\lambda T} - 1)^{-1} \ \mathrm{W \cdot m^{-3}}$$

where the radiation constants are taken as

$$c_1 = 3.74150 \cdot 10^{-16} \ \mathrm{W \cdot m^2}$$

$$c_2 = 1.4388 \cdot 10^{-2} \ \mathrm{m \cdot K}, \text{ and}$$

the temperature T is set equal to

$$T = \frac{1.4388}{1.4350} 2848 \ \mathrm{K} \cong 2856 \ \mathrm{K}$$

The choice of this temperature assures a spectral power distribution that is identical to the one adopted in 1931 for illuminant A when c_2 was equal to $1.4350 \cdot 10^{-2}$ m · K and T was set equal to 2848 K in accordance with the 'International Practical Temperature Scale, 1927'.

The calculated values of $M_{e,\lambda}$ have been normalized by computing $S(\lambda) = 100 \ M_{e,\lambda}/M_{e,560}$; that is $S(\lambda) = 100.00$ for $\lambda = 560 \cdot 10^{-9}$ m = 560 nm. Thus the numerical value of c_1 is of no importance in the calculations. The relative spectral power distribution $S(\lambda)$ is given in Table 1.1.5 from 300 to 830 nm at 1 nm intervals and with six significant figures. In Table 1.1.1 these values are given at 5 nm intervals and rounded-off to two decimals.

The values of $S(\lambda)$ for illuminant A given in Table 1.1.1 show, in several instances, small and insignificant discrepancies of one unit in the last decimal from corresponding values commonly used in various publications. The values given in Table 1.1.1 are adopted here as the correctly rounded-off values.

(c) The correlated color temperature of an illuminant is defined by the temperature corresponding to the point on the Planckian locus which is nearest to the point representing the chromaticity of the illuminant in the CIE 1960 UCS diagram when based on the data of the CIE 1931 standard colorimetric observer (see Section 3.1). The correlated color temperatures given in this document for illuminants B, C, and D_{65} have been determined by commonly used graphical and numerical methods.

The correlated color temperatures are affected by the numerical value of the radiation constant c_2. In accordance with the 'International Practical Temperature Scale, 1948, amended 1960' the value of c_2 was equal to $1.4380 \cdot 10^{-2}$ m · K. With this value the correlated color temperatures of illuminants B, C, and D_{65} are approximately equal to 4871 K, 6770 K, and 6500 K, respectively. The change of c_2 to the value of $1.4388 \cdot 10^{-2}$ m · K ('International Practical Temperature Scale, 1968') increases the correlated color temperatures of illuminants B, C, and D_{65} each by the factor 1.4388/1.4380. Thus the correlated color temperatures of these illuminants increase by approximately 3 K, 4 K, and 4 K, respectively.

(d) Illuminants B and C do not adequately represent, as originally intended, common phases of daylight. It is anticipated that at some future date, that is yet to be decided, illuminants B and C will be dropped from the list of recommended standard illuminants.

(e) The coefficients of the formulae for x_D have been changed slightly to account for the change of c_2 from $1.4380 \cdot 10^{-2}$ m · K to $1.4388 \cdot 10^{-2}$ m · K. The original coefficients (see CIE Proc. 16th Session, Washington 1967, Compte Rendu d'Activité du Comité d'Experts E-1.3.1 (colorimetry) have been multiplied by $(1.4388/1.4380)^n$ where n is equal to the exponent of T_c associated with the coefficient.

(f) The precision of the calculated values x_D, y_D, M_1, M_2, and $S(\lambda)$ is affected by the number of significant figures carried through the various stages of calculation. Thus rounded-off values from one set of calculations to another may differ occasionally by one unit in the last digit.

2. This recommendation supersedes the original given in CIE Proc. 8th Session, Cambridge 1931, p. 23, resolution 3a, and is in accordance with agreements reached in 1959 and 1967 (CIE Proc. 14th Session, Brussels 1959, Vol. A, p. 36, recommendation 2; Meeting of E-1.3.1 on June 15, 1967 in Washington).

3. This recommendation has been changed from the original given in CIE Proc. 8th Session, Cambridge 1931, p. 23, resolution 3, and is in accordance with an agreement reached at the joint meeting of E-1.3.1, E-1.3.2 and E-1.2 on June 28, 1967 in Washington.

4. These recommendations are based on the originals given in: CIE Proc. 8th Session, Cambridge 1931, p. 19, resolution 1; p.23, resolution 4; p. 24, resolution 5. CIE Proc. 14th Session, Brussels 1959, Vol. A, p. 36, recommendation 3. CIE Proc. 15th Session, Vienna 1963, Vol. A, p. 35, recommendation 1.

The recommendations given in this document regarding the CIE 1931 standard colorimetric observer data deviate from the originals in several ways. The CIE 1931 standard colorimetric observer is now defined by the spectral tristimulus values (color-matching functions) $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ from 360 to 830 nm at 1 nm intervals. From these data an abridged table is derived for the spectral range 380 to 780 nm at 5 nm intervals. The abridged data agree very closely with the original definition of the $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ functions given in 1931. The new data have been smoothed slightly and the few and minor deviations (see Section 2.3, Note 1) from the original data are caused by the smoothing.

The spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ were orginally derived from spectral tristimulus values $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ referring to spectral matching stimuli (R), (G), (B). These matching stimuli are specified as stimuli of wavelengths 700.0, 546.1, and 435.8 nm, respectively. Their units are so chosen as to make a mixture of equal quantities of the three spectral stimuli match the equi-energy stimulus, which is defined as a stimulus whose total radiant power at all wavelengths between any two limiting wavelengths within the visible spectrum is a constant multiple of the difference between these limiting wavelengths. The luminances of the units of the three spectral stimuli are in the ratios 1.0000 : 4.5907 : 0.0601; their radiances are in the ratios 72.0962 : 1.3791 : 1.0000.

The spectral tristimulus values $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ and corresponding chromaticity coordinates $r(\lambda)$, $g(\lambda)$, $b(\lambda)$ based on the above matching stimuli are given in Table 2.4.

The derivation of the (X), (Y), (Z) system from the (R), (G), (B) system was based on a number of relations which may be specified as follows:

	(R), (G), (B) System (Chromaticity Coordinates)			(X), (Y), (Z) System (Chromaticity Coordinates)		
Stimulus	r	g	b	x	y	z
(R) 700.0 nm	1	0	0	0.73469	0.26531	0.00000
(G) 546.1 nm	0	1	0	0.27368	0.71743	0.00890
(B) 435.8 nm	0	0	1	0.16654	0.00888	0.82458
Source B	0.36230	0.34305	0.29465	0.34842	0.35161	0.29997

The relationship between the chromaticity coordinates $r(\lambda)$, $g(\lambda)$, $b(\lambda)$ and $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ of a given spectral stimulus of wavelength λ are expressed by the following projective transformation:

$$x(\lambda) = \frac{0.49000\, r(\lambda) + 0.31000\, g(\lambda) + 0.20000\, b(\lambda)}{0.66697\, r(\lambda) + 1.13240\, g(\lambda) + 1.20063\, b(\lambda)}$$

$$y(\lambda) = \frac{0.17697\, r(\lambda) + 0.81240\, g(\lambda) + 0.01063\, b(\lambda)}{0.66697\, r(\lambda) + 1.13240\, g(\lambda) + 1.20063\, b(\lambda)}$$

$$z(\lambda) = \frac{0.00000\, r(\lambda) + 0.01000\, g(\lambda) + 0.99000\, b(\lambda)}{0.66697\, r(\lambda) + 1.13240\, g(\lambda) + 1.20063\, b(\lambda)}$$

The chromaticity coordinates $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ are converted to the spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ as follows:

$$\bar{x}(\lambda) = \frac{x(\lambda)}{y(\lambda)} V(\lambda),\ \bar{y}(\lambda) = V(\lambda),\ \bar{z}(\lambda) = \frac{z(\lambda)}{y(\lambda)} V(\lambda)$$

where $V(\lambda)$ is the photopic luminous efficiency function.

The spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ defining the CIE 1964 supplementary standard colorimetric observer given in Table 2.2 and abridged in Table 2.3.2, were derived from spectral tristimulus values referring to matching stimuli (R_{10}), (G_{10}), (B_{10}). These are stimuli specified in terms of wavenumbers ($\bar{\nu}$) 15500, 19000, and 22500 cm^{-1} (corresponding approximately to wavelengths 645.2, 526.3, and 444.4 nm), and their amounts are given in power units.
The spectral tristimulus values based on the above stimuli are given in Table 2.5 from wavenumbers 27750 to 12250 cm^{-1} at intervals of 250 cm^{-1}. Also given are the corresponding chromaticity coordinates for the specified spectral stimuli.
The derivation of the (X_{10}), (Y_{10}), (Z_{10}) system from the (R_{10}), (G_{10}), (B_{10}) system is based on principles which lead to a coordinate system similar to that of the coordinate system associated with the CIE 1931 standard colorimetric observer. The following transformation equations relate very closely the $\bar{r}_{10}(\bar{\nu})$, $\bar{g}_{10}(\bar{\nu})$, $\bar{b}_{10}(\bar{\nu})$ values of Table 2.5 to $\bar{x}_{10}(\bar{\nu})$, $\bar{y}_{10}(\bar{\nu})$, $\bar{z}_{10}(\bar{\nu})$ values:

$$\bar{x}_{10}(\bar{\nu}) = 0.341080\, \bar{r}_{10}(\bar{\nu}) + 0.189145\, \bar{g}_{10}(\bar{\nu}) + 0.387529\, \bar{b}_{10}(\bar{\nu})$$

$$\bar{y}_{10}(\bar{\nu}) = 0.139058\, \bar{r}_{10}(\bar{\nu}) + 0.837460\, \bar{g}_{10}(\bar{\nu}) + 0.073316\, \bar{b}_{10}(\bar{\nu})$$

$$\bar{z}_{10}(\bar{\nu}) = 0.000000\, \bar{r}_{10}(\bar{\nu}) + 0.039553\, \bar{g}_{10}(\bar{\nu}) + 2.026200\, \bar{b}_{10}(\bar{\nu})$$

Chromaticity coordinates $x_{10}(\bar{\nu})$, $y_{10}(\bar{\nu})$, $z_{10}(\bar{\nu})$ were then computed from

$$x_{10}(\bar{\nu}) = \frac{\bar{x}_{10}(\bar{\nu})}{\bar{x}_{10}(\bar{\nu}) + \bar{y}_{10}(\bar{\nu}) + \bar{z}_{10}(\bar{\nu})}$$

$$y_{10}(\bar{\nu}) = \frac{\bar{y}_{10}(\bar{\nu})}{\bar{x}_{10}(\bar{\nu}) + \bar{y}_{10}(\bar{\nu}) + \bar{z}_{10}(\bar{\nu})}$$

$$z_{10}(\bar{\nu}) = \frac{\bar{z}_{10}(\bar{\nu})}{\bar{x}_{10}(\bar{\nu}) + \bar{y}_{10}(\bar{\nu}) + \bar{z}_{10}(\bar{\nu})}$$

The Table 2.2 contains the spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ and chromaticity coordinates $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$ on a wavelength basis obtained by interpolation and extrapolation of the functions $\bar{x}_{10}(\bar{\nu})$, $\bar{y}_{10}(\bar{\nu})$, $\bar{z}_{10}(\bar{\nu})$, and $x_{10}(\bar{\nu})$, $y_{10}(\bar{\nu})$, $z_{10}(\bar{\nu})$.

The above transformation equations deviate somewhat from those published in the CIE Proc. 14th Session, Brussels 1959, Vol. A, p. 93 which related unsmoothed values of $\bar{r}_{10}(\bar{\nu})$, $\bar{g}_{10}(\bar{\nu})$, $\bar{b}_{10}(\bar{\nu})$ with unsmoothed values of $\bar{x}_{10}(\bar{\nu})$, $\bar{y}_{10}(\bar{\nu})$, $\bar{z}_{10}(\bar{\nu})$.

5(a) These recommendations are essentially as given in CIE Proc. 14th Session, Brussels 1959, Vol. A, p. 36, recommendation 4; and CIE Proc. 15th Session, Vienna 1963, Vol. A, p. 3, recommendation 4.

The CIE colorimetry committee recognizes the importance of color-difference calculations to industrial color-control problems and the desire to make use of a color-difference formula that applies accurately to visual comparisons of differences between object colors under visual observing conditions. None of the existing color-difference formulae, including the one recommended by the CIE, is entirely satisfactory and more experimental work is required to arrive at an accurate method of calculating color-differences.

In June 1967 the CIE colorimetry committee recommended to the National Committees of the CIE a detailed working program for pursuing the problem of color-difference calculations. Details of this program have been published in J. Opt. Soc. Am. *58*, 290 (1968).

(b) Tables 2.3.3 and 2.3.4 supersede those computed by I. Nimeroff, J. Opt. Soc. Am. *54*, 1365 (1964).

6(a) This recommendation is new but in accordance with general practice of colorimetric calculations.

(b) Report on the Principles of Light Measurements. Publication CIE No. 18 (E-1.2), 1970.

7. This recommendation is based on the original given in CIE Proc. 13th Session, Zurich, 1955, Vol. I. Section 1.3.1, p. II, recommendation 6, amended in CIE Bulletin No. 3, May 1957, p. 8, 16, 24. The use of boldface Roman letters as symbols for vector notations is another alternative which is now added.

8. This recommendation is essentially that given originally in CIE Proc. 11th Session, Paris 1948, p. 16, recommendation 2.

9. This recommendation is essentially the same as the original given in CIE Proc. 14th Session, Brussels 1959, Vol. A. p. 36 recommendation 1. Note 2 of the original recommendation has been omitted.

135

HEADINGS OF TABLES

Table 1.1.1: Relative spectral power distributions of standard illuminants A, B, C, and D_{65} from 300 to 830 nm at 5 nm intervals.

Table 1.1.2: Components $S_0(\lambda)$, $S_1(\lambda)$, $S_2(\lambda)$, of daylight used in the calculation of relative spectral power distributions of daylight of different correlated color temperatures.

Table 1.1.3: Chromaticity coordinates x_D, y_D and factors M_1, M_2 used in the calculation of the relative spectral power distribution of daylight for correlated color temperatures T_c in the range 4000 to 25000 K. The corresponding chromaticity coordinates u_D, v_D are also given.

Table 1.1.4: Relative spectral power distributions of daylight D_{55} and D_{75} calculated in accordance with the standardized method of calculation.

Table 1.1.5: Relative spectral power distributions of standard illuminants A and D_{65} from 300 to 830 nm at 1 nm intervals.

Table 1.1.6: Chromaticity coordinates x, y and u, v of standard illuminants A, B, C, D_{55}, D_{65} and D_{75} computed for the 1931 and 1964 standard colorimetric observers.

Table 2.1: CIE 1931 standard colorimetric observer. Spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, and corresponding chromaticity coordinates $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ for λ= 360 to 830 nm at 1 nm intervals.

Table 2.2: CIE 1964 supplementary standard colorimetric observer. Spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ and corresponding chromaticity coordinates $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$ for λ = 360 to 830 nm at 1 nm intervals.

Table 2.3.1: CIE 1931 standard colorimetric observer. Abridged set of spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ and corresponding chromaticity coordinates $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ for λ = 380 to 780 nm at 5 nm intervals. (For 10 nm intervals, omit alternate values).

Table 2.3.2: CIE 1964 supplementary standard colorimetric observer. Abridged set of spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ and corresponding chromaticity coordinates $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$ for λ = 380 to 780 nm at 5 nm intervals. (For 10 nm intervals, omit alternate values.)

Table 2.3.3: Spectral tristimulus values $\bar{u}(\lambda)$, $\bar{v}(\lambda)$, $\bar{w}(\lambda)$ and corresponding chromaticity coordinates $u(\lambda)$, $v(\lambda)$, $w(\lambda)$ for λ = 380 to 780 nm at 5 nm intervals. These data are derived from the spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ of the CIE 1931 standard colorimetric observer (Table 2.1) in accordance with transformations given in Note 4 of recommendation 3.1.

Table 2.3.4: Spectral tristimulus values $\bar{u}_{10}(\lambda)$, $\bar{v}_{10}(\lambda)$, $\bar{w}_{10}(\lambda)$ and corresponding chromaticity coordinates $u_{10}(\lambda)$, $v_{10}(\lambda)$, $w_{10}(\lambda)$ for λ = 380 to 780 nm at 5 nm intervals. These data are derived from the spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ of the CIE 1964 supplementary standard colorimetric observer (Table 2.2) in accordance with transformations given in Note 4 of recommendation 3.1.

Table 2.4: CIE 1931 standard colorimetric observer. Spectral tristimulus values $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ and corresponding chromaticity coordinates $r(\lambda)$, $g(\lambda)$, $b(\lambda)$ for λ = 380 to 780 nm at 5 nm intervals.

Table 2.5: CIE 1964 supplementary standard colorimetric observer. Spectral tristimulus values $\bar{r}_{10}(\bar{\nu})$, $\bar{g}_{10}(\bar{\nu})$, $\bar{b}_{10}(\bar{\nu})$ and corresponding chromaticity coordinates $\bar{r}_{10}(\bar{\nu})$, $\bar{g}_{10}(\bar{\nu})$, $\bar{b}_{10}(\bar{\nu})$ for wavenumbers $\bar{\nu}$ = 27750 to 12250 cm^{-1} at 250 cm^{-1} intervals.

136

TABLE 1.1.1.

λ (nm)	(A) S(λ)	(B) S(λ)	(C) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(B) S(λ)	(C) S(λ)	(D_{65}) S(λ)
300	0.93			0.03	575	110.80	101.90	100.15	96.1
05	1.13			1.7	80	114.44	101.00	97.80	95.8
10	1.36			3.3	85	118.08	100.07	95.43	92.2
15	1.62			11.8	90	121.73	99.20	93.20	88.7
20	1.93	0.02	0.01	20.2	95	125.39	98.44	91.22	89.3
325	2.27	0.26	0.20	28.6	600	129.04	98.00	89.70	90.0
30	2.66	0.50	0.40	37.1	05	132.70	98.08	88.83	89.8
35	3.10	1.45	1.55	38.5	10	136.35	98.50	88.40	89.6
40	3.59	2.40	2.70	39.9	15	139.99	99.06	88.19	88.6
45	4.14	4.00	4.85	42.4	20	143.62	99.70	88.10	87.7
350	4.74	5.60	7.00	44.9	625	147.24	100.36	88.06	85.5
55	5.41	7.60	9.95	45.8	30	150.84	101.00	88.00	83.3
60	6.14	9.60	12.90	46.6	35	154.42	101.56	87.86	83.5
65	6.95	12.40	17.20	49.4	40	157.98	102.20	87.80	83.7
70	7.82	15.20	21.40	52.1	45	161.52	103.05	87.99	81.9
375	8.77	18.80	27.50	51.0	650	165.03	103.90	88.20	80.0
80	9.80	22.40	33.00	50.0	55	168.51	104.59	88.20	80.1
85	10.90	26.85	39.92	52.3	60	171.96	105.00	87.90	80.2
90	12.09	31.30	47.40	54.6	65	175.38	105.08	87.22	81.2
95	13.35	36.18	55.17	68.7	70	178.77	104.90	86.30	82.3
400	14.71	41.30	63.30	82.8	675	182.12	104.55	85.30	80.3
05	16.15	46.62	71.81	87.1	80	185.43	103.90	84.00	78.3
10	17.68	52.10	80.60	91.5	85	188.70	102.84	82.21	74.0
15	19.29	57.70	89.53	92.5	90	191.93	101.60	80.20	69.7
20	20.99	63.20	98.10	93.4	95	195.12	100.38	78.24	70.7
425	22.79	68.37	105.80	90.1	700	198.26	99.10	76.30	71.6
30	24.67	73.10	112.40	86.7	05	201.36	97.70	74.36	73.0
35	26.64	77.31	117.75	95.8	10	204.41	96.20	72.40	74.3
40	28.70	80.80	121.50	104.9	15	207.41	94.60	70.40	68.0
45	30.85	83.44	123.45	110.9	20	210.36	92.90	68.30	61.6
450	33.09	85.40	124.00	117.0	725	213.27	91.10	66.30	65.7
55	35.41	86.88	123.60	117.4	30	216.12	89.40	64.40	69.9
60	37.81	88.30	123.10	117.8	35	218.92	88.00	62.80	72.5
65	40.30	90.08	123.30	116.3	40	221.67	86.90	61.50	75.1
70	42.87	92.00	123.80	114.9	45	224.36	85.90	60.20	69.3
475	45.52	93.75	124.09	115.4	750	227.00	85.20	59.20	63.6
80	48.24	95.20	123.90	115.9	55	229.59	84.80	58.50	55.0
85	51.04	96.23	122.92	112.4	60	232.12	84.70	58.10	46.4
90	53.91	96.50	120.70	108.8	65	234.59	84.90	58.00	56.6
95	56.85	95.71	116.90	109.1	70	237.01	85.40	58.20	66.8
500	59.86	94.20	112.10	109.4	775	239.37			65.1
05	62.93	92.37	106.98	108.6	80	241.68			63.4
10	66.06	90.70	102.30	107.8	85	243.92			63.8
15	69.25	89.65	98.81	106.3	90	246.12			64.3
20	72.50	89.50	96.90	104.8	95	248.25			61.9
525	75.79	90.43	96.78	106.2	800	250.33			59.5
30	79.13	92.20	98.00	107.7	05	252.35			55.7
35	82.52	94.46	99.94	106.0	10	254.31			52.0
40	85.95	96.90	102.10	104.4	15	256.22			54.7
45	89.41	99.16	103.95	104.2	20	258.07			57.4
550	92.91	101.00	105.20	104.0	825	259.86			58.9
55	96.44	102.20	105.67	102.0	30	261.60			60.3
60	100.00	102.80	105.30	100.0					
65	103.58	102.92	104.11	98.2					
70	107.18	102.60	102.30	96.3					

137

TABLE 1.1.2

λ (nm)	$S_0(\lambda)$	$S_1(\lambda)$	$S_2(\lambda)$
300	0.04	0.02	0.0
310	6.0	4.5	2.0
320	29.6	22.4	4.0
330	55.3	42.0	8.5
340	57.3	40.6	7.8
350	61.8	41.6	6.7
360	61.5	38.0	5.3
370	68.8	42.4	6.1
380	63.4	38.5	3.0
390	65.8	35.0	1.2
400	94.8	43.4	- 1.1
410	104.8	46.3	- 0.5
420	105.9	43.9	- 0.7
430	96.8	37.1	- 1.2
440	113.9	36.7	- 2.6
450	125.6	35.9	- 2.9
460	125.5	32.6	- 2.8
470	121.3	27.9	- 2.6
480	121.3	24.3	- 2.6
490	113.5	20.1	- 1.8
500	113.1	16.2	- 1.5
510	110.8	13.2	- 1.3
520	106.5	8.6	- 1.2
530	108.8	6.1	- 1.0
540	105.3	4.2	- 0.5
550	104.4	1.9	- 0.3
560	100.0	0.0	0.0
570	96.0	- 1.6	0.2
580	95.1	- 3.5	0.5
590	89.1	- 3.5	2.1
600	90.5	- 5.8	3.2
610	90.3	- 7.2	4.1
620	88.4	- 8.6	4.7
630	84.0	- 9.5	5.1
640	85.1	-10.9	6.7
650	81.9	-10.7	7.3
660	82.6	-12.0	8.6
670	84.9	-14.0	9.8
680	81.3	-13.6	10.2
690	71.9	-12.0	8.3
700	74.3	-13.3	9.6
710	76.4	-12.9	8.5
720	63.3	-10.6	7.0
730	71.7	-11.6	7.6
740	77.0	-12.2	8.0
750	65.2	-10.2	6.7
760	47.7	- 7.8	5.2
770	68.6	-11.2	7.4
780	65.0	-10.4	6.8
790	66.0	-10.6	7.0
800	61.0	- 9.7	6.4
810	53.3	- 8.3	5.5
820	58.9	- 9.3	6.1
830	61.9	- 9.8	6.5

138

TABLE 1.1.3

T_c 1)	x_D	y_D	u_D	v_D	M_1	M_2
4000	0.3823	0.3838	0.2236	0.3366	-1.505	2.827
4100	0.3779	0.3812	0.2217	0.3354	-1.464	2.460
4200	0.3737	0.3786	0.2200	0.3343	-1.422	2.127
4300	0.3697	0.3760	0.2183	0.3331	-1.378	1.825
4400	0.3658	0.3734	0.2168	0.3320	-1.333	1.550
4500	0.3621	0.3709	0.2153	0.3308	-1.286	1.302
4600	0.3585	0.3684	0.2139	0.3297	-1.238	1.076
4700	0.3551	0.3659	0.2126	0.3286	-1.190	0.871
4800	0.3519	0.3634	0.2114	0.3275	-1.140	0.686
4900	0.3487	0.3610	0.2102	0.3265	-1.090	0.518
5000	0.3457	0.3587	0.2091	0.3254	-1.040	0.367
5100	0.3429	0.3564	0.2081	0.3244	-0.989	0.230
5200	0.3401	0.3541	0.2071	0.3234	-0.939	0.106
5300	0.3375	0.3519	0.2062	0.3225	-0.888	-0.005
5400	0.3349	0.3497	0.2053	0.3215	-0.837	-0.105
5500	0.3325	0.3476	0.2044	0.3206	-0.786	-0.195
5600	0.3302	0.3455	0.2036	0.3196	-0.736	-0.276
5700	0.3279	0.3435	0.2028	0.3187	-0.685	-0.348
5800	0.3258	0.3416	0.2021	0.3179	-0.635	-0.412
5900	0.3237	0.3397	0.2014	0.3170	-0.586	-0.469
6000	0.3217	0.3378	0.2007	0.3162	-0.536	-0.519
6100	0.3198	0.3360	0.2001	0.3154	-0.487	-0.563
6200	0.3179	0.3342	0.1995	0.3146	-0.439	-0.602
6300	0.3161	0.3325	0.1989	0.3138	-0.391	-0.635
6400	0.3144	0.3308	0.1983	0.3130	-0.343	-0.664
6500	0.3128	0.3292	0.1978	0.3123	-0.296	-0.688
6600	0.3112	0.3276	0.1973	0.3116	-0.250	-0.709
6700	0.3097	0.3260	0.1968	0.3109	-0.204	-0.726
6800	0.3082	0.3245	0.1963	0.3102	-0.159	-0.739
6900	0.3067	0.3231	0.1959	0.3095	-0.114	-0.749
7000	0.3054	0.3216	0.1955	0.3088	-0.070	-0.757
7100	0.3040	0.3202	0.1950	0.3082	-0.026	-0.762
7200	0.3027	0.3189	0.1946	0.3076	0.017	-0.765
7300	0.3015	0.3176	0.1943	0.3069	0.060	-0.765
7400	0.3003	0.3163	0.1939	0.3063	0.102	-0.763
7500	0.2991	0.3150	0.1935	0.3057	0.144	-0.760
7600	0.2980	0.3138	0.1932	0.3052	0.184	-0.755
7700	0.2969	0.3126	0.1928	0.3046	0.225	-0.748
7800	0.2958	0.3115	0.1925	0.3041	0.264	-0.740
7900	0.2948	0.3103	0.1922	0.3035	0.303	-0.730
8000	0.2938	0.3092	0.1919	0.3030	0.342	-0.720
8100	0.2928	0.3081	0.1916	0.3025	0.380	-0.708
8200	0.2919	0.3071	0.1913	0.3020	0.417	-0.695
8300	0.2910	0.3061	0.1911	0.3015	0.454	-0.682
8400	0.2901	0.3051	0.1908	0.3010	0.490	-0.667
8500	0.2892	0.3041	0.1906	0.3006	0.526	-0.652
9000	0.2853	0.2996	0.1894	0.2984	0.697	-0.566
9500	0.2818	0.2956	0.1884	0.2964	0.856	-0.471
10000	0.2788	0.2920	0.1876	0.2946	1.003	-0.369
10500	0.2761	0.2887	0.1868	0.2930	1.139	-0.265
11000	0.2737	0.2858	0.1861	0.2915	1.266	-0.160
12000	0.2697	0.2808	0.1850	0.2890	1.495	0.045
13000	0.2664	0.2767	0.1841	0.2868	1.693	0.239
14000	0.2637	0.2732	0.1834	0.2850	1.868	0.419
15000	0.2614	0.2702	0.1828	0.2835	2.021	0.586
17000	0.2578	0.2655	0.1818	0.2809	2.278	0.878

139

TABLE 1.1.3 (continued)

20000	0.2539	0.2603	0.1809	0.2781	2.571	1.231
25000	0.2499	0.2548	0.1798	0.2751	2.907	1.655
5503[2])	0.3324	0.3475	0.2044	0.3205	-0.785	-0.198
6504[3])	0.3127	0.3291	0.1978	0.3123	-0.295	-0.689
7504[4])	0.2990	0.3150	0.1935	0.3057	0.145	-0.760

$$u_D = 4x_D/(-2x_D + 12y_D + 3)$$
$$v_D = 6y_D/(-2x_D + 12y_D + 3)$$

[1]) All correlated color temperatures T_c are based on $c_2 = 1.4388 \cdot 10^{-2}$ m · K.

[2]) Standard illuminant D_{55}; $T_c = 5500(1.4388/1.4380) = 5503$ K (approximately)

[3]) Standard illuminant D_{65}; $T_c = 6500(1.4388/1.4380) = 6504$ K (approximately)

[4]) Standard illuminant D_{75}; $T_c = 7500(1.4388/1.4380) = 7504$ K (approximately)

140

TABLE 1.1.4

λ (nm)	(D_{55}) S(λ)	(D_{75}) S(λ)
300	0.02	0.04
310	2.1	5.1
320	11.2	29.8
330	20.6	54.9
340	23.9	57.3
350	27.8	62.7
360	30.6	63.0
370	34.3	70.3
380	32.6	66.7
390	38.1	70.0
400	61.0	101.9
410	68.6	111.9
420	71.6	112.8
430	67.9	103.1
440	85.6	121.2
450	98.0	133.0
460	100.5	132.4
470	99.9	127.3
480	102.7	126.8
490	98.1	117.8
500	100.7	116.6
510	100.7	113.7
520	100.0	108.7
530	104.2	110.4
540	102.1	106.3
550	103.0	104.9
560	100.0	100.0
570	97.2	95.6
580	97.7	94.2
590	91.4	87.0
600	94.4	87.2
610	95.1	86.1
620	94.2	83.6
630	90.4	78.7
640	92.3	78.4
650	88.9	74.8
660	90.3	74.3
670	93.9	75.4
680	90.0	71.6
690	79.7	63.9
700	82.8	65.1
710	84.8	68.1
720	70.2	56.4
730	79.3	64.2
740	85.0	69.2
750	71.9	58.6
760	52.8	42.6
770	75.9	61.4
780	71.8	58.3
790	72.9	59.1
800	67.3	54.7
810	58.7	47.9
820	65.0	52.9
830	68.3	55.5

141

TABLE 1.1.5

λ (nm)	(A) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(D_{65}) S(λ)
300	0.930 483	0.034 100 0	355	5.410 70	45.775 0
301	0.967 643	0.360 140	356	5.552 13	45.947 7
302	1.005 97	0.686 180	357	5.696 22	46.120 3
303	1.045 49	1.012 22	358	5.842.98	46.293 0
304	1.086 23	1.338 26	359	5.992 44	46.465 6
305	1.128 21	1.664 30	360	6.144 62	46.638 3
306	1.171 47	1.990 34	361	6.299 55	47.183 4
307	1.216 02	2.316 38	362	6.457 24	47.728 5
308	1.261 88	2.642 42	363	6.617 74	48.273 5
309	1.309 10	2.968 46	364	6.781 05	48.818 6
310	1.357 69	3.294 50	365	6.947 20	49.363 7
311	1.407 68	4.988 65	366	7.116 21	49.908 8
312	1.459 10	6.682 80	367	7.288 11	50.453 9
313	1.511 98	8.376 95	368	7.462 92	50.998 9
314	1.566 33	10.071 1	369	7.640 66	51.544 0
315	1.622 19	11.765 2	370	7.821 35	52.089 1
316	1.679 59	13.459 4	371	8.005 01	51.877 7
317	1.738 55	15.153 5	372	8.191 67	51.666 4
318	1.799 10	16.847 7	373	8.381 34	51.455 0
319	1.861 27	18.541 8	374	8.574 04	51.243 7
320	1.925 08	20.236 0	375	8.769 80	51.032 3
321	1.990 57	21.917 7	376	8.968 64	50.820 9
322	2.057 76	23.599 5	377	9.170 56	50.609 6
323	2.126 67	25.281 3	378	9.375 61	50.398 2
324	2.197 34	26.963 0	379	9.583 78	50.186 9
325	2.269 80	28.644 7	380	9.795 10	49.975 5
326	2.344 06	30.326 5	381	10.009 6	50.442 8
327	2.420 17	32.008 2	382	10.227 3	50.910 0
328	2.498 14	33.690 0	383	10.448 1	51.377 3
329	2.578 01	35.371 7	384	10.672 2	51.844 6
330	2.659 81	37.053 5	385	10.899 6	52.311 8
331	2.743 55	37.343 0	386	11.130 2	52.779 1
332	2.829 28	37.632 6	387	11.364 0	53.246 4
333	2.917 01	37.922 1	388	11.601 2	53.713 7
334	3.006 78	38.211 6	389	11.841 6	54.180 9
335	3.098 61	38.501 1	390	12.085 3	54.648 2
336	3.192 53	38.790 7	391	12.332 4	57.458 9
337	3.288 57	39.080 2	392	12.582 8	60.269 5
338	3.386 76	39.369 7	393	12.836 6	63.080 2
339	3.487 12	39.659 3	394	13.093 8	65.890 9
340	3.589 68	39.948 8	395	13.354 3	68.701 5
341	3.694 47	40.445 1	396	13.618 2	71.512 2
342	3.801 52	40.941 4	397	13.885 5	74.322 9
343	3.910 85	41.437 7	398	14.156 3	77.133 6
344	4.022 50	41.934 0	399	14.430 4	79.944 2
345	4.136 48	42.430 2	400	14.708 0	82.754 9
346	4.252 82	42.926 5	401	14.989 1	83.628 0
347	4.371 56	43.422 8	402	15.273 6	84.501 1
348	4.492 72	43.919 1	403	15.561 6	85.374 2
349	4.616 31	44.415 4	404	15.853 0	86.247 3
350	4.742 38	44.911 7	405	16.148 0	87.120 4
351	4.870 95	45.084 4	406	16.446 4	87.993 6
352	5.002 04	45.257 0	407	16.748 4	88.866 7
353	5.135 68	45.429 7	408	17.053 8	89.739 8
354	5.271 89	45.602 3	409	17.362 8	90.612 9

142

TABLE 1.1.5 (continued)

λ (nm)	(A) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(D_{65}) S(λ)
410	17.675 3	91.486 0	465	40.300 2	116.337
411	17.991 3	91.680 6	466	40.807 6	116.041
412	18.310 8	91.875 2	467	41.318 2	115.746
413	18.633 9	92.069 7	468	41.832 0	115.451
414	18.960 5	92.264 3	469	42.349 1	115.156
415	19.290 7	92.458 9	470	42.869 3	114.861
416	19.624 4	92.653 5	471	43.392 6	114.967
417	19.961 7	92.848 1	472	43.919 2	115.073
418	20.302 6	93.042 6	473	44.448 8	115.179
419	20.647 0	93.237 2	474	44.981 6	115.286
420	20.995 0	93.431 8	475	45.517 4	115.392
421	21.346 5	92.756 8	476	46.056 3	115.498
422	21.701 6	92.081 9	477	46.598 3	115.604
423	22.060 3	91.406 9	478	47.143 3	115.710
424	22.422 5	90.732 0	479	47.691 3	115.817
425	22.788 3	90.057 0	480	48.242 3	115.923
426	23.157 7	89.382 1	481	48.796 3	115.212
427	23.530 7	88.707 1	482	49.353 3	114.500
428	23.907 2	88.032 2	483	49.913 2	113.789
429	24.287 3	87.357 2	484	50.476 0	113.078
430	24.670 9	86.682 3	485	51.041 8	112.367
431	25.058 1	88.500 6	486	51.610 4	111.656
432	25.448 9	90.318 8	487	52.181 8	110.944
433	25.843 2	92.137 1	488	52.756 1	110.233
434	26.241 1	93.955 3	489	53.333 2	109.522
435	26.642 5	95.773 6	490	53.913 2	108.811
436	27.047 5	97.591 9	491	54.495 8	108.865
437	27.456 0	99.410 1	492	55.081 3	108.919
438	27.868 1	101.228	493	55.669 4	108.974
439	28.283 6	103.047	494	56.260 3	109.028
440	28.702 7	104.865	495	56.853 9	109.083
441	29.125 3	106.079	496	57.450 1	109.137
442	29.551 5	107.293	497	58.048 9	109.191
443	29.981 1	108.508	498	58.650 4	109.246
444	30.414 2	109.722	499	59.254 5	109.300
445	30.850 8	110.936	500	59.861 1	109.354
446	31.290 9	112.151	501	60.470 3	109.199
447	31.734 5	113.365	502	61.082 0	109.044
448	32.181 5	114.579	503	61.696 2	108.889
449	32.632 0	115.793	504	62.312 8	108.733
450	33.085 9	117.008	505	62.932 0	108.578
451	33.543 2	117.088	506	63.553 5	108.423
452	34.004 0	117.169	507	64.177 5	108.268
453	34.468 2	117.249	508	64.803 8	108.112
454	34.935 8	117.329	509	65.432 5	107.957
455	35.406 8	117.410	510	66.063 5	107.802
456	35.881 1	117.490	511	66.696 8	107.501
457	36.358 8	117.571	512	67.332 4	107.199
458	36.839 9	117.651	513	67.970 2	106.898
459	37.324 3	117.732	514	68.610 2	106.597
460	37.812 1	117.812	515	69.252 5	106.296
461	38.303 1	117.517	516	69.896 9	105.995
462	38.797 5	117.222	517	70.543 5	105.693
463	39.295 1	116.927	518	71.192 2	105.392
464	39.796 0	116.632	519	71.843 0	105.091

143

TABLE 1.1.5 (continued)

λ (nm)	(A) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(D_{65}) S(λ)
520	72.495 9	104.790	575	110.803	96.061 1
521	73.150 8	105.080	576	111.529	96.006 5
522	73.807 7	105.370	577	112.255	95.951 9
523	74.466 6	105.660	578	112.982	95.897 2
524	75.127 5	105.950	579	113.709	95.842 6
525	75.790 3	106.240	580	114.436	95.788 0
526	76.455 1	106.530	581	115.164	95.077 8
527	77.121 7	106.820	582	115.893	94.367 5
528	77.790 2	107.110	583	116.622	93.657 3
529	78.460 5	107.400	584	117.351	92.947 0
530	79.132 6	107.689	585	118.080	92.236 8
531	79.806 5	107.361	586	118.810	91.526 6
532	80.482 1	107.033	587	119.540	90.816 3
533	81.159 5	106.704	588	120.270	90.106 1
534	81.838 6	106.376	589	121.001	89.395 8
535	82.519 3	106.047	590	121.731	88.685 6
536	83.201 7	105.719	591	122.462	88.817 7
537	83.885 6	105.391	592	123.193	88.949 7
538	84.571 2	105.062	593	123.924	89.081 8
539	85.258 4	104.734	594	124.655	89.213 8
540	85.947 0	104.405	595	125.386	89.345 9
541	86.637 2	104.370	596	126.118	89.478 0
542	87.328 8	104.334	597	126.849	89.610 0
543	88.021 9	104.298	598	127.580	89.742 1
544	88.716 5	104.262	599	128.312	89.874 1
545	89.412 4	104.226	600	129.043	90.006 2
546	90.109 7	104.190	601	129.774	89.965 5
547	90.808 3	104.154	602	130.505	89.924 8
548	91.508 2	104.118	603	131.236	89.884 1
549	92.209 5	104.082	604	131.966	89.843 4
550	92.912 0	104.046	605	132.697	89.802 6
551	93.615 7	103.642	606	133.427	89.761 9
552	94.320 6	103.237	607	134.157	89.721 2
553	95.026 7	102.832	608	134.887	89.680 5
554	95.733 9	102.428	609	135.617	89.639 8
555	96.442 3	102.023	610	136.346	89.599 1
556	97.151 8	101.618	611	137.075	89.409 1
557	97.862 3	101.214	612	137.804	89.219 0
558	98.573 9	100.809	613	138.532	89.029 0
559	99.286 4	100.405	614	139.260	88.838 9
560	100.000	100.000	615	139.988	88.648 9
561	100.715	99.633 4	616	140.715	88.458 9
562	101.430	99.266 8	617	141.441	88.268 8
563	102.146	98.900 3	618	142.167	88.078 8
564	102.864	98.533 7	619	142.893	87.888 7
565	103.582	98.167 1	620	143.618	87.698 7
566	104.301	97.800 5	621	144.343	87.257 7
567	105.020	97.433 9	622	145.067	86.816 7
568	105.741	97.067 4	623	145.790	86.375 7
569	106.462	96.700 8	624	146.513	85.934 7
570	107.184	96.334 2	625	147.235	85.493 6
571	107.906	96.279 6	626	147.957	85.052 6
572	108.630	96.225 0	627	148.678	84.611 6
573	109.354	96.170 3	628	149.398	84.170 6
574	110.078	96.115 7	629	150.117	83.729 6

TABLE 1.1.5 (continued)

λ (nm)	(A) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(D_{65}) S(λ)
630	150.836	83.288 6	685	188.701	74.002 7
631	151.554	83.329 7	686	189.350	73.146 5
632	152.271	83.370 7	687	189.998	72.290 2
633	152.988	83.411 8	688	190.644	71.433 9
634	153.704	83.452 8	689	191.288	70.577 6
635	154.418	83.493 9	690	191.931	69.721 3
636	155.132	83.535 0	691	192.572	69.910 1
637	155.845	83.576 0	692	193.211	70.098 9
638	156.558	83.617 1	693	193.849	70.287 6
639	157.269	83.658 1	694	194.484	70.476 4
640	157.979	83.699 2	695	195.118	70.665 2
641	158.689	83.332 0	696	195.750	70.854 0
642	159.397	82.964 7	697	196.381	71.042 8
643	160.104	82.597 5	698	197.009	71.231 5
644	160.811	82.230 2	699	197.636	71.420 3
645	161.516	81.863 0	700	198.261	71.609 1
646	162.221	81.495 8	701	198.884	71.883 1
647	162.924	81.128 5	702	199.506	72.157 1
648	163.626	80.761 3	703	200.125	72.431 1
649	164.327	80.394 0	704	200.743	72.705 1
650	165.028	80.026 8	705	201.359	72.979 0
651	165.726	80.045 6	706	201.972	73.253 0
652	166.424	80.064 4	707	202.584	73.527 0
653	167.121	80.083 1	708	203.195	73.801 0
654	167.816	80.101 9	709	203.803	74.075 0
655	168.510	80.120 7	710	204.409	74.349 0
656	169.203	80.139 5	711	205.013	73.074 5
657	169.895	80.158 3	712	205.616	71.800 0
658	170.586	80.177 0	713	206.216	70.525 5
659	171.275	80.195 8	714	206.815	69.251 0
660	171.963	80.214 6	715	207.411	67.976 5
661	172.650	80.420 9	716	208.006	66.702 0
662	173.335	80.627 2	717	208.599	65.427 5
663	174.019	80.833 6	718	209.189	64.153 0
664	174.702	81.039 9	719	209.778	62.878 5
665	175.383	81.246 2	720	210.365	61.604 0
666	176.063	81.452 5	721	210.949	62.432 2
667	176.741	81.658 8	722	211.532	63.260 3
668	177.419	81.865 2	723	212.112	64.088 5
669	178.094	82.071 5	724	212.691	64.916 6
670	178.769	82.277 8	725	213.268	65.744 8
671	179.441	81.878 4	726	213.842	66.573 0
672	180.113	81.479 1	727	214.415	67.401 1
673	180.783	81.079 7	728	214.985	68.229 3
674	181.451	80.680 4	729	215.553	69.057 4
675	182.118	80.281 0	730	216.120	69.885 6
676	182.783	79.881 6	731	216.684	70.405 7
677	183.447	79.482 3	732	217.246	70.925 9
678	184.109	79.082 9	733	217.806	71.446 0
679	184.770	78.683 6	734	218.364	71.966 2
680	185.429	78.284 2	735	218.920	72.486 3
681	186.087	77.427 9	736	219.473	73.006 4
682	186.743	76.571 6	737	220.025	73.526 6
683	187.397	75.715 3	738	220.574	74.046 7
684	188.050	74.859 0	739	221.122	74.566 9

TABLE 1.1.5 (continued)

λ (nm)	(A) S(λ)	(D_{65}) S(λ)	λ (nm)	(A) S(λ)	(D_{65}) S(λ)
740	221.667	75.087 0	785	243.924	63.843 4
741	222.210	73.937 6	786	244.367	63.935 5
742	222.751	72.788 1	787	244.808	64.027 6
743	223.290	71.638 7	788	245.246	64.119 8
744	223.826	70.489 3	789	245.682	64.211 9
745	224.361	69.339 8	790	246.116	64.304 0
746	224.893	68.190 4	791	246.548	63.818 8
747	225.423	67.041 0	792	246.977	63.333 6
748	225.951	65.891 6	793	247.404	62.848 4
749	226.477	64.742 1	794	247.829	62.363 2
750	227.000	63.592 7	795	248.251	61.877 9
751	227.522	61.875 2	796	248.671	61.392 7
752	228.041	60,157 8	797	249.089	60.907 5
753	228.558	58.440 4	798	249.505	60.422 3
754	229.073	56.722 9	799	249.918	59.937 1
755	229.585	55.005 4	800	250.329	59.451 9
756	230.096	53.288 0	801	250.738	58.702 6
757	230.604	51.570 5	802	251.144	57.953 3
758	231.110	49.853 1	803	251.548	57.204 0
759	231.614	48.135 6	804	251.950	56.454 7
760	232.115	46.418 2	805	252.350	55.705 4
761	232.615	48.456 9	806	252.747	54.956 2
762	233.112	50.495 6	807	253.142	54.206 9
763	233.606	52.534 4	808	253.535	53.457 6
764	234.099	54.573 1	809	253.925	52.708 3
765	234.589	56.611 8	810	254.314	51.959 0
766	235.078	58.650 5	811	254.700	52.507 2
767	235.564	60.689 2	812	255.083	53.055 3
768	236.047	62.728 0	813	255.465	53.603 5
769	236.529	64.766 7	814	255.844	54.151 6
770	237.008	66.805 4	815	256.221	54.699 8
771	237.485	66.463 1	816	256.595	55.248 0
772	237.959	66.120 9	817	256.968	55.796 1
773	238.432	65.778 6	818	257.338	56.344 3
774	238.902	65.436 4	819	257.706	56.892 4
775	239.370	65.094 1	820	258.071	57.440 6
776	239.836	64.751 8	821	258.434	57.727 8
777	240.299	64.409 6	822	258.795	58.015 0
778	240.760	64.067 3	823	259.154	58.302 2
779	241.219	63.725 1	824	259.511	58.589 4
780	241.675	63.382 8	825	259.865	58.876 5
781	242.130	63.474 9	826	260.217	59.163 7
782	242.582	63.567 0	827	260.567	59.450 9
783	243.031	63.659 2	828	260.914	59.738 1
784	243.479	63.751 3	829	261.259	60.025 3
			830	261.602	60.312 5

146

TABLE 1.1.6

1. For CIE 1931 standard colorimetric observer as defined in Table 2.3.1, and illuminants A, B, C, D_{65} as defined in Table 1.1.1 (5 nm intervals).

Illuminant	x	y	u	v
A	0.447 581	0.407 444	0.255 974	0.349 529
B	0.348 424	0.351 608	0.213 677	0.323 444
C	0.310 063	0.316 158	0.200 890	0.307 259
D_{65}	0.312 713	0.329 016	0.197 833	0.312 220

2. For CIE 1964 supplementary standard colorimetric observer as defined in Table 2.3.2, and illuminants A, B, C, D_{65} as defined in Table 1.1.1 (5 nm intervals).

Illuminant	x_{10}	y_{10}	u_{10}	v_{10}
A	0.451 179	0.405 933	0.258 969	0.349 498
B	0.349 829	0.352 670	0.214 212	0.323 928
C	0.310 387	0.319 053	0.199 996	0.308 370
D_{65}	0.313 793	0.330 967	0.197 851	0.313 020

3. For CIE 1931 standard colorimetric observer as defined in Table 2.1, and illuminants A and D_{65} as defined in Table 1.1.5 (1 nm intervals).

Illuminant	x	y	u	v
A	0.447 573 514 1	0.407 439 444 3	0.255 971 079 0	0.349 527 097 4
D_{65}	0.312 726 866 0	0.329 023 512 6	0.197 839 856 0	0.312 224 363 0

TABLE 1.1.6 (continued)

4. For CIE 1964 supplementary standard colorimetric observer as defined in Table 2.2, and illuminants A and D_{65} as defined in Table 1.1.5 (1 nm intervals).

Illuminant	x_{10}	y_{10}	u_{10}	v_{10}
A	0.451 173 939 7	0.405 936 604 2	0.258 964 541 5	0.349 498 865 1
D_{65}	0.313 823 671 7	0.330 999 256 6	0.197 860 446 9	0.313 034 038 2

5. For CIE 1931 standard colorimetric observer as defined in Table 2.3.1, and illuminants D_{55} and D_{75} as defined in Table 1.1.4 (10 nm intervals).

Illuminant	x	y	u	v
D_{55}	0.332 407	0.347 548	0.204 377	0.320 529
D_{75}	0.299 023	0.314 961	0.193 496	0.305 714

6. For CIE 1964 supplementary standard colorimetric observer as defined in Table 2.3.2, and illuminants D_{55} and D_{75} as defined in Table 1.1.4 (10 nm intervals).

Illuminant	x_{10}	y_{10}	u_{10}	v_{10}
D_{55}	0.334 059	0.348 694	0.205 063	0.321 071
D_{75}	0.299 631	0.317 307	0.193 048	0.306 655

148

TABLE 2.1

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	$x(\lambda)$	$y(\lambda)$	$z(\lambda)$
360	0.000 129 900 0	0.000 003 917 000	0.000 606 100 0	0.175 56	0.005 29	0.819 15
61	0.000 145 847 0	0.000 004 393 581	0.000 680 879 2	0.175 48	0.005 29	0.819 23
62	0.000 163 802 1	0.000 004 929 604	0.000 765 145 6	0.175 40	0.005 28	0.819 32
63	0.000 184 003 7	0.000 005 532 136	0.000 860 012 4	0.175 32	0.005 27	0.819 41
64	0.000 206 690 2	0.000 006 208 245	0.000 966 592 8	0.175 24	0.005 26	0.819 50
365	0.000 232 100 0	0.000 006 965 000	0.001 086 000	0.175 16	0.005 26	0.819 58
66	0.000 260 728 0	0.000 007 813 219	0.001 220 586	0.175 09	0.005 25	0.819 66
67	0.000 293 075 0	0.000 008 767 336	0.001 372 729	0.175 01	0.005 24	0.819 75
68	0.000 329 388 0	0.000 009 839 844	0.001 543 579	0.174 94	0.005 23	0.819 83
69	0.000 369 914 0	0.000 011 043 23	0.001 734 286	0.174 88	0.005 22	0.819 90
370	0.000 414 900 0	0.000 012 390 00	0.001 946 000	0.174 82	0.005 22	0.819 96
71	0.000 464 158 7	0.000 013 886 41	0.002 177 777	0.174 77	0.005 23	0.820 00
72	0.000 518 986 0	0.000 015 557 28	0.002 435 809	0.174 72	0.005 24	0.820 04
73	0.000 581 854 0	0.000 017 442 96	0.002 731 953	0.174 66	0.005 24	0.820 10
74	0.000 655 234 7	0.000 019 583 75	0.003 078 064	0.174 59	0.005 22	0.820 19
375	0.000 741 600 0	0.000 022 020 00	0.003 486 000	0.174 51	0.005 18	0.820 31
76	0.000 845 029 6	0.000 024 839 65	0.003 975 227	0.174 41	0.005 13	0.820 46
77	0.000 964 526 8	0.000 028 041 26	0.004 540 880	0.174 31	0.005 07	0.820 62
78	0.001 094 949	0.000 031 531 04	0.005 158 320	0.174 22	0.005 02	0.820 76
79	0.001 231 154	0.000 035 215 21	0.005 802 907	0.174 16	0.004 98	0.820 86
380	0.001 368 000	0.000 039 000 00	0.006 450 001	0.174 11	0.004 96	0.820 93
81	0.001 502 050	0.000 042 826 40	0.007 083 216	0.174 09	0.004 96	0.820 95
82	0.001 642 328	0.000 046 914 60	0.007 745 488	0.174 07	0.004 97	0.820 96
83	0.001 802 382	0.000 051 589 60	0.008 501 152	0.174 06	0.004 98	0.820 96
84	0.001 995 757	0.000 057 176 40	0.009 414 544	0.174 04	0.004 98	0.820 98
385	0.002 236 000	0.000 064 000 00	0.010 549 99	0.174 01	0.004 98	0.821 01
86	0.002 535 385	0.000 072 344 21	0.011 965 80	0.173 97	0.004 97	0.821 06
87	0.002 892 603	0.000 082 212 24	0.013 655 87	0.173 93	0.004 94	0.821 13
88	0.003 300 829	0.000 093 508 16	0.015 588 05	0.173 89	0.004 93	0.821 18
89	0.003 753 236	0.000 106 136 1	0.017 730 15	0.173 84	0.004 92	0.821 24
390	0.004 243 000	0.000 120 000 0	0.020 050 01	0.173 80	0.004 92	0.821 28
91	0.004 762 389	0.000 134 984 0	0.022 511 36	0.173 76	0.004 92	0.821 32
92	0.005 330 048	0.000 151 492 0	0.025 202 88	0.173 70	0.004 94	0.821 36
93	0.005 978 712	0.000 170 208 0	0.028 279 72	0.173 66	0.004 94	0.821 40
94	0.006 741 117	0.000 191 816 0	0.031 897 04	0.173 61	0.004 94	0.821 45
395	0.007 650 000	0.000 217 000 0	0.036 210 00	0.173 56	0.004 92	0.821 52
96	0.008 751 373	0.000 246 906 7	0.041 437 71	0.173 51	0.004 90	0.821 59
97	0.010 028 88	0.000 281 240 0	0.047 503 72	0.173 47	0.004 86	0.821 67
98	0.011 421 70	0.000 318 520 0	0.054 119 88	0.173 42	0.004 84	0.821 74
99	0.012 869 01	0.000 357 266 7	0.060 998 03	0.173 38	0.004 81	0.821 81
400	0.014 310 00	0.000 396 000 0	0.067 850 01	0.173 34	0.004 80	0.821 86
01	0.015 704 43	0.000 433 714 7	0.074 486 32	0.173 29	0.004 79	0.821 92
02	0.017 147 44	0.000 473 024 0	0.081 361 56	0.173 24	0.004 78	0.821 98
03	0.018 781 22	0.000 517 876 0	0.089 153 64	0.173 17	0.004 78	0.822 05
04	0.020 748 01	0.000 572 218 7	0.098 540 48	0.173 10	0.004 77	0.822 13
405	0.023 190 00	0.000 640 000 0	0.110 200 0	0.173 02	0.004 78	0.822 20
06	0.026 207 36	0.000 724 560 0	0.124 613 3	0.172 93	0.004 78	0.822 29
07	0.029 782 48	0.000 825 500 0	0.141 701 7	0.172 84	0.004 79	0.822 37
08	0.033 880 92	0.000 941 160 0	0.161 303 5	0.172 75	0.004 80	0.822 45
09	0.038 468 24	0.001 069 880	0.183 256 8	0.172 66	0.004 80	0.822 54

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	CHROMATICITY COORDINATES $x(\lambda)$	$y(\lambda)$	$z(\lambda)$
410	0.043 510 00	0.001 210 000	0.207 400 0	0.172 58	0.004 80	0.822 62
11	0.048 995 60	0.001 362 091	0.233 692 1	0.172 49	0.004 80	0.822 71
12	0.055 022 60	0.001 530 752	0.262 611 4	0.172 39	0.004 80	0.822 81
13	0.061 718 80	0.001 720 368	0.294 774 6	0.172 30	0.004 80	0.822 90
14	0.069 212 00	0.001 935 323	0.330 798 5	0.172 19	0.004 82	0.822 99
415	0.077 630 00	0.002 180 000	0.371 300 0	0.172 09	0.004 83	0.823 08
16	0.086 958 11	0.002 454 800	0.416 209 1	0.171 98	0.004 86	0.823 16
17	0.097 176 72	0.002 764 000	0.465 464 2	0.171 87	0.004 89	0.823 24
18	0.108 406 3	0.003 117 800	0.519 694 8	0.171 74	0.004 94	0.823 32
19	0.120 767 2	0.003 526 400	0.579 530 3	0.171 59	0.005 01	0.823 40
420	0.134 380 0	0.004 000 000	0.645 600 0	0.171 41	0.005 10	0.823 49
21	0.149 358 2	0.004 546 240	0.718 483 8	0.171 21	0.005 21	0.823 58
22	0.165 395 7	0.005 159 320	0.796 713 3	0.170 99	0.005 33	0.823 68
23	0.181 983 1	0.005 829 280	0.877 845 9	0.170 77	0.005 47	0.823 76
24	0.198 611 0	0.006 546 160	0.959 439 0	0.170 54	0.005 62	0.823 84
425	0.214 770 0	0.007 300 000	1.039 050 1	0.170 30	0.005 79	0.823 91
26	0.230 186 8	0.008 086 507	1.115 367 3	0.170 05	0.005 97	0.823 98
27	0.244 879 7	0.008 908 720	1.188 497 1	0.169 78	0.006 18	0.824 04
28	0.258 777 3	0.009 767 680	1.258 123 3	0.169 50	0.006 40	0.824 10
29	0.271 807 9	0.010 664 43	1.323 929 6	0.169 20	0.006 64	0.824 16
430	0.283 900 0	0.011 600 00	1.385 600 0	0.168 88	0.006 90	0.824 22
31	0.294 943 8	0.012 573 17	1.442 635 2	0.168 53	0.007 18	0.824 29
32	0.304 896 5	0.013 582 72	1.494 803 5	0.168 15	0.007 49	0.824 36
33	0.313 787 3	0.014 629 68	1.542 190 3	0.167 75	0.007 82	0.824 43
34	0.321 645 4	0.015 715 09	1.584 880 7	0.167 33	0.008 17	0.824 50
435	0.328 500 0	0.016 840 00	1.622 960 0	0.166 90	0.008 55	0.824 55
36	0.334 351 3	0.018 007 36	1.656 404 8	0.166 45	0.008 96	0.824 59
37	0.339 210 1	0.019 214 48	1.685 295 9	0.165 98	0.009 40	0.824 62
38	0.343 121 3	0.020 453 92	1.709 874 5	0.165 48	0.009 87	0.824 65
39	0.346 129 6	0.021 718 24	1.730 382 1	0.164 96	0.010 35	0.824 69
440	0.348 280 0	0.023 000 00	1.747 060 0	0.164 41	0.010 86	0.824 73
41	0.349 599 9	0.024 294 61	1.760 044 6	0.163 83	0.011 38	0.824 79
42	0.350 147 4	0.025 610 24	1.769 623 3	0.163 21	0.011 94	0.824 85
43	0.350 013 0	0.026 958 57	1.776 263 7	0.162 55	0.012 52	0.824 93
44	0.349 287 0	0.028 351 25	1.780 433 4	0.161 85	0.013 14	0.825 01
445	0.348 060 0	0.029 800 00	1.782 600 0	0.161 11	0.013 79	0.825 10
46	0.346 373 3	0.031 310 83	1.782 968 2	0.160 31	0.014 49	0.825 20
47	0.344 262 4	0.032 883 68	1.781 699 8	0.159 47	0.015 23	0.825 30
48	0.341 808 8	0.034 521 12	1.779 198 2	0.158 57	0.016 02	0.825 41
49	0.339 094 1	0.036 225 71	1.775 867 1	0.157 63	0.016 84	0.825 53
450	0.336 200 0	0.038 000 00	1.772 110 0	0.156 64	0.017 71	0.825 65
51	0.333 197 7	0.039 846 67	1.768 258 9	0.155 60	0.018 61	0.825 79
52	0.330 041 1	0.041 768 00	1.764 039 0	0.154 52	0.019 56	0.825 92
53	0.326 635 7	0.043 766 00	1.758 943 8	0.153 40	0.020 55	0.826 05
54	0.322 886 8	0.045 842 67	1.752 466 3	0.152 22	0.021 61	0.826 17
455	0.318 700 0	0.048 000 00	1.744 100 0	0.150 99	0.022 74	0.826 27
56	0.314 025 1	0.050 243 68	1.733 559 5	0.149 69	0.023 95	0.826 36
57	0.308 884 0	0.052 573 04	1.720 858 1	0.148 34	0.025 25	0.826 41
58	0.303 290 4	0.054 980 56	1.705 936 9	0.146 93	0.026 63	0.826 44
59	0.297 257 9	0.057 458 72	1.688 737 2	0.145 47	0.028 12	0.826 41

TABLE 2.1 (CONTINUED)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	CHROMATICITY COORDINATES $x(\lambda)$	$y(\lambda)$	$z(\lambda)$
460	0.290 800 0	0.060 000 00	1.669 200 0	0.143 96	0.029 70	0.826 34
61	0.283 970 1	0.062 601 97	1.647 528 7	0.142 41	0.031 39	0.826 20
62	0.276 721 4	0.065 277 52	1.623 412 7	0.140 80	0.033 21	0.825 99
63	0.268 917 8	0.068 042 08	1.596 022 3	0.139 12	0.035 20	0.825 68
64	0.260 422 7	0.070 911 09	1.564 528 0	0.137 37	0.037 40	0.825 23
465	0.251 100 0	0.073 900 00	1.528 100 0	0.135 50	0.039 88	0.824 62
66	0.240 847 5	0.077 016 00	1.486 111 4	0.133 51	0.042 69	0.823 80
67	0.229 851 2	0.080 266 40	1.439 521 5	0.131 37	0.045 88	0.822 75
68	0.218 407 2	0.083 666 80	1.389 879 9	0.129 09	0.049 45	0.821 46
69	0.206 811 5	0.087 232 80	1.338 736 2	0.126 66	0.053 43	0.819 91
470	0.195 360 0	0.090 980 00	1.287 640 0	0.124 12	0.057 80	0.818 08
71	0.184 213 6	0.094 917 55	1.237 422 3	0.121 47	0.062 59	0.815 94
72	0.173 327 3	0.099 045 84	1.187 824 3	0.118 70	0.067 83	0.813 47
73	0.162 688 1	0.103 367 4	1.138 761 1	0.115 81	0.073 58	0.810 61
74	0.152 283 3	0.107 884 6	1.090 148 0	0.112 78	0.079 89	0.807 33
475	0.142 100 0	0.112 600 0	1.041 900 0	0.109 60	0.086 84	0.803 56
76	0.132 178 6	0.117 532 0	0.994 197 6	0.106 26	0.094 49	0.799 25
77	0.122 569 6	0.122 674 4	0.947 347 3	0.102 78	0.102 86	0.794 36
78	0.113 275 2	0.127 992 8	0.901 453 1	0.099 13	0.112 01	0.788 86
79	0.104 297 9	0.133 452 8	0.856 619 3	0.095 31	0.121 94	0.782 75
480	0.095 640 00	0.139 020 0	0.812 950 1	0.091 29	0.132 70	0.776 01
81	0.087 299 55	0.144 676 4	0.770 517 3	0.087 08	0.144 32	0.768 60
82	0.079 308 04	0.150 469 3	0.729 444 8	0.082 68	0.156 87	0.760 45
83	0.071 717 76	0.156 461 9	0.689 913 6	0.078 12	0.170 42	0.751 46
84	0.064 580 99	0.162 717 7	0.652 104 9	0.073 44	0.185 03	0.741 53
485	0.057 950 01	0.169 300 0	0.616 200 0	0.068 71	0.200 72	0.730 57
86	0.051 862 11	0.176 243 1	0.582 328 6	0.063 99	0.217 47	0.718 54
87	0.046 281 52	0.183 558 1	0.550 416 2	0.059 32	0.235 25	0.705 43
88	0.041 150 88	0.191 273 5	0.520 337 6	0.054 67	0.254 09	0.691 24
89	0.036 412 83	0.199 418 0	0.491 967 3	0.050 03	0.274 00	0.675 97
490	0.032 010 00	0.208 020 0	0.465 180 0	0.045 39	0.294 98	0.659 63
91	0.027 917 20	0.217 119 9	0.439 924 6	0.040 76	0.316 98	0.642 26
92	0.024 144 40	0.226 734 5	0.416 183 6	0.036 20	0.339 90	0.623 90
93	0.020 687 00	0.236 857 1	0.393 882 2	0.031 76	0.363 60	0.604 64
94	0.017 540 40	0.247 481 2	0.372 945 9	0.027 49	0.387 92	0.584 59
495	0.014 700 00	0.258 600 0	0.353 300 0	0.023 46	0.412 70	0.563 84
96	0.012 161 79	0.270 184 9	0.334 857 8	0.019 70	0.437 76	0.542 54
97	0.009 919 960	0.282 293 9	0.317 552 1	0.016 27	0.462 95	0.520 78
98	0.007 967 240	0.295 050 5	0.301 337 5	0.013 18	0.488 21	0.498 61
99	0.006 296 346	0.308 578 0	0.286 168 6	0.010 48	0.513 40	0.476 12
500	0.004 900 000	0.323 000 0	0.272 000 0	0.008 17	0.538 42	0.453 41
01	0.003 777 173	0.338 402 1	0.258 817 1	0.006 28	0.563 07	0.430 65
02	0.002 945 320	0.354 685 8	0.246 483 8	0.004 87	0.587 12	0.408 01
03	0.002 424 880	0.371 698 6	0.234 771 8	0.003 98	0.610 45	0.385 57
04	0.002 236 293	0.389 287 5	0.223 453 3	0.003 64	0.633 01	0.363 35
505	0.002 400 000	0.407 300 0	0.212 300 0	0.003 86	0.654 82	0.341 32
06	0.002 925 520	0.425 629 9	0.201 169 2	0.004 64	0.675 90	0.319 46
07	0.003 836 560	0.444 309 6	0.190 119 6	0.006 01	0.696 12	0.297 87
08	0.005 174 840	0.463 394 4	0.179 225 4	0.007 99	0.715 34	0.276 67
09	0.006 982 080	0.482 939 5	0.168 560 8	0.010 60	0.733 41	0.255 99

151

TABLE 2.1. (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES x̄(λ)	ȳ(λ)	z̄(λ)	CHROMATICITY COORDINATES x(λ)	y(λ)	z(λ)
510	0.009 300 000	0.503 000 0	0.158 200 0	0.013 87	0.750 19	0.235 94
11	0.012 149 49	0.523 569 3	0.148 138 3	0.017 77	0.765 61	0.216 62
12	0.015 535 88	0.544 512 0	0.138 375 8	0.022 24	0.779 63	0.198 13
13	0.019 477 52	0.565 690 0	0.128 994 2	0.027 27	0.792 11	0.180 62
14	0.023 992 77	0.586 965 3	0.120 075 1	0.032 82	0.802 93	0.164 25
515	0.029 100 00	0.608 200 0	0.111 700 0	0.038 85	0.812 02	0.149 13
16	0.034 814 85	0.629 345 6	0.103 904 8	0.045 33	0.819 39	0.135 28
17	0.041 120 16	0.650 306 8	0.096 667 48	0.052 18	0.825 16	0.122 66
18	0.047 985 04	0.670 875 2	0.089 982 72	0.059 32	0.829 43	0.111 25
19	0.055 378 61	0.690 842 4	0.083 845 31	0.066 72	0.832 27	0.101 01
520	0.063 270 00	0.710 000 0	0.078 249 99	0.074 30	0.833 80	0.091 90
21	0.071 635 01	0.728 185 2	0.073 208 99	0.082 05	0.834 09	0.083 86
22	0.080 462 24	0.745 463 6	0.068 678 16	0.089 94	0.833 29	0.076 77
23	0.089 739 96	0.761 969 4	0.064 567 84	0.097 94	0.831 59	0.070 47
24	0.099 456 45	0.777 836 8	0.060 788 35	0.106 02	0.829 18	0.064 80
525	0.109 600 0	0.793 200 0	0.057 250 01	0.114 16	0.826 21	0.059 63
26	0.120 167 4	0.808 110 4	0.053 904 35	0.122 35	0.822 77	0.054 88
27	0.131 114 5	0.822 496 2	0.050 746 64	0.130 55	0.818 93	0.050 52
28	0.142 367 9	0.836 306 8	0.047 752 76	0.138 70	0.814 78	0.046 52
29	0.153 854 2	0.849 491 6	0.044 898 59	0.146 77	0.810 40	0.042 83
530	0.165 500 0	0.862 000 0	0.042 160 00	0.154 72	0.805 86	0.039 42
31	0.177 257 1	0.873 810 8	0.039 507 28	0.162 53	0.801 24	0.036 23
32	0.189 140 0	0.884 962 4	0.036 935 64	0.170 24	0.796 52	0.033 24
33	0.201 169 4	0.895 493 6	0.034 458 36	0.177 85	0.791 69	0.030 46
34	0.213 365 8	0.905 443 2	0.032 088 72	0.185 39	0.786 73	0.027 88
535	0.225 749 9	0.914 850 1	0.029 840 00	0.192 88	0.781 63	0.025 49
36	0.238 320 9	0.923 734 8	0.027 711 81	0.200 31	0.776 40	0.023 29
37	0.251 066 8	0.932 092 4	0.025 694 44	0.207 69	0.771 05	0.021 26
38	0.263 992 2	0.939 922 6	0.023 787 16	0.215 03	0.765 59	0.019 38
39	0.277 101 7	0.947 225 2	0.021 989 25	0.222 34	0.760 02	0.017 64
540	0.290 400 0	0.954 000 0	0.020 300 00	0.229 62	0.754 33	0.016 05
41	0.303 891 2	0.960 256 1	0.018 718 05	0.236 89	0.748 52	0.014 59
42	0.317 572 6	0.966 007 4	0.017 240 36	0.244 13	0.742 62	0.013 25
43	0.331 438 4	0.971 260 6	0.015 863 64	0.251 36	0.736 61	0.012 03
44	0.345 482 8	0.976 022 5	0.014 584 61	0.258 58	0.730 51	0.010 91
545	0.359 700 0	0.980 300 0	0.013 400 00	0.265 78	0.724 32	0.009 90
46	0.374 083 9	0.984 092 4	0.012 307 23	0.272 96	0.718 06	0.008 98
47	0.388 639 6	0.987 418 2	0.011 301 88	0.280 13	0.711 72	0.008 15
48	0.403 378 4	0.990 312 8	0.010 377 92	0.287 29	0.705 32	0.007 39
49	0.418 311 5	0.992 811 6	0.009 529 306	0.294 45	0.698 84	0.006 71
550	0.433 449 9	0.994 950 1	0.008 749 999	0.301 60	0.692 31	0.006 09
51	0.448 795 3	0.996 710 8	0.008 035 200	0.308 76	0.685 71	0.005 53
52	0.464 336 0	0.998 098 3	0.007 381 600	0.315 92	0.679 06	0.005 02
53	0.480 064 0	0.999 112 0	0.006 785 400	0.323 06	0.672 37	0.004 57
54	0.495 971 3	0.999 748 2	0.006 242 800	0.330 21	0.665 63	0.004 16
555	0.512 050 1	1.000 000 0	0.005 749 999	0.337 36	0.658 85	0.003 79
56	0.528 295 9	0.999 856 7	0.005 303 600	0.344 51	0.652 03	0.003 46
57	0.544 691 6	0.999 304 6	0.004 899 800	0.351 67	0.645 17	0.003 16
58	0.561 209 4	0.998 325 5	0.004 534 200	0.358 81	0.638 29	0.002 90
59	0.577 821 5	0.996 898 7	0.004 202 400	0.365 96	0.631 38	0.002 66

152

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	CHROMATICITY COORDINATES $x(\lambda)$	$y(\lambda)$	$z(\lambda)$
560	0.594 500 0	0.995 000 0	0.003 900 000	0.373 10	0.624 45	0.002 45
61	0.611 220 9	0.992 600 5	0.003 623 200	0.380 24	0.617 50	0.002 26
62	0.627 975 8	0.989 742 6	0.003 370 600	0.387 38	0.610 54	0.002 08
63	0.644 760 2	0.986 444 4	0.003 141 400	0.394 51	0.603 57	0.001 92
64	0.661 569 7	0.982 724 1	0.002 934 800	0.401 63	0.596 59	0.001 78
565	0.678 400 0	0.978 600 0	0.002 749 999	0.408 73	0.589 61	0.001 66
66	0.695 239 2	0.974 083 7	0.002 585 200	0.415 83	0.582 62	0.001 55
67	0.712 058 6	0.969 171 2	0.002 438 600	0.422 92	0.575 63	0.001 45
68	0.728 828 4	0.963 856 8	0.002 309 400	0.429 99	0.568 65	0.001 36
69	0.745 518 8	0.958 134 9	0.002 196 800	0.437 04	0.561 67	0.001 29
570	0.762 100 0	0.952 000 0	0.002 100 000	0.444 06	0.554 72	0.001 22
71	0.778 543 2	0.945 450 4	0.002 017 733	0.451 06	0.547 77	0.001 17
72	0.794 825 6	0.938 499 2	0.001 948 200	0.458 04	0.540 84	0.001 12
73	0.810 926 4	0.931 162 8	0.001 889 800	0.464 99	0.533 93	0.001 08
74	0.826 824 8	0.923 457 6	0.001 840 933	0.471 90	0.527 05	0.001 05
575	0.842 500 0	0.915 400 0	0.001 800 000	0.478 78	0.520 20	0.001 02
76	0.857 932 5	0.907 006 4	0.001 766 267	0.485 61	0.513 39	0.001 00
77	0.873 081 6	0.898 277 2	0.001 737 800	0.492 41	0.506 61	0.000 98
78	0.887 894 4	0.889 204 8	0.001 711 200	0.499 15	0.499 89	0.000 96
79	0.902 318 1	0.879 781 6	0.001 683 067	0.505 85	0.493 21	0.000 94
580	0.916 300 0	0.870 000 0	0.001 650 001	0.512 49	0.486 59	0.000 92
81	0.929 799 5	0.859 861 3	0.001 610 133	0.519 07	0.480 03	0.000 90
82	0.942 798 4	0.849 392 0	0.001 564 400	0.525 60	0.473 53	0.000 87
83	0.955 277 6	0.838 622 0	0.001 513 600	0.532 07	0.467 09	0.000 84
84	0.967 217 9	0.827 581 3	0.001 458 533	0.538 46	0.460 73	0.000 81
585	0.978 600 0	0.816 300 0	0.001 400 000	0.544 79	0.454 43	0.000 78
86	0.989 385 6	0.804 794 7	0.001 336 667	0.551 03	0.448 23	0.000 74
87	0.999 548 8	0.793 082 0	0.001 270 000	0.557 19	0.442 10	0.000 71
88	1.009 089 2	0.781 192 0	0.001 205 000	0.563 27	0.436 06	0.000 67
89	1.018 006 4	0.769 154 7	0.001 146 667	0.569 26	0.430 10	0.000 64
590	1.026 300 0	0.757 000 0	0.001 100 000	0.575 15	0.424 23	0.000 62
91	1.033 982 7	0.744 754 1	0.001 068 800	0.580 94	0.418 46	0.000 60
92	1.040 986 0	0.732 422 4	0.001 049 400	0.586 65	0.412 76	0.000 59
93	1.047 188 0	0.720 003 6	0.001 035 600	0.592 22	0.407 19	0.000 59
94	1.052 466 7	0.707 496 5	0.001 021 200	0.597 66	0.401 76	0.000 58
595	1.056 700 0	0.694 900 0	0.001 000 000	0.602 93	0.396 50	0.000 57
96	1.059 794 4	0.682 219 2	0.000 968 640 0	0.608 03	0.391 41	0.000 56
97	1.061 799 2	0.669 471 6	0.000 929 920 0	0.612 98	0.386 48	0.000 54
98	1.062 806 8	0.656 674 4	0.000 886 880 0	0.617 78	0.381 71	0.000 51
99	1.062 909 6	0.643 844 8	0.000 842 560 0	0.622 46	0.377 05	0.000 49
600	1.062 200 0	0.631 000 0	0.000 800 000 0	0.627 04	0.372 49	0.000 47
01	1.060 735 2	0.618 155 5	0.000 760 960 0	0.631 52	0.368 03	0.000 45
02	1.058 443 6	0.605 314 4	0.000 723 680 0	0.635 90	0.363 67	0.000 43
03	1.055 224 4	0.592 475 6	0.000 685 920 0	0.640 16	0.359 43	0.000 41
04	1.050 976 8	0.579 637 9	0.000 645 440 0	0.644 27	0.355 33	0.000 40
605	1.045 600 0	0.566 800 0	0.000 600 000 0	0.648 23	0.351 40	0.000 37
06	1.039 036 9	0.553 961 1	0.000 547 866 7	0.652 03	0.347 63	0.000 34
07	1.031 360 8	0.541 137 2	0.000 491 600 0	0.655 67	0.344 02	0.000 31
08	1.022 666 2	0.528 352 8	0.000 435 400 0	0.659 17	0.340 55	0.000 28
09	1.013 047 7	0.515 632 3	0.000 383 466 7	0.662 53	0.337 22	0.000 25

153

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES x̄(λ)	ȳ(λ)	z̄(λ)	CHROMATICITY COORDINATES x(λ)	y(λ)	z(λ)
610	1.002 600 0	0.503 000 0	0.000 340 000 0	0.665 76	0.334 01	0.000 23
11	0.991 367 5	0.490 468 8	0.000 307 253 3	0.668 87	0.330 92	0.000 21
12	0.979 331 4	0.478 030 4	0.000 283 160 0	0.671 86	0.327 95	0.000 19
13	0.966 491 6	0.465 677 6	0.000 265 440 0	0.674 72	0.325 09	0.000 19
14	0.952 847 9	0.453 403 2	0.000 251 813 3	0.677 46	0.322 36	0.000 18
615	0.938 400 0	0.441 200 0	0.000 240 000 0	0.680 08	0.319 75	0.000 17
16	0.923 194 0	0.429 080 0	0.000 229 546 7	0.682 58	0.317 25	0.000 17
17	0.907 244 0	0.417 036 0	0.000 220 640 0	0.684 97	0.314 86	0.000 17
18	0.890 502 0	0.405 032 0	0.000 211 960 0	0.687 25	0.312 59	0.000 16
19	0.872 920 0	0.393 032 0	0.000 202 186 7	0.689 43	0.310 41	0.000 16
620	0.854 449 9	0.381 000 0	0.000 190 000 0	0.691 51	0.308 34	0.000 15
21	0.835 084 0	0.368 918 4	0.000 174 213 3	0.693 49	0.306 37	0.000 14
22	0.814 946 0	0.356 827 2	0.000 155 640 0	0.695 39	0.304 48	0.000 13
23	0.794 186 0	0.344 776 8	0.000 135 960 0	0.697 21	0.302 67	0.000 12
24	0.772 954 0	0.332 817 6	0.000 116 853 3	0.698 94	0.300 95	0.000 11
625	0.751 400 0	0.321 000 0	0.000 100 000 0	0.700 61	0.299 30	0.000 09
26	0.729 583 6	0.309 338 1	0.000 086 133 33	0.702 19	0.297 73	0.000 08
27	0.707 588 8	0.297 850 4	0.000 074 600 00	0.703 71	0.296 22	0.000 07
28	0.685 602 2	0.286 593 6	0.000 065 000 00	0.705 16	0.294 77	0.000 07
29	0.663 810 4	0.275 624 5	0.000 056 933 33	0.706 56	0.293 38	0.000 06
630	0.642 400 0	0.265 000 0	0.000 049 999 99	0.707 92	0.292 03	0.000 05
31	0.621 514 9	0.254 763 2	0.000 044 160 00	0.709 23	0.290 72	0.000 05
32	0.601 113 8	0.244 889 6	0.000 039 480 00	0.710 50	0.289 45	0.000 05
33	0.581 105 2	0.235 334 4	0.000 035 720 00	0.711 73	0.288 23	0.000 04
34	0.561 397 7	0.226 052 8	0.000 032 640 00	0.712 90	0.287 06	0.000 04
635	0.541 900 0	0.217 000 0	0.000 030 000 00	0.714 03	0.285 93	0.000 04
36	0.522 599 5	0.208 161 6	0.000 027 653 33	0.715 12	0.284 84	0.000 04
37	0.503 546 4	0.199 548 8	0.000 025 560 00	0.716 16	0.283 80	0.000 04
38	0.484 743 6	0.191 155 2	0.000 023 640 00	0.717 16	0.282 81	0.000 03
39	0.466 193 9	0.182 974 4	0.000 021 813 33	0.718 12	0.281 85	0.000 03
640	0.447 900 0	0.175 000 0	0.000 020 000 00	0.719 03	0.280 94	0.000 03
41	0.429 861 3	0.167 223 5	0.000 018 133 33	0.719 91	0.280 06	0.000 03
42	0.412 098 0	0.159 646 4	0.000 016 200 00	0.720 75	0.279 22	0.000 03
43	0.394 644 0	0.152 277 6	0.000 014 200 00	0.721 55	0.278 42	0.000 03
44	0.377 533 3	0.145 125 9	0.000 012 133 33	0.722 32	0.277 66	0.000 02
645	0.360 800 0	0.138 200 0	0.000 010 000 00	0.723 03	0.276 95	0.000 02
46	0.344 456 3	0.131 500 3	0.000 007 733 333	0.723 70	0.276 28	0.000 02
47	0.328 516 8	0.125 024 8	0.000 005 400 000	0.724 33	0.275 66	0.000 01
48	0.313 019 2	0.118 779 2	0.000 003 200 000	0.724 91	0.275 08	0.000 01
49	0.298 001 1	0.112 769 1	0.000 001 333 333	0.725 47	0.274 53	0.000 00
650	0.283 500 0	0.107 000 0	0.000 000 000 000	0.725 99	0.274 01	0.000 00
51	0.269 544 8	0.101 476 2		0.726 49	0.273 51	
52	0.256 118 4	0.096 188 64		0.726 98	0.273 02	
53	0.243 189 6	0.091 122 96		0.727 43	0.272 57	
54	0.230 727 2	0.086 264 85		0.727 86	0.272 14	

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	CHROMATICITY COORDINATES $x(\lambda)$	$y(\lambda)$	$z(\lambda)$
655	0.218 700 0	0.081 600 00	0.000 000 0	0.728 27	0.271 73	0.000 00
56	0.207 097 1	0.077 120 64		0.728 66	0.271 34	
57	0.195 923 2	0.072 825 52		0.729 02	0.270 98	
58	0.185 170 8	0.068 710 08		0.729 36	0.270 64	
59	0.174 832 3	0.064 769 76		0.729 68	0.270 32	
660	0.164 900 0	0.061 000 00		0.729 97	0.270 03	
61	0.155 366 7	0.057 396 21		0.730 23	0.269 77	
62	0.146 230 0	0.053 955 04		0.730 47	0.269 53	
63	0.137 490 0	0.050 673 76		0.730 69	0.269 31	
64	0.129 146 7	0.047 549 65		0.730 90	0.269 10	
665	0.121 200 0	0.044 580 00		0.731 09	0.268 91	
66	0.113 639 7	0.041 758 72		0.731 28	0.268 72	
67	0.106 465 0	0.039 084 96		0.731 47	0.268 53	
68	0.099 690 44	0.036 563 84		0.731 65	0.268 35	
69	0.093 330 61	0.034 200 48		0.731 83	0.268 17	
670	0.087 400 00	0.032 000 00		0.731 99	0.268 01	
71	0.081 900 96	0.029 962 61		0.732 15	0.267 85	
72	0.076 804 28	0.028 076 64		0.732 30	0.267 70	
73	0.072 077 12	0.026 329 36		0.732 44	0.267 56	
74	0.067 686 64	0.024 708 05		0.732 58	0.267 42	
675	0.063 600 00	0.023 200 00		0.732 72	0.267 28	
76	0.059 806 85	0.021 800 77		0.732 86	0.267 14	
77	0.056 282 16	0.020 501 12		0.733 00	0.267 00	
78	0.052 971 04	0.019 281 08		0.733 14	0.266 86	
79	0.049 818 61	0.018 120 69		0.733 28	0.266 72	
680	0.046 770 00	0.017 000 00		0.733 42	0.266 58	
81	0.043 784 05	0.015 903 79		0.733 55	0.266 45	
82	0.040 875 36	0.014 837 18		0.733 68	0.266 32	
83	0.038 072 64	0.013 810 68		0.733 81	0.266 19	
84	0.035 404 61	0.012 834 78		0.733 94	0.266 06	
685	0.032 900 00	0.011 920 00		0.734 05	0.265 95	
86	0.030 564 19	0.011 068 31		0.734 14	0.265 86	
87	0.028 380 56	0.010 273 39		0.734 22	0.265 78	
88	0.026 344 84	0.009 533 311		0.734 29	0.265 71	
89	0.024 452 75	0.008 846 157		0.734 34	0.265 66	
690	0.022 700 00	0.008 210 000		0.734 39	0.265 61	
91	0.021 084 29	0.007 623 781		0.734 44	0.265 56	
92	0.019 599 88	0.007 085 424		0.734 48	0.265 52	
93	0.018 237 32	0.006 591 476		0.734 52	0.265 48	
94	0.016 987 17	0.006 138 485		0.734 56	0.265 44	
695	0.015 840 00	0.005 723 000		0.734 59	0.265 41	
96	0.014 790 64	0.005 343 059		0.734 62	0.265 38	
97	0.013 831 32	0.004 995 796		0.734 65	0.265 35	
98	0.012 948 68	0.004 676 404		0.734 67	0.265 33	
99	0.012 129 20	0.004 380 075		0.734 69	0.265 31	
700	0.011 359 16	0.004 102 000		0.734 69	0.265 31	
01	0.010 629 35	0.003 838 453		0.734 69	0.265 31	
02	0.009 938 846	0.003 589 099		0.734 69	0.265 31	
03	0.009 288 422	0.003 354 219		0.734 69	0.265 31	
04	0.008 678 854	0.003 134 093		0.734 69	0.265 31	

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES x̄(λ)	ȳ(λ)	z̄(λ)	CHROMATICITY COORDINATES x(λ)	y(λ)	z(λ)
705	0.008 110 916	0.002 929 000	0.000 000 0	0.734 69	0.265 31	0.000 00
06	0.007 582 388	0.002 738 139		0.734 69	0.265 31	
07	0.007 088 746	0.002 559 876		0.734 69	0.265 31	
08	0.006 627 313	0.002 393 244		0.734 69	0.265 31	
09	0.006 195 408	0.002 237 275		0.734 69	0.265 31	
710	0.005 790 346	0.002 091 000		0.734 69	0.265 31	
11	0.005 409 826	0.001 953 587		0.734 69	0.265 31	
12	0.005 052 583	0.001 824 580		0.734 69	0.265 31	
13	0.004 717 512	0.001 703 580		0.734 69	0.265 31	
14	0.004 403 507	0.001 590 187		0.734 69	0.265 31	
715	0.004 109 457	0.001 484 000		0.734 69	0.265 31	
16	0.003 833 913	0.001 384 496		0.734 69	0.265 31	
17	0.003 575 748	0.001 291 268		0.734 69	0.265 31	
18	0.003 334 342	0.001 204 092		0.734 69	0.265 31	
19	0.003 109 075	0.001 122 744		0.734 69	0.265 31	
720	0.002 899 327	0.001 047 000		0.734 69	0.265 31	
21	0.002 704 348	0.000 976 589 6		0.734 69	0.265 31	
22	0.002 523 020	0.000 911 108 8		0.734 69	0.265 31	
23	0.002 354 168	0.000 850 133 2		0.734 69	0.265 31	
24	0.002 196 616	0.000 793 238 4		0.734 69	0.265 31	
725	0.002 049 190	0.000 740 000 0		0.734 69	0.265 31	
26	0.001 910 960	0.000 690 082 7		0.734 69	0.265 31	
27	0.001 781 438	0.000 643 310 0		0.734 69	0.265 31	
28	0.001 660 110	0.000 599 496 0		0.734 69	0.265 31	
29	0.001 546 459	0.000 558 454 7		0.734 69	0.265 31	
730	0.001 439 971	0.000 520 000 0		0.734 69	0.265 31	
31	0.001 340 042	0.000 483 913 6		0.734 69	0.265 31	
32	0.001 246 275	0.000 450 052 8		0.734 69	0.265 31	
33	0.001 158 471	0.000 418 345 2		0.734 69	0.265 31	
34	0.001 076 430	0.000 388 718 4		0.734 69	0.265 31	
735	0.000 999 949 3	0.000 361 100 0		0.734 69	0.265 31	
36	0.000 928 735 8	0.000 335 383 5		0.734 69	0.265 31	
37	0.000 862 433 2	0.000 311 440 4		0.734 69	0.265 31	
38	0.000 800 750 3	0.000 289 165 6		0.734 69	0.265 31	
39	0.000 743 396 0	0.000 268 453 9		0.734 69	0.265 31	
740	0.000 690 078 6	0.000 249 200 0		0.734 69	0.265 31	
41	0.000 640 515 6	0.000 231 301 9		0.734 69	0.265 31	
42	0.000 594 502 1	0.000 214 685 6		0.734 69	0.265 31	
43	0.000 551 864 6	0.000 199 288 4		0.734 69	0.265 31	
44	0.000 512 429 0	0.000 185 047 5		0.734 69	0.265 31	
745	0.000 476 021 3	0.000 171 900 0		0.734 69	0.265 31	
46	0.000 442 453 6	0.000 159 778 1		0.734 69	0.265 31	
47	0.000 411 511 7	0.000 148 604 4		0.734 69	0.265 31	
48	0.000 382 981 4	0.000 138 301 6		0.734 69	0.265 31	
49	0.000 356 649 1	0.000 128 792 5		0.734 69	0.265 31	
750	0.000 332 301 1	0.000 120 000 0		0.734 69	0.265 31	
51	0.000 309 758 6	0.000 111 859 5		0.734 69	0.265 31	
52	0.000 288 887 1	0.000 104 322 4		0.734 69	0.265 31	
53	0.000 269 539 4	0.000 097 335 60		0.734 69	0.265 31	
54	0.000 251 568 2	0.000 090 845 87		0.734 69	0.265 31	

TABLE 2.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES x̄(λ)	ȳ(λ)	z̄(λ)	CHROMATICITY COORDINATES x(λ)	y(λ)	z(λ)
755	0.000 234 826 1	0.000 084 800 00	0.000 000 0	0.734 69	0.265 31	0.000 00
56	0.000 219 171 0	0.000 079 146 67		0.734 69	0.265 31	
57	0.000 204 525 8	0.000 073 858 00		0.734 69	0.265 31	
58	0.000 190 840 5	0.000 068 916 00		0.734 69	0.265 31	
59	0.000 178 065 4	0.000 064 302 67		0.734 69	0.265 31	
760	0.000 166 150 5	0.000 060 000 00		0.734 69	0.265 31	
61	0.000 155 023 6	0.000 055 981 87		0.734 69	0.265 31	
62	0.000 144 621 9	0.000 052 225 60		0.734 69	0.265 31	
63	0.000 134 909 8	0.000 048 718 40		0.734 69	0.265 31	
64	0.000 125 852 0	0.000 045 447 47		0.734 69	0.265 31	
765	0.000 117 413 0	0.000 042 400 00		0.734 69	0.265 31	
66	0.000 109 551 5	0.000 039 561 04		0.734 69	0.265 31	
67	0.000 102 224 5	0.000 036 915 12		0.734 69	0.265 31	
68	0.000 095 394 45	0.000 034 448 68		0.734 69	0.265 31	
69	0.000 089 023 90	0.000 032 148 16		0.734 69	0.265 31	
770	0.000 083 075 27	0.000 030 000 00		0.734 69	0.265 31	
71	0.000 077 512 69	0.000 027 991 25		0.734 69	0.265 31	
72	0.000 072 313 04	0.000 026 113 56		0.734 69	0.265 31	
73	0.000 067 457 78	0.000 024 360 24		0.734 69	0.265 31	
74	0.000 062 928 44	0.000 022 724 61		0.734 69	0.265 31	
775	0.000 058 706 52	0.000 021 200 00		0.734 69	0.265 31	
76	0.000 054 770 28	0.000 019 778 55		0.734 69	0.265 31	
77	0.000 051 099 18	0.000 018 452 85		0.734 69	0.265 31	
78	0.000 047 676 54	0.000 017 216 87		0.734 69	0.265 31	
79	0.000 044 485 67	0.000 016 064 59		0.734 69	0.265 31	
780	0.000 041 509 94	0.000 014 990 00		0.734 69	0.265 31	
81	0.000 038 733 24	0.000 013 987 28		0.734 69	0.265 31	
82	0.000 036 142 03	0.000 013 051 55		0.734 69	0.265 31	
83	0.000 033 723 52	0.000 012 178 18		0.734 69	0.265 31	
84	0.000 031 464 87	0.000 011 362 54		0.734 69	0.265 31	
785	0.000 029 353 26	0.000 010 600 00		0.734 69	0.265 31	
86	0.000 027 375 73	0.000 009 885 877		0.734 69	0.265 31	
87	0.000 025 524 33	0.000 009 217 304		0.734 69	0.265 31	
88	0.000 023 793 76	0.000 008 592 362		0.734 69	0.265 31	
89	0.000 022 178 70	0.000 008 009 133		0.734 69	0.265 31	
790	0.000 020 673 83	0.000 007 465 700		0.734 69	0.265 31	
91	0.000 019 272 26	0.000 006 959 567		0.734 69	0.265 31	
92	0.000 017 966 40	0.000 006 487 995		0.734 69	0.265 31	
93	0.000 016 749 91	0.000 006 048 699		0.734 69	0.265 31	
94	0.000 015 616 48	0.000 005 639 396		0.734 69	0.265 31	
795	0.000 014 559 77	0.000 005 257 800		0.734 69	0.265 31	
96	0.000 013 573 87	0.000 004 901 771		0.734 69	0.265 31	
97	0.000 012 654 36	0.000 004 569 720		0.734 69	0.265 31	
98	0.000 011 797 23	0.000 004 260 194		0.734 69	0.265 31	
99	0.000 010 998 44	0.000 003 971 739		0.734 69	0.265 31	
800	0.000 010 253 98	0.000 003 702 900		0.734 69	0.265 31	
01	0.000 009 559 646	0.000 003 452 163		0.734 69	0.265 31	
02	0.000 008 912 044	0.000 003 218 302		0.734 69	0.265 31	
03	0.000 008 308 358	0.000 003 000 300		0.734 69	0.265 31	
04	0.000 007 745 769	0.000 002 797 139		0.734 69	0.265 31	

157

TABLE 2.1 (CONTINUED)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	CHROMATICITY COORDINATES $x(\lambda)$	$y(\lambda)$	$z(\lambda)$
805	0.000 007 221 456	0.000 002 607 800	0.000 000 0	0.734 69	0.265 31	0.000 00
06	0.000 006 732 475	0.000 002 431 220		0.734 69	0.265 31	
07	0.000 006 276 423	0.000 002 266 531		0.734 69	0.265 31	
08	0.000 005 851 304	0.000 002 113 013		0.734 69	0.265 31	
09	0.000 005 455 118	0.000 001 969 943		0.734 69	0.265 31	
810	0.000 005 085 868	0.000 001 836 600		0.734 69	0.265 31	
11	0.000 004 741 466	0.000 001 712 230		0.734 69	0.265 31	
12	0.000 004 420 236	0.000 001 596 228		0.734 69	0.265 31	
13	0.000 004 120 783	0.000 001 488 090		0.734 69	0.265 31	
14	0.000 003 841 716	0.000 001 387 314		0.734 69	0.265 31	
815	0.000 003 581 652	0.000 001 293 400		0.734 69	0.265 31	
16	0.000 003 339 127	0.000 001 205 820		0.734 69	0.265 31	
17	0.000 003 112 949	0.000 001 124 143		0.734 69	0.265 31	
18	0.000 002 902 121	0.000 001 048 009		0.734 69	0.265 31	
19	0.000 002 705 645	0.000 000 977 057 8		0.734 69	0.265 31	
820	0.000 002 522 525	0.000 000 910 930 0		0.734 69	0.265 31	
21	0.000 002 351 726	0.000 000 849 251 3		0.734 69	0.265 31	
22	0.000 002 192 415	0.000 000 791 721 2		0.734 69	0.265 31	
23	0.000 002 043 902	0.000 000 738 090 4		0.734 69	0.265 31	
24	0.000 001 905 497	0.000 000 688 109 8		0.734 69	0.265 31	
825	0.000 001 776 509	0.000 000 641 530 0		0.734 69	0.265 31	
26	0.000 001 656 215	0.000 000 598 089 5		0.734 69	0.265 31	
27	0.000 001 544 022	0.000 000 557 574 6		0.734 69	0.265 31	
28	0.000 001 439 440	0.000 000 519 808 0		0.734 69	0.265 31	
29	0.000 001 341 977	0.000 000 484 612 3		0.734 69	0.265 31	
830	0.000 001 251 141	0.000 000 451 810 0		0.734 69	0.265 31	

$\Sigma\bar{x}(\lambda)$ = 106.865 469 489 595
$\Sigma\bar{y}(\lambda)$ = 106.856 917 101 172
$\Sigma\bar{z}(\lambda)$ = 106.892 251 278 636

158

TABLE 2.2

	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
λ (nm)	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
360	0.000 000 122 200	0.000 000 013 398	0.000 000 535 027	0.182 22	0.019 98	0.797 80
361	0.000 000 185 138	0.000 000 020 294	0.000 000 810 720	0.182 20	0.019 97	0.797 83
362	0.000 000 278 83	0.000 000 030 56	0.000 001 221 20	0.182 17	0.019 97	0.797 86
363	0.000 000 417 47	0.000 000 045 74	0.000 001 828 70	0.182 15	0.019 96	0.797 89
364	0.000 000 621 33	0.000 000 068 05	0.000 002 722 20	0.182 12	0.019 95	0.797 93
365	0.000 000 919 27	0.000 000 100 65	0.000 004 028 30	0.182 10	0.019 94	0.797 96
366	0.000 001 351 98	0.000 000 147 98	0.000 005 925 70	0.182 07	0.019 93	0.798 00
367	0.000 001 976 54	0.000 000 216 27	0.000 008 665 10	0.182 04	0.019 92	0.798 04
368	0.000 002 872 5	0.000 000 314 2	0.000 012 596 0	0.182 00	0.019 91	0.798 09
369	0.000 004 149 5	0.000 000 453 7	0.000 018 201 0	0.181 96	0.019 90	0.798 14
370	0.000 005 958 6	0.000 000 651 1	0.000 026 143 7	0.181 92	0.019 88	0.798 20
371	0.000 008 505 6	0.000 000 928 8	0.000 037 330 0	0.181 88	0.019 86	0.798 26
372	0.000 012 068 6	0.000 001 317 5	0.000 052 987 0	0.181 83	0.019 85	0.798 32
373	0.000 017 022 6	0.000 001 857 2	0.000 074 764 0	0.181 78	0.019 83	0.798 39
374	0.000 023 868	0.000 002 602	0.000 104 870	0.181 73	0.019 81	0.798 46
375	0.000 033 266	0.000 003 625	0.000 146 220	0.181 67	0.019 80	0.798 53
376	0.000 046 087	0.000 005 019	0.000 202 660	0.181 61	0.019 78	0.798 61
377	0.000 063 472	0.000 006 907	0.000 279 230	0.181 55	0.019 76	0.798 69
378	0.000 086 892	0.000 009 449	0.000 382 450	0.181 48	0.019 74	0.798 78
379	0.000 118 246	0.000 012 848	0.000 520 720	0.181 41	0.019 71	0.798 88
380	0.000 159 952	0.000 017 364	0.000 704 776	0.181 33	0.019 69	0.798 98
381	0.000 215 080	0.000 023 327	0.000 948 230	0.181 25	0.019 66	0.799 09
382	0.000 287 49	0.000 031 15	0.001 268 20	0.181 17	0.019 63	0.799 20
383	0.000 381 99	0.000 041 35	0.001 686 10	0.181 09	0.019 60	0.799 31
384	0.000 504 55	0.000 054 56	0.002 228 50	0.181 00	0.019 57	0.799 43
385	0.000 662 44	0.000 071 56	0.002 927 80	0.180 91	0.019 54	0.799 55
386	0.000 864 50	0.000 093 30	0.003 823 70	0.180 80	0.019 51	0.799 69
387	0.001 121 50	0.000 120 87	0.004 964 20	0.180 70	0.019 47	0.799 83
388	0.001 446 16	0.000 155 64	0.006 406 70	0.180 58	0.019 43	0.799 99
389	0.001 853 59	0.000 199 20	0.008 219 30	0.180 45	0.019 39	0.800 16
390	0.002 361 6	0.000 253 4	0.010 482 2	0.180 31	0.019 35	0.800 34
391	0.002 990 6	0.000 320 2	0.013 289 0	0.180 16	0.019 29	0.800 55
392	0.003 764 5	0.000 402 4	0.016 747 0	0.180 00	0.019 24	0.800 76
393	0.004 710 2	0.000 502 3	0.020 980 0	0.179 83	0.019 18	0.800 99
394	0.005 858 1	0.000 623 2	0.026 127 0	0.179 65	0.019 11	0.801 24
395	0.007 242 3	0.000 768 5	0.032 344 0	0.179 47	0.019 04	0.801 49
396	0.008 899 6	0.000 941 7	0.039 802 0	0.179 27	0.018 97	0.801 76
397	0.010 870 9	0.001 147 8	0.048 691 0	0.179 06	0.018 91	0.802 03
398	0.013 198 9	0.001 390 3	0.059 210 0	0.178 85	0.018 84	0.802 31
399	0.015 929 2	0.001 674 0	0.071 576 0	0.178 62	0.018 77	0.802 61
400	0.019 109 7	0.002 004 4	0.086 010 9	0.178 39	0.018 71	0.802 90
401	0.022 788	0.002 386	0.102 740	0.178 15	0.018 65	0.803 20
402	0.027 011	0.002 822	0.122 000	0.177 90	0.018 59	0.803 51
403	0.031 829	0.003 319	0.144 020	0.177 65	0.018 52	0.803 83
404	0.037 278	0.003 880	0.168 990	0.177 39	0.018 46	0.804 15
405	0.043 400	0.004 509	0.197 120	0.177 12	0.018 40	0.804 48
406	0.050 223	0.005 209	0.228 570	0.176 84	0.018 34	0.804 82
407	0.057 764	0.005 985	0.263 470	0.176 53	0.018 29	0.805 18
408	0.066 038	0.006 833	0.301 900	0.176 21	0.018 23	0.805 56
409	0.075 033	0.007 757	0.343 870	0.175 86	0.018 18	0.805 96
410	0.084 736	0.008 756	0.389 366	0.175 49	0.018 13	0.806 38

159

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
411	0.095 041	0.009 816	0.437 970	0.175 09	0.018 08	0.806 83
412	0.105 836	0.010 918	0.489 220	0.174 65	0.018 02	0.807 33
413	0.117 066	0.012 058	0.542 900	0.174 20	0.017 94	0.807 86
414	0.128 682	0 013 237	0.598 810	0.173 72	0.017 87	0.808 41
415	0.140 638	0.014 456	0.656 760	0.173 23	0.017 81	0.808 96
416	0.152 893	0.015 717	0.716 580	0.172 72	0.017 76	0.809 52
417	0.165 416	0.017 025	0.778 120	0.172 21	0.017 72	0.810 07
418	0.178 191	0.018 399	0.841 310	0.171 68	0.017 73	0.810 59
419	0.191 214	0.019 848	0.906 110	0.171 16	0.017 77	0.811 07
420	0.204 492	0.021 391	0.972 542	0.170 63	0.017 85	0.811 52
421	0.217 650	0.022 992	1.038 90	0.170 10	0.017 97	0.811 93
422	0.230 267	0.024 598	1.103 10	0.169 57	0.018 11	0.812 32
423	0.242 311	0.026 213	1.165 10	0.169 02	0.018 28	0.812 70
424	0.253 793	0.027 841	1.224 90	0.168 46	0.018 48	0.813 06
425	0.264 737	0.029 497	1.282 50	0.167 90	0.018 71	0.813 39
426	0.275 195	0.031 195	1.338 20	0.167 33	0.018 97	0.813 70
427	0.285 301	0.032 927	1.392 60	0.166 76	0.019 25	0.813 99
428	0.295 143	0.034 738	1.446 10	0.166 19	0.019 56	0.814 25
429	0.304 869	0.036 654	1.499 40	0.165 61	0.019 91	0.814 48
430	0.314 679	0.038 676	1.553 48	0.165 03	0.020 28	0.814 69
431	0.324 355	0.040 792	1.607 20	0.164 45	0.020 68	0.814 87
432	0.333 570	0.042 946	1.658 90	0.163 88	0.021 10	0.815 02
433	0.342 243	0.045 114	1.708 20	0.163 32	0.021 53	0.815 15
434	0.350 312	0.047 333	1.754 80	0.162 75	0.021 99	0.815 26
435	0.357 719	0.049 602	1.798 50	0.162 17	0.022 49	0.815 34
436	0.364 482	0.051 934	1.839 20	0.161 59	0.023 02	0.815 39
437	0.370 493	0.054 337	1.876 60	0.160 98	0.023 61	0.815 41
438	0.375 727	0.056 822	1.910 50	0.160 36	0.024 25	0.815 39
439	0.380 158	0.059 399	1.940 80	0.159 71	0.024 95	0.815 34
440	0.383 734	0.062 077	1.967 28	0.159 02	0.025 73	0.815 25
441	0.386 327	0.064 737	1.989 10	0.158 32	0.026 53	0.815 15
442	0.387 858	0.067 285	2.005 70	0.157 61	0.027 34	0.815 05
443	0.388 396	0.069 764	2.017 40	0.156 89	0.028 18	0.814 93
444	0.387 978	0.072 218	2.024 40	0.156 15	0.029 07	0.814 78
445	0.386 726	0.074 704	2.027 30	0.155 39	0.030 02	0.814 59
446	0.384 696	0.077 272	2.026 40	0.154 60	0.031 05	0.814 35
447	0.382 006	0.079 979	2.022 30	0.153 77	0.032 19	0.814 04
448	0.378 709	0.082 874	2.015 30	0.152 90	0.033 46	0.813 64
449	0.374 915	0.086 000	2.006 00	0.151 98	0.034 86	0.813 16
450	0.370 702	0.089 456	1.994 80	0.151 00	0.036 44	0.812 56
451	0.366 089	0.092 947	1.981 40	0.150 01	0.038 09	0.811 90
452	0.361 045	0.096 275	1.965 30	0.149 03	0.039 74	0.811 23
453	0.355 518	0.099 535	1.946 40	0.148 04	0.041 45	0.810 51
454	0.349 486	0.102 829	1.924 80	0.147 02	0.043 26	0.809 72
455	0.342 957	0.106 256	1.900 70	0.145 94	0.045 22	0.808 84
456	0.335 893	0.109 901	1.874 10	0.144 79	0.047 37	0.807 84
457	0.328 284	0.113 835	1.845 10	0.143 53	0.049 77	0.806 70
458	0.320 150	0.118 167	1.813 90	0.142 15	0.052 47	0.805 38
459	0.311 475	0.122 932	1.780 60	0.140 62	0.055 50	0.803 88
460	0.302 273	0.128 201	1.745 37	0.138 92	0.058 92	0.802 16

160

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
461	0.292 858	0.133 457	1.709 10	0.137 14	0.062 50	0.800 36
462	0.283 502	0.138 323	1.672 30	0.135 38	0.066 05	0.798 57
463	0.274 044	0.143 042	1.634 70	0.133 56	0.069 72	0.796 72
464	0.264 263	0.147 787	1.595 60	0.131 63	0.073 61	0.794 76
465	0.254 085	0.152 761	1.554 90	0.129 52	0.077 87	0.792 61
466	0.243 392	0.158 102	1.512 20	0.127 18	0.082 62	0.790 20
467	0.232 187	0.163 941	1.467 30	0.124 60	0.087 98	0.787 42
468	0.220 488	0.170 362	1.419 90	0.121 77	0.094 08	0.784 15
469	0.208 198	0.177 425	1.370 00	0.118 59	0.101 06	0.780 35
470	0.195 618	0.185 190	1.317 56	0.115 18	0.109 04	0.775 78
471	0.183 034	0.193 025	1.262 40	0.111 71	0.117 81	0.770 48
472	0.170 222	0.200 313	1.205 00	0.108 04	0.127 14	0.764 82
473	0.157 348	0.207 156	1.146 60	0.104 13	0.137 09	0.758 78
474	0.144 650	0.213 644	1.088 00	0.100 01	0.147 72	0.752 27
475	0.132 349	0.219 940	1.030 20	0.095 73	0.159 09	0.745 18
476	0.120 584	0.226 170	0.973 830	0.091 31	0.171 27	0.737 42
477	0.109 456	0.232 467	0.919 430	0.086 78	0.184 30	0.728 92
478	0.099 042	0.239 025	0.867 460	0.082 16	0.198 27	0.719 57
479	0.089 388	0.245 997	0.818 280	0.077 48	0.213 23	0.709 29
480	0.080 507	0.253 589	0.772 125	0.072 78	0.229 24	0.697 98
481	0.072 034	0.261 876	0.728 290	0.067 82	0.246 54	0.685 64
482	0.063 710	0.270 643	0.686 040	0.062 44	0.265 23	0.672 33
483	0.055 694	0.279 645	0.645 530	0.056 78	0.285 10	0.658 12
484	0.048 117	0.288 694	0.606 850	0.050 99	0.305 93	0.643 08
485	0.041 072	0.297 665	0.570 060	0.045 19	0.327 54	0.627 27
486	0.034 642	0.306 469	0.535 220	0.039 53	0.349 72	0.610 75
487	0.028 896	0.315 035	0.502 340	0.034 15	0.372 26	0.593 59
488	0.023 876	0.323 335	0.471 400	0.029 17	0.394 98	0.575 85
489	0.019 628	0.331 366	0.442 390	0.024 74	0.417 66	0.557 60
490	0.016 172	0.339 133	0.415 254	0.020 99	0.440 11	0.538 90
491	0.013 300	0.347 860	0.390 024	0.017 71	0.463 08	0.519 21
492	0.010 759	0.358 326	0.366 399	0.014 63	0.487 20	0.498 17
493	0.008 542	0.370 001	0.344 015	0.011 82	0.512 07	0.476 11
494	0.006 661	0.382 464	0.322 689	0.009 36	0.537 31	0.453 33
495	0.005 132	0.395 379	0.302 356	0.007 30	0.562 52	0.430 18
496	0.003 982	0.408 482	0.283 036	0.005 73	0.587 32	0.406 95
497	0.003 239	0.421 588	0.264 816	0.004 70	0.611 31	0.383 99
498	0.002 934	0.434 619	0.247 848	0.004 28	0.634 11	0.361 61
499	0.003 114	0.447 601	0.232 318	0.004 56	0.655 31	0.340 13
500	0.003 816	0.460 777	0.218 502	0.005 59	0.674 54	0.319 87
501	0.005 095	0.474 340	0.205 851	0.007 43	0.692 18	0.300 39
502	0.006 936	0.488 200	0.193 596	0.010 07	0.708 84	0.281 09
503	0.009 299	0.502 340	0.181 736	0.013 41	0.724 49	0.262 10
504	0.012 147	0.516 740	0.170 281	0.017 37	0.739 08	0.243 55
505	0.015 444	0.531 360	0.159 249	0.021 87	0.752 58	0.225 55
506	0.019 156	0.546 190	0.148 673	0.026 83	0.764 95	0.208 22
507	0.023 250	0.561 180	0.138 609	0.032 16	0.776 14	0.191 70
508	0.027 690	0.576 290	0.129 096	0.037 77	0.786 13	0.176 10
509	0.032 444	0.591 500	0.120 215	0.043 60	0.794 86	0.161 54
510	0.037 465	0.606 741	0.112 044	0.049 54	0.802 30	0.148 16

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
511	0.042 956	0.622 150	0.104 710	0.055 80	0.808 18	0.136 02
512	0.049 114	0.637 830	0.098 196	0.062 55	0.812 38	0.125 07
513	0.055 920	0.653 710	0.092 361	0.069 73	0.815 11	0.115 16
514	0.063 349	0.669 680	0.087 088	0.077 24	0.816 57	0.106 19
515	0.071 358	0.685 660	0.082 248	0.085 02	0.816 98	0.098 00
516	0.079 901	0.701 550	0.077 744	0.093 00	0.816 52	0.090 48
517	0.088 909	0.717 230	0.073 456	0.101 08	0.815 41	0.083 51
518	0.098 293	0.732 570	0.069 268	0.109 20	0.813 85	0.076 95
519	0.107 949	0.747 460	0.065 060	0.117 28	0.812 04	0.070 68
520	0.117 749	0.761 757	0.060 709	0.125 24	0.810 19	0.064 57
521	0.127 839	0.775 340	0.056 457	0.133 22	0.807 95	0.058 83
522	0.138 450	0.788 220	0.052 609	0.141 38	0.804 90	0.053 72
523	0.149 516	0.800 460	0.049 122	0.149 65	0.801 18	0.049 17
524	0.161 041	0.812 140	0.045 954	0.158 02	0.796 89	0.045 09
525	0.172 953	0.823 330	0.043 050	0.166 41	0.792 17	0.041 42
526	0.185 209	0.834 120	0.040 368	0.174 78	0.787 13	0.038 09
527	0.197 755	0.844 600	0.037 839	0.183 07	0.781 90	0.035 03
528	0.210 538	0.854 870	0.035 384	0.191 26	0.776 60	0.032 14
529	0.223 460	0.865 040	0.032 949	0.199 26	0.771 36	0.029 38
530	0.236 491	0.875 211	0.030 451	0.207 06	0.766 28	0.026 66
531	0.249 633	0.885 370	0.028 029	0.214 64	0.761 26	0.024 10
532	0.262 972	0.895 370	0.025 862	0.222 07	0.756 09	0.021 84
533	0.276 515	0.905 150	0.023 920	0.229 36	0.750 80	0.019 84
534	0.290 269	0.914 650	0.022 174	0.236 55	0.745 38	0.018 07
535	0.304 213	0.923 810	0.020 584	0.243 64	0.739 87	0.016 49
536	0.318 361	0.932 550	0.019 127	0.250 67	0.734 27	0.015 06
537	0.332 705	0.940 810	0.017 740	0.257 66	0.728 60	0.013 74
538	0.347 232	0.948 520	0.016 403	0.264 63	0.722 87	0.012 50
539	0.361 926	0.955 600	0.015 064	0.271 60	0.717 10	0.011 30
540	0.376 772	0.961 988	0.013 676	0.278 59	0.711 30	0.010 11
541	0.391 683	0.967 540	0.012 308	0.285 58	0.705 45	0.008 97
542	0.406 594	0.972 230	0.011 056	0.292 54	0.699 51	0.007 95
543	0.421 539	0.976 170	0.009 915	0.299 47	0.693 49	0.007 04
544	0.436 517	0.979 460	0.008 872	0.306 36	0.687 41	0.006 23
545	0.451 584	0.982 200	0.007 918	0.313 23	0.681 28	0.005 49
546	0.466 782	0.984 520	0.007 030	0.320 08	0.675 10	0.004 82
547	0.482 147	0.986 520	0.006 223	0.326 90	0.668 88	0.004 22
548	0.497 738	0.988 320	0.005 453	0.333 71	0.662 63	0.003 66
549	0.513 606	0.990 020	0.004 714	0.340 51	0.656 36	0.003 13
550	0.529 826	0.991 761	0.003 988	0.347 30	0.650 09	0.002 61
551	0.546 440	0.993 530	0.003 289	0.354 08	0.643 79	0.002 13
552	0.563 426	0.995 230	0.002 646	0.360 87	0.637 44	0.001 69
553	0.580 726	0.996 770	0.002 063	0.367 65	0.631 04	0.001 31
554	0.598 290	0.998 090	0.001 533	0.374 42	0.624 62	0.000 96
555	0.616 053	0.999 110	0.001 091	0.381 16	0.618 16	0.000 68
556	0.633 948	0.999 770	0.000 711	0.387 87	0.611 69	0.000 44
557	0.651 901	1.000 000	0.000 407	0.394 54	0.605 21	0.000 25
558	0.669 824	0.999 710	0.000 184	0.401 16	0.598 73	0.000 11
559	0.687 632	0.998 850	0.000 047	0.407 72	0.592 25	0.000 03
560	0.705 224	0.997 340	0.000 000	0.414 21	0.585 79	0.000 00

162

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
561	0.722 773	0.995 260	0.000 000	0.420 70	0.579 30	0.000 00
562	0.740 483	0.992 740		0.427 23	0.572 77	
563	0.758 273	0.989 750		0.433 79	0.566 21	
564	0.776 083	0.986 300		0.440 36	0.559 64	
565	0.793 832	0.982 380		0.446 92	0.553 08	
566	0.811 436	0.977 980		0.453 46	0.546 54	
567	0.828 822	0.973 110		0.459 96	0.540 04	
568	0.845 879	0.967 740		0.466 40	0.533 60	
569	0.862 525	0.961 890		0.472 77	0.527 23	
570	0.878 655	0.955 552		0.479 04	0.520 96	
571	0.894 208	0.948 601		0.485 24	0.514 76	
572	0.909 206	0.940 981		0.491 41	0.508 59	
573	0.923 672	0.932 798		0.497 54	0.502 46	
574	0.937 638	0.924 158		0.503 62	0.496 38	
575	0.951 162	0.915 175		0.509 64	0.490 36	
576	0.964 283	0.905 954		0.515 59	0.484 41	
577	0.977 068	0.896 608		0.521 47	0.478 53	
578	0.989 590	0.887 249		0.527 26	0.472 74	
579	1.001 91	0.877 986		0.532 96	0.467 04	
580	1.014 16	0.868 934		0.538 56	0.461 44	
581	1.026 50	0.860 164		0.544 08	0.455 92	
582	1.038 80	0.851 519		0.549 54	0.450 46	
583	1.051 00	0.842 963		0.554 92	0.445 08	
584	1.062 90	0.834 393		0.560 22	0.439 78	
585	1.074 30	0.825 623		0.565 44	0.434 56	
586	1.085 20	0.816 764		0.570 57	0.429 43	
587	1.095 20	0.807 544		0.575 59	0.424 41	
588	1.104 20	0.797 947		0.580 50	0.419 50	
589	1.112 00	0.787 893		0.585 30	0.414 70	
590	1.118 52	0.777 405		0.589 96	0.410 04	
591	1.123 80	0.766 490		0.594 51	0.405 49	
592	1.128 00	0.755 309		0.598 95	0.401 05	
593	1.131 10	0.743 845		0.603 27	0.396 73	
594	1.133 20	0.732 190		0.607 49	0.392 51	
595	1.134 30	0.720 353		0.611 60	0.388 40	
596	1.134 30	0.708 281		0.615 60	0.384 40	
597	1.133 30	0.696 055		0.619 51	0.380 49	
598	1.131 20	0.683 621		0.623 31	0.376 69	
599	1.128 10	0.671 048		0.627 02	0.372 98	
600	1.123 99	0.658 341		0.630 63	0.369 37	
601	1.118 90	0.645 545		0.634 14	0.365 86	
602	1.112 90	0.632 718		0.637 54	0.362 46	
603	1.105 90	0.619 815		0.640 84	0.359 16	
604	1.098 00	0.606 887		0.644 03	0.355 97	
605	1.089 10	0.593 878		0.647 13	0.352 87	
606	1.079 20	0.580 781		0.650 13	0.349 87	
607	1.068 40	0.567 653		0.653 04	0.346 96	
608	1.056 70	0.554 490		0.655 85	0.344 15	
609	1.044 00	0.541 228		0.658 58	0.341 42	
610	1.030 48	0.527 963		0.661 22	0.338 78	

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
611	1.016 00	0.514 634	0.000 000	0.663 78	0.336 22	0.000 00
612	1.000 80	0.501 363		0.666 24	0.333 76	
613	0.984 790	0.488 124		0.668 60	0.331 40	
614	0.968 080	0.474 935		0.670 87	0.329 13	
615	0.950 740	0.461 834		0.673 06	0.326 94	
616	0.932 800	0.448 823		0.675 15	0.324 85	
617	0.914 340	0.435 917		0.677 16	0.322 84	
618	0.895 390	0.423 153		0.679 08	0.320 92	
619	0.876 030	0.410 526		0.680 91	0.319 09	
620	0.856 297	0.398 057		0.682 66	0.317 34	
621	0.836 350	0.385 835		0.684 31	0.315 69	
622	0.816 290	0.373 951		0.685 82	0.314 18	
623	0.796 050	0.362 311		0.687 22	0.312 78	
624	0.775 610	0.350 863		0.688 53	0.311 47	
625	0.754 930	0.339 554		0.689 76	0.310 24	
626	0.733 990	0.328 309		0.690 94	0.309 06	
627	0.712 780	0.317 118		0.692 09	0.307 91	
628	0.691 290	0.305 936		0.693 21	0.306 79	
629	0.669 520	0.294 737		0.694 34	0.305 66	
630	0.647 467	0.283 493		0.695 48	0.304 52	
631	0.625 110	0.272 222		0.696 63	0.303 37	
632	0.602 520	0.260 990		0.697 76	0.302 24	
633	0.579 890	0.249 877		0.698 86	0.301 14	
634	0.557 370	0.238 946		0.699 94	0.300 06	
635	0.535 110	0.228 254		0.700 99	0.299 01	
636	0.513 240	0.217 853		0.702 02	0.297 98	
637	0.491 860	0.207 780		0.703 02	0.296 98	
638	0.471 080	0.198 072		0.704 00	0.296 00	
639	0.450 960	0.188 748		0.704 95	0.295 05	
640	0.431 567	0.179 828		0.705 87	0.294 13	
641	0.412 870	0.171 285		0.706 78	0.293 22	
642	0.394 750	0.163 059		0.707 68	0.292 32	
643	0.377 210	0.155 151		0.708 56	0.291 44	
644	0.360 190	0.147 535		0.709 42	0.290 58	
645	0.343 690	0.140 211		0.710 25	0.289 75	
646	0.327 690	0.133 170		0.711 04	0.288 96	
647	0.312 170	0.126 400		0.711 79	0.288 21	
648	0.297 110	0.119 892		0.712 49	0.287 51	
649	0.282 500	0.113 640		0.713 13	0.286 87	
650	0.268 329	0.107 633		0.713 71	0.286 29	
651	0.254 590	0.101 870		0.714 22	0.285 78	
652	0.241 300	0.096 347		0.714 65	0.285 35	
653	0.228 480	0.091 063		0.715 02	0.284 98	
654	0.216 140	0.086 010		0.715 34	0.284 66	
655	0.204 300	0.081 187		0.715 62	0.284 38	
656	0.192 950	0.076 583		0.715 87	0.284 13	
657	0.182 110	0.072 198		0.716 10	0.283 90	
658	0.171 770	0.068 024		0.716 32	0.283 68	
659	0.161 920	0.064 052		0.716 55	0.283 45	
660	0.152 568	0.060 281		0.716 79	0.283 21	

164

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
661	0.143 670	0.056 697	0.000 000	0.717 03	0.282 97	0.000 00
662	0.135 200	0.053 292		0.717 27	0.282 73	
663	0.127 130	0.050 059		0.717 48	0.282 52	
664	0.119 480	0.046 998		0.717 69	0.282 31	
665	0.112 210	0.044 096		0.717 89	0.282 11	
666	0.105 310	0.041 345		0.718 08	0.281 92	
667	0.098 786 0	0.038 750 7		0.718 25	0.281 75	
668	0.092 610 0	0.036 297 8		0.718 42	0.281 58	
669	0.086 773 0	0.033 983 2		0.718 58	0.281 42	
670	0.081 260 6	0.031 800 4		0.718 73	0.281 27	
671	0.076 048 0	0.029 739 5		0.718 88	0.281 12	
672	0.071 114 0	0.027 791 8		0.719 01	0.280 99	
673	0.066 454 0	0.025 955 1		0.719 13	0.280 87	
674	0.062 062 0	0.024 226 3		0.719 24	0.280 76	
675	0.057 930 0	0.022 601 7		0.719 34	0.280 66	
676	0.054 050 0	0.021 077 9		0.719 44	0.280 56	
677	0.050 412 0	0.019 650 5		0.719 53	0.280 47	
678	0.047 006 0	0.018 315 3		0.719 61	0.280 39	
679	0.043 823 0	0.017 068 6		0.719 69	0.280 31	
680	0.040 850 8	0.015 905 1		0.719 76	0.280 24	
681	0.038 072 0	0.014 818 3		0.719 83	0.280 17	
682	0.035 468 0	0.013 800 8		0.719 89	0.280 11	
683	0.033 031 0	0.012 849 5		0.719 94	0.280 06	
684	0.030 753 0	0.011 960 7		0.719 98	0.280 02	
685	0.028 623 0	0.011 130 3		0.720 02	0.279 98	
686	0.026 635 0	0.010 355 5		0.720 05	0.279 95	
687	0.024 781 0	0.009 633 2		0.720 08	0.279 92	
688	0.023 052 0	0.008 959 9		0.720 11	0.279 89	
689	0.021 441 0	0.008 332 4		0.720 14	0.279 86	
690	0.019 941 3	0.007 748 8		0.720 16	0.279 84	
691	0.018 544 0	0.007 204 6		0.720 19	0.279 81	
692	0.017 241 0	0.006 697 5		0.720 22	0.279 78	
693	0.016 027 0	0.006 225 1		0.720 25	0.279 75	
694	0.014 896 0	0.005 785 0		0.720 27	0.279 73	
695	0.013 842 0	0.005 375 1		0.720 30	0.279 70	
696	0.012 862 0	0.004 994 1		0.720 31	0.279 69	
697	0.011 949 0	0.004 639 2		0.720 33	0.279 67	
698	0.011 100 0	0.004 309 3		0.720 34	0.279 66	
699	0.010 311 0	0.004 002 8		0.720 35	0.279 65	
700	0.009 576 88	0.003 717 74		0.720 36	0.279 64	
701	0.008 894 00	0.003 452 62		0.720 36	0.279 64	
702	0.008 258 10	0.003 205 83		0.720 36	0.279 64	
703	0.007 666 40	0.002 976 23		0.720 35	0.279 65	
704	0.007 116 30	0.002 762 81		0.720 34	0.279 66	
705	0.006 605 20	0.002 564 56		0.720 32	0.279 68	
706	0.006 130 60	0.002 380 48		0.720 31	0.279 69	
707	0.005 690 30	0.002 209 71		0.720 29	0.279 71	
708	0.005 281 90	0.002 051 32		0.720 27	0.279 73	
709	0.004 903 30	0.001 904 49		0.720 25	0.279 75	
710	0.004 552 63	0.001 768 47		0.720 23	0.279 77	

165

TABLE 2.2 (continued)

λ (nm)	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
711	0.004 227 50	0.001 642 36	0.000 000	0.720 20	0.279 80	0.000 00
712	0.003 925 80	0.001 525 35		0.720 18	0.279 82	
713	0.003 645 70	0.001 416 72		0.720 15	0.279 85	
714	0.003 385 90	0.001 315 95		0.720 12	0.279 88	
715	0.003 144 70	0.001 222 39		0.720 09	0.279 91	
716	0.002 920 80	0.001 135 55		0.720 06	0.279 94	
717	0.002 713 00	0.001 054 94		0.720 02	0.279 98	
718	0.002 520 20	0.000 980 14		0.719 99	0.280 01	
719	0.002 341 10	0.000 910 66		0.719 95	0.280 05	
720	0.002 174 96	0.000 846 19		0.719 91	0.280 09	
721	0.002 020 60	0.000 786 29		0.719 87	0.280 13	
722	0.001 877 30	0.000 730 68		0.719 83	0.280 17	
723	0.001 744 10	0.000 678 99		0.719 78	0.280 22	
724	0.001 620 50	0.000 631 01		0.719 74	0.280 26	
725	0.001 505 70	0.000 586 44		0.719 69	0.280 31	
726	0.001 399 20	0.000 545 11		0.719 64	0.280 36	
727	0.001 300 40	0.000 506 72		0.719 60	0.280 40	
728	0.001 208 70	0.000 471 11		0.719 55	0.280 45	
729	0.001 123 60	0.000 438 05		0.719 50	0.280 50	
730	0.001 044 76	0.000 407 41		0.719 45	0.280 55	
731	0.000 971 560	0.000 378 962		0.719 40	0.280 60	
732	0.000 903 600	0.000 352 543		0.719 34	0.280 66	
733	0.000 840 480	0.000 328 001		0.719 29	0.280 71	
734	0.000 781 870	0.000 305 208		0.719 24	0.280 76	
735	0.000 727 450	0.000 284 041		0.719 19	0.280 81	
736	0.000 676 900	0.000 264 375		0.719 13	0.280 87	
737	0.000 629 960	0.000 246 109		0.719 08	0.280 92	
738	0.000 586 370	0.000 229 143		0.719 02	0.280 98	
739	0.000 545 870	0.000 213 376		0.718 96	0.281 04	
740	0.000 508 258	0.000 198 730		0.718 91	0.281 09	
741	0.000 473 300	0.000 185 115		0.718 85	0.281 15	
742	0.000 440 800	0.000 172 454		0.718 79	0.281 21	
743	0.000 410 580	0.000 160 678		0.718 73	0.281 27	
744	0.000 382 490	0.000 149 730		0.718 67	0.281 33	
745	0.000 356 380	0.000 139 550		0.718 61	0.281 39	
746	0.000 332 110	0.000 130 086		0.718 55	0.281 45	
747	0.000 309 550	0.000 121 290		0.718 48	0.281 52	
748	0.000 288 580	0.000 113 106		0.718 42	0.281 58	
749	0.000 269 090	0.000 105 501		0.718 36	0.281 64	
750	0.000 250 969	0.000 098 428		0.718 29	0.281 71	
751	0.000 234 130	0.000 091 853		0.718 23	0.281 77	
752	0.000 218 470	0.000 085 738		0.718 16	0.281 84	
753	0.000 203 910	0.000 080 048		0.718 10	0.281 90	
754	0.000 190 350	0.000 074 751		0.718 03	0.281 97	
755	0.000 177 730	0.000 069 819		0.717 96	0.282 04	
756	0.000 165 970	0.000 065 222		0.717 89	0.282 11	
757	0.000 155 020	0.000 060 939		0.717 82	0.282 18	
758	0.000 144 800	0.000 056 942		0.717 75	0.282 25	
759	0.000 135 280	0.000 053 217		0.717 68	0.282 32	
760	0.000 126 390	0.000 049 737		0.717 61	0.282 39	

166

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
761	0.000 118 100	0.000 046 491	0.000 000	0.717 54	0.282 46	0.000 00
762	0.000 110 370	0.000 043 464		0.717 46	0.282 54	
763	0.000 103 150	0.000 040 635		0.717 39	0.282 61	
764	0.000 096 427 0	0.000 038 000 0		0.717 32	0.282 68	
765	0.000 090 151 0	0.000 035 540 5		0.717 24	0.282 76	
766	0.000 084 294 0	0.000 033 244 8		0.717 16	0.282 84	
767	0.000 078 830 0	0.000 031 100 6		0.717 09	0.282 91	
768	0.000 073 729 0	0.000 029 099 0		0.717 01	0.282 99	
769	0.000 068 969 0	0.000 027 230 7		0.716 94	0.283 06	
770	0.000 064 525 8	0.000 025 486 0		0.716 86	0.283 14	
771	0.000 060 376 0	0.000 023 856 1		0.716 78	0.283 22	
772	0.000 056 500 0	0.000 022 333 2		0.716 70	0.283 30	
773	0.000 052 880 0	0.000 020 910 4		0.716 62	0.283 38	
774	0.000 049 498 0	0.000 019 580 8		0.716 54	0.283 46	
775	0.000 046 339 0	0.000 018 338 4		0.716 46	0.283 54	
776	0.000 043 389 0	0.000 017 177 7		0.716 38	0.283 62	
777	0.000 040 634 0	0.000 016 093 4		0.716 30	0.283 70	
778	0.000 038 060 0	0.000 015 080 0		0.716 22	0.283 78	
779	0.000 035 657 0	0.000 014 133 6		0.716 14	0.283 86	
780	0.000 033 411 7	0.000 013 249 0		0.716 06	0.283 94	
781	0.000 031 315 0	0.000 012 422 6		0.715 97	0.284 03	
782	0.000 029 355 0	0.000 011 649 9		0.715 89	0.284 11	
783	0.000 027 524 0	0.000 010 927 7		0.715 81	0.284 19	
784	0.000 025 811 0	0.000 010 251 9		0.715 72	0.284 28	
785	0.000 024 209 0	0.000 009 619 6		0.715 64	0.284 36	
786	0.000 022 711 0	0.000 009 028 1		0.715 55	0.284 45	
787	0.000 021 308 0	0.000 008 474 0		0.715 47	0.284 53	
788	0.000 019 994 0	0.000 007 954 8		0.715 38	0.284 62	
789	0.000 018 764 0	0.000 007 468 6		0.715 29	0.284 71	
790	0.000 017 611 5	0.000 007 012 8		0.715 21	0.284 79	
791	0.000 016 532 0	0.000 006 585 8		0.715 12	0.284 88	
792	0.000 015 521 0	0.000 006 185 7		0.715 03	0.284 97	
793	0.000 014 574 0	0.000 005 810 7		0.714 95	0.285 05	
794	0.000 013 686 0	0.000 005 459 0		0.714 86	0.285 14	
795	0.000 012 855 0	0.000 005 129 8		0.714 77	0.285 23	
796	0.000 012 075 0	0.000 004 820 6		0.714 68	0.285 32	
797	0.000 011 345 0	0.000 004 531 2		0.714 59	0.285 41	
798	0.000 010 659 0	0.000 004 259 1		0.714 50	0.285 50	
799	0.000 010 017 0	0.000 004 004 2		0.714 42	0.285 58	
800	0.000 009 413 63	0.000 003 764 73		0.714 32	0.285 68	
801	0.000 008 847 90	0.000 003 539 95		0.714 24	0.285 76	
802	0.000 008 317 10	0.000 003 329 14		0.714 14	0.285 86	
803	0.000 007 819 00	0.000 003 131 15		0.714 05	0.285 95	
804	0.000 007 351 60	0.000 002 945 29		0.713 96	0.286 04	
805	0.000 006 913 00	0.000 002 770 81		0.713 87	0.286 13	
806	0.000 006 501 50	0.000 002 607 05		0.713 78	0.286 22	
807	0.000 006 115 30	0.000 002 453 29		0.713 69	0.286 31	
808	0.000 005 752 90	0.000 002 308 94		0.713 60	0.286 40	
809	0.000 005 412 70	0.000 002 173 38		0.713 50	0.286 50	
810	0.000 005 093 47	0.000 002 046 13		0.713 41	0.286 59	

167

TABLE 2.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	CHROMATICITY COORDINATES $x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
811	0.000 004 793 80	0.000 001 926 62	0.000 000	0.713 32	0.286 68	0.000 00
812	0.000 004 512 50	0.000 001 814 40		0.713 22	0.286 78	
813	0.000 004 248 30	0.000 001 708 95		0.713 13	0.286 87	
814	0.000 004 000 20	0.000 001 609 88		0.713 04	0.286 96	
815	0.000 003 767 10	0.000 001 516 77		0.712 94	0.287 06	
816	0.000 003 548 00	0.000 001 429 21		0.712 85	0.287 15	
817	0.000 003 342 10	0.000 001 346 86		0.712 76	0.287 24	
818	0.000 003 148 50	0.000 001 269 45		0.712 66	0.287 34	
819	0.000 002 966 50	0.000 001 196 62		0.712 57	0.287 43	
820	0.000 002 795 31	0.000 001 128 09		0.712 47	0.287 53	
821	0.000 002 634 50	0.000 001 063 68		0.712 38	0.287 62	
822	0.000 002 483 40	0.000 001 003 13		0.712 28	0.287 72	
823	0.000 002 341 40	0.000 000 946 22		0.712 19	0.287 81	
824	0.000 002 207 80	0.000 000 892 63		0.712 09	0.287 91	
825	0.000 002 082 00	0.000 000 842 16		0.712 00	0.288 00	
826	0.000 001 963 60	0.000 000 794 64		0.711 90	0.288 10	
827	0.000 001 851 90	0.000 000 749 78		0.711 81	0.288 19	
828	0.000 001 746 50	0.000 000 707 44		0.711 71	0.288 29	
829	0.000 001 647 10	0.000 000 667 48		0.711 62	0.288 38	
830	0.000 001 553 14	0.000 000 629 70		0.711 52	0.288 48	

$\Sigma\bar{x}_{10}(\lambda) = 116.648\ 519\ 508\ 908$

$\Sigma\bar{y}_{10}(\lambda) = 116.661\ 877\ 102\ 312$

$\Sigma\bar{z}_{10}(\lambda) = 116.673\ 980\ 514\ 647$

168

TABLE 2.3.1

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	$x(\lambda)$	$y(\lambda)$	$z(\lambda)$
380	0.0014	0.0000	0.0065	0.1741	0.0050	0.8209
385	0.0022	0.0001	0.0105	0.1740	0.0050	0.8210
390	0.0042	0.0001	0.0201	0.1738	0.0049	0.8213
395	0.0076	0.0002	0.0362	0.1736	0.0049	0.8215
400	0.0143	0.0004	0.0679	0.1733	0.0048	0.8219
405	0.0232	0.0006	0.1102	0.1730	0.0048	0.8222
410	0.0435	0.0012	0.2074	0.1726	0.0048	0.8226
415	0.0776	0.0022	0.3713	0.1721	0.0048	0.8231
420	0.1344	0.0040	0.6456	0.1714	0.0051	0.8235
425	0.2148	0.0073	1.0391	0.1703	0.0058	0.8239
430	0.2839	0.0116	1.3856	0.1689	0.0069	0.8242
435	0.3285	0.0168	1.6230	0.1669	0.0086	0.8245
440	0.3483	0.0230	1.7471	0.1644	0.0109	0.8247
445	0.3481	0.0298	1.7826	0.1611	0.0138	0.8251
450	0.3362	0.0380	1.7721	0.1566	0.0177	0.8257
455	0.3187	0.0480	1.7441	0.1510	0.0227	0.8263
460	0.2908	0.0600	1.6692	0.1440	0.0297	0.8263
465	0.2511	0.0739	1.5281	0.1355	0.0399	0.8246
470	0.1954	0.0910	1.2876	0.1241	0.0578	0.8181
475	0.1421	0.1126	1.0419	0.1096	0.0868	0.8036
480	0.0956	0.1390	0.8130	0.0913	0.1327	0.7760
485	0.0580	0.1693	0.6162	0.0687	0.2007	0.7306
490	0.0320	0.2080	0.4652	0.0454	0.2950	0.6596
495	0.0147	0.2586	0.3533	0.0235	0.4127	0.5638
500	0.0049	0.3230	0.2720	0.0082	0.5384	0.4534
505	0.0024	0.4073	0.2123	0.0039	0.6548	0.3413
510	0.0093	0.5030	0.1582	0.0139	0.7502	0.2359
515	0.0291	0.6082	0.1117	0.0389	0.8120	0.1491
520	0.0633	0.7100	0.0782	0.0743	0.8338	0.0919
525	0.1096	0.7932	0.0573	0.1142	0.8262	0.0596
530	0.1655	0.8620	0.0422	0.1547	0.8059	0.0394
535	0.2257	0.9149	0.0298	0.1929	0.7816	0.0255
540	0.2904	0.9540	0.0203	0.2296	0.7543	0.0161
545	0.3597	0.9803	0.0134	0.2658	0.7243	0.0099
550	0.4334	0.9950	0.0087	0.3016	0.6923	0.0061
555	0.5121	1.0000	0.0057	0.3373	0.6589	0.0038
560	0.5945	0.9950	0.0039	0.3731	0.6245	0.0024
565	0.6784	0.9786	0.0027	0.4087	0.5896	0.0017
570	0.7621	0.9520	0.0021	0.4441	0.5547	0.0012
575	0.8425	0.9154	0.0018	0.4788	0.5202	0.0010
580	0.9163	0.8700	0.0017	0.5125	0.4866	0.0009
585	0.9786	0.8163	0.0014	0.5448	0.4544	0.0008
590	1.0263	0.7570	0.0011	0.5752	0.4242	0.0006
595	1.0567	0.6949	0,0010	0.6029	0.3965	0.0006
600	1.0622	0.6310	0.0008	0.6270	0.3725	0.0005
605	1.0456	0.5668	0.0006	0.6482	0.3514	0.0004
610	1.0026	0.5030	0.0003	0.6658	0.3340	0.0002
615	0.9384	0.4412	0.0002	0.6801	0.3197	0.0002
620	0.8544	0.3810	0.0002	0.6915	0.3083	0.0002

TABLE 2.3.1 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	$x(\lambda)$	$y(\lambda)$	$z(\lambda)$
625	0.7514	0.3210	0.0001	0.7006	0.2993	0.0001
630	0.6424	0.2650	0.0000	0.7079	0.2920	0.0001
635	0.5419	0.2170	0.0000	0.7140	0.2859	0.0001
640	0.4479	0.1750	0.0000	0.7190	0.2809	0.0001
645	0.3608	0.1382	0.0000	0.7230	0.2770	0.0000
650	0.2835	0.1070	0.0000	0.7260	0.2740	0.0000
655	0.2187	0.0816	0.0000	0.7283	0.2717	0.0000
660	0.1649	0.0610	0.0000	0.7300	0.2700	0.0000
665	0.1212	0.0446	0.0000	0.7311	0.2689	0.0000
670	0.0874	0.0320	0.0000	0.7320	0.2680	0.0000
675	0.0636	0.0232	0.0000	0.7327	0.2673	0.0000
680	0.0468	0.0170	0.0000	0.7334	0.2666	0.0000
685	0.0329	0.0119	0.0000	0.7340	0.2660	0.0000
690	0.0227	0.0082	0.0000	0.7344	0.2656	0.0000
695	0.0158	0.0057	0.0000	0.7346	0.2654	0.0000
700	0.0114	0.0041	0.0000	0.7347	0.2653	0.0000
705	0.0081	0.0029	0.0000	0.7347	0.2653	0.0000
710	0.0058	0.0021	0.0000	0.7347	0.2653	0.0000
715	0.0041	0.0015	0.0000	0.7347	0.2653	0.0000
720	0.0029	0.0010	0.0000	0.7347	0.2653	0.0000
725	0.0020	0.0007	0.0000	0.7347	0.2653	0.0000
730	0.0014	0.0005	0.0000	0.7347	0.2653	0.0000
735	0.0010	0.0004	0.0000	0.7347	0.2653	0.0000
740	0.0007	0.0002	0.0000	0.7347	0.2653	0.0000
745	0.0005	0.0002	0.0000	0.7347	0.2653	0.0000
750	0.0003	0.0001	0.0000	0.7347	0.2653	0.0000
755	0.0002	0.0001	0.0000	0.7347	0.2653	0.0000
760	0.0002	0.0001	0.0000	0.7347	0.2653	0.0000
765	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
770	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
775	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
780	0.0000	0.0000	0.0000	0.7347	0.2653	0.0000

Summation at 5 nm intervals:

$\Sigma\bar{x}(\lambda) = 21.3714$
$\Sigma\bar{y}(\lambda) = 21.3711$
$\Sigma\bar{z}(\lambda) = 21.3715$

Summation at 10 nm intervals:

$\Sigma\bar{x}(\lambda) = 10.6836$
$\Sigma\bar{y}(\lambda) = 10.6856$
$\Sigma\bar{z}(\lambda) = 10.6770$

170

TABLE 2.3.2

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
380	0.0002	0.0000	0.0007	0.1813	0.0197	0.7990
385	0.0007	0.0001	0.0029	0.1809	0.0195	0.7996
390	0.0024	0.0003	0.0105	0.1803	0.0194	0.8003
395	0.0072	0.0008	0.0323	0.1795	0.0190	0.8015
400	0.0191	0.0020	0.0860	0.1784	0.0187	0.8029
405	0.0434	0.0045	0.1971	0.1771	0.0184	0.8045
410	0.0847	0.0088	0.3894	0.1755	0.0181	0.8064
415	0.1406	0.0145	0.6568	0.1732	0.0178	0.8090
420	0.2045	0.0214	0.9725	0.1706	0.0179	0.8115
425	0.2647	0.0295	1.2825	0.1679	0.0187	0.8134
430	0.3147	0.0387	1.5535	0.1650	0.0203	0.8147
435	0.3577	0.0496	1.7985	0.1622	0.0225	0.8153
440	0.3837	0.0621	1.9673	0.1590	0.0257	0.8153
445	0.3867	0.0747	2.0273	0.1554	0.0300	0.8146
450	0.3707	0.0895	1.9948	0.1510	0.0364	0.8126
455	0.3430	0.1063	1.9007	0.1459	0.0452	0.8088
460	0.3023	0.1282	1.7454	0.1389	0.0589	0.8022
465	0.2541	0.1528	1.5549	0.1295	0.0779	0.7926
470	0.1956	0.1852	1.3176	0.1152	0.1090	0.7758
475	0.1323	0.2199	1.0302	0.0957	0.1591	0.7452
480	0.0805	0.2536	0.7721	0.0728	0.2292	0.6980
485	0.0411	0.2977	0.5701	0.0452	0.3275	0.6273
490	0.0162	0.3391	0.4153	0.0210	0.4401	0.5389
495	0.0051	0.3954	0.3024	0.0073	0.5625	0.4302
500	0.0038	0.4608	0.2185	0.0056	0.6745	0.3199
505	0.0154	0.5314	0.1592	0.0219	0.7526	0.2256
510	0.0375	0.6067	0.1120	0.0495	0.8023	0.1482
515	0.0714	0.6857	0.0822	0.0850	0.8170	0.0980
520	0.1177	0.7618	0.0607	0.1252	0.8102	0.0646
525	0.1730	0.8233	0.0431	0.1664	0.7922	0.0414
530	0.2365	0.8752	0.0305	0.2071	0.7663	0.0267
535	0.3042	0.9238	0.0206	0.2436	0.7399	0.0165
540	0.3768	0.9620	0.0137	0.2786	0.7113	0.0101
545	0.4516	0.9822	0.0079	0.3132	0.6813	0.0055
550	0.5298	0.9918	0.0040	0.3473	0.6501	0.0026
555	0.6161	0.9991	0.0011	0.3812	0.6182	0.0007
560	0.7052	0.9973	0.0000	0.4142	0.5858	0.0000
565	0.7938	0.9824	0.0000	0.4469	0.5531	0.0000
570	0.8787	0.9556	0.0000	0.4790	0.5210	0.0000
575	0.9512	0.9152	0.0000	0.5096	0.4904	0.0000
580	1.0142	0.8689	0.0000	0.5386	0.4614	0.0000
585	1.0743	0.8256	0.0000	0.5654	0.4346	0.0000
590	1.1185	0.7774	0.0000	0.5900	0.4100	0.0000
595	1.1343	0.7204	0.0000	0.6116	0.3884	0.0000
600	1.1240	0.6583	0.0000	0.6306	0.3694	0.0000
605	1.0891	0.5939	0.0000	0.6471	0.3529	0.0000
610	1.0305	0.5280	0.0000	0.6612	0.3388	0.0000
615	0.9507	0.4618	0.0000	0.6731	0.3269	0.0000
620	0.8563	0.3981	0.0000	0.6827	0.3173	0.0000

171

TABLE 2.3.2 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
625	0.7549	0.3396	0.0000	0.6898	0.3102	0.0000
630	0.6475	0.2835	0.0000	0.6955	0.3045	0.0000
635	0.5351	0.2283	0.0000	0.7010	0.2990	0.0000
640	0.4316	0.1798	0.0000	0.7059	0.2941	0.0000
645	0.3437	0.1402	0.0000	0.7103	0.2898	0.0000
650	0.2683	0.1076	0.0000	0.7137	0.2863	0.0000
655	0.2043	0.0812	0.0000	0.7156	0.2844	0.0000
660	0.1526	0.0603	0.0000	0.7168	0.2832	0.0000
665	0.1122	0.0441	0.0000	0.7179	0.2821	0.0000
670	0.0813	0.0318	0.0000	0.7187	0.2813	0.0000
675	0.0579	0.0226	0.0000	0.7193	0.2807	0.0000
680	0.0409	0.0159	0.0000	0.7198	0.2802	0.0000
685	0.0286	0.0111	0.0000	0.7200	0.2800	0.0000
690	0.0199	0.0077	0.0000	0.7202	0.2798	0.0000
695	0.0138	0.0054	0.0000	0.7203	0.2797	0.0000
700	0.0096	0.0037	0.0000	0.7204	0.2796	0.0000
705	0.0066	0.0026	0.0000	0.7203	0.2797	0.0000
710	0.0046	0.0018	0.0000	0.7202	0.2798	0.0000
715	0.0031	0.0012	0.0000	0.7201	0.2799	0.0000
720	0.0022	0.0008	0.0000	0.7199	0.2801	0.0000
725	0.0015	0.0006	0.0000	0.7197	0.2803	0.0000
730	0.0010	0.0004	0.0000	0.7195	0.2806	0.0000
735	0.0007	0.0003	0.0000	0.7192	0.2808	0.0000
740	0.0005	0.0002	0.0000	0.7189	0.2811	0.0000
745	0.0004	0.0001	0.0000	0.7186	0.2814	0.0000
750	0.0003	0.0001	0.0000	0.7183	0.2817	0.0000
755	0.0002	0.0001	0.0000	0.7180	0.2820	0.0000
760	0.0001	0.0000	0.0000	0.7176	0.2824	0.0000
765	0.0001	0.0000	0.0000	0.7172	0.2828	0.0000
770	0.0001	0.0000	0.0000	0.7169	0.2831	0.0000
775	0.0000	0.0000	0.0000	0.7165	0.2835	0.0000
780	0.0000	0.0000	0.0000	0.7161	0.2839	0.0000

Summation at 5 nm intervals:

$\Sigma\bar{x}_{10}(\lambda) = 23.3294$
$\Sigma\bar{y}_{10}(\lambda) = 23.3324$
$\Sigma\bar{z}_{10}(\lambda) = 23.3343$

Summation at 10 nm intervals:

$\Sigma\bar{x}_{10}(\lambda) = 11.6646$
$\Sigma\bar{y}_{10}(\lambda) = 11.6644$
$\Sigma\bar{z}_{10}(\lambda) = 11.6645$

172

TABLE 2.3.3

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	ū(λ)	v̄(λ)	w̄(λ)	u(λ)	v(λ)	w(λ)
380	0.0009	0.0000	0.0026	0.2569	0.0110	0.7322
385	0.0015	0.0001	0.0043	0.2567	0.0110	0.7323
390	0.0028	0.0001	0.0081	0.2564	0.0109	0.7327
395	0.0051	0.0002	0.0146	0.2560	0.0109	0.7331
400	0.0095	0.0004	0.0274	0.2558	0.0106	0.7336
405	0.0155	0.0006	0.0445	0.2553	0.0106	0.7342
410	0.0290	0.0012	0.0838	0.2545	0.0106	0.7349
415	0.0518	0.0022	0.1501	0.2536	0.0107	0.7357
420	0.0896	0.0040	0.2616	0.2522	0.0113	0.7365
425	0.1432	0.0073	0.4231	0.2496	0.0127	0.7376
430	0.1893	0.0116	0.5682	0.2461	0.0151	0.7388
435	0.2190	0.0168	0.6725	0.2411	0.0185	0.7404
440	0.2322	0.0230	0.7339	0.2348	0.0233	0.7420
445	0.2320	0.0298	0.7620	0.2266	0.0291	0.7442
450	0.2241	0.0380	0.7750	0.2161	0.0366	0.7472
455	0.2125	0.0480	0.7847	0.2033	0.0459	0.7508
460	0.1939	0.0600	0.7792	0.1877	0.0581	0.7543
465	0.1674	0.0739	0.7493	0.1690	0.0746	0.7564
470	0.1302	0.0910	0.6826	0.1441	0.1007	0.7552
475	0.0947	0.1126	0.6188	0.1147	0.1363	0.7490
480	0.0638	0.1390	0.5672	0.0828	0.1806	0.7366
485	0.0386	0.1693	0.5331	0.0521	0.2285	0.7194
490	0.0213	0.2080	0.5286	0.0282	0.2744	0.6974
495	0.0098	0.2586	0.5572	0.0119	0.3132	0.6749
500	0.0033	0.3230	0.6180	0.0035	0.3420	0.6545
505	0.0016	0.4073	0.7159	0.0014	0.3621	0.6365
510	0.0062	0.5030	0.8289	0.0046	0.3759	0.6195
515	0.0194	0.6082	0.9536	0.0123	0.3846	0.6031
520	0.0422	0.7100	1.0725	0.0231	0.3891	0.5878
525	0.0731	0.7932	1.1636	0.0360	0.3908	0.5732
530	0.1103	0.8620	1.2313	0.0501	0.3912	0.5588
535	0.1505	0.9149	1.2743	0.0643	0.3910	0.5447
540	0.1936	0.9540	1.2959	0.0792	0.3904	0.5304
545	0.2398	0.9803	1.2973	0.0953	0.3894	0.5153
550	0.2890	0.9950	1.2801	0.1127	0.3880	0.4993
555	0.3414	1.0000	1.2468	0.1319	0.3864	0.4817
560	0.3963	0.9950	1.1972	0.1531	0.3844	0.4625
565	0.4523	0.9786	1.1301	0.1766	0.3821	0.4413
570	0.5081	0.9520	1.0480	0.2026	0.3796	0.4179
575	0.5617	0.9154	0.9528	0.2312	0.3767	0.3921
580	0.6109	0.8700	0.8477	0.2623	0.3736	0.3640
585	0.6524	0.8163	0.7358	0.2959	0.3703	0.3338
590	0.6842	0.7570	0.6229	0.3315	0.3667	0.3018
595	0.7045	0.6949	0.5145	0.3681	0.3631	0.2688
600	0.7081	0.6310	0.4158	0.4035	0.3596	0.2369
605	0.6971	0.5668	0.3277	0.4380	0.3561	0.2059
610	0.6684	0.5030	0.2534	0.4691	0.3530	0.1778
615	0.6256	0.4412	0.1927	0.4967	0.3503	0.1530
620	0.5696	0.3810	0.1444	0.5202	0.3479	0.1318
625	0.5009	0.3210	0.1058	0.5399	0.3460	0.1141

173

TABLE 2.3.3 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{u}(\lambda)$	$\bar{v}(\lambda)$	$\bar{w}(\lambda)$	$u(\lambda)$	$v(\lambda)$	$w(\lambda)$
630	0.4283	0.2650	0.0763	0.5565	0.3443	0.0992
635	0.3613	0.2170	0.0546	0.5709	0.3429	0.0862
640	0.2986	0.1750	0.0386	0.5830	0.3417	0.0753
645	0.2405	0.1382	0.0269	0.5930	0.3407	0.0663
650	0.1890	0.1070	0.0187	0.6005	0.3400	0.0596
655	0.1458	0.0816	0.0130	0.6064	0.3394	0.0543
660	0.1099	0.0610	0.0090	0.6108	0.3389	0.0503
665	0.0808	0.0446	0.0063	0.6137	0.3386	0.0476
670	0.0583	0.0320	0.0043	0.6161	0.3384	0.0455
675	0.0424	0.0232	0.0030	0.6181	0.3382	0.0437
680	0.0312	0.0170	0.0021	0.6199	0.3380	0.0421
685	0.0219	0.0119	0.0014	0.6216	0.3378	0.0405
690	0.0151	0.0082	0.0010	0.6226	0.3377	0.0397
695	0.0106	0.0057	0.0007	0.6231	0.3377	0.0392
700	0.0076	0.0041	0.0005	0.6234	0.3377	0.0390
705	0.0054	0.0029	0.0003	0.6234	0.3377	0.0390
710	0.0039	0.0021	0.0002	0.6234	0.3377	0.0390
715	0.0027	0.0015	0.0002	0.6234	0.3377	0.0390
720	0.0019	0.0010	0.0001	0.6234	0.3377	0.0390
725	0.0014	0.0007	0.0001	0.6234	0.3377	0.0390
730	0.0010	0.0005	0.0001	0.6234	0.3377	0.0390
735	0.0007	0.0004	0.0000	0.6234	0.3377	0.0390
740	0.0005	0.0002	0.0000	0.6234	0.3377	0.0390
745	0.0003	0.0002	0.0000	0.6234	0.3377	0.0390
750	0.0002	0.0001	0.0000	0.6234	0.3377	0.0390
755	0.0002	0.0001	0.0000	0.6234	0.3377	0.0390
760	0.0001	0.0001	0.0000	0.6234	0.3377	0.0390
765	0.0001	0.0000	0.0000	0.6234	0.3377	0.0390
770	0.0001	0.0000	0.0000	0.6234	0.3377	0.0390
775	0.0000	0.0000	0.0000	0.6234	0.3377	0.0390
780	0.0000	0.0000	0.0000	0.6234	0.3377	0.0390

Summation at 5 nm intervals:

$\Sigma\bar{u}(\lambda) = 14.2480$
$\Sigma\bar{v}(\lambda) = 21.3711$
$\Sigma\bar{w}(\lambda) = 32.0568$

Summation at 10 nm intervals:

$\Sigma\bar{u}(\lambda) = 7.1225$
$\Sigma\bar{v}(\lambda) = 10.6856$
$\Sigma\bar{w}(\lambda) = 16.0252$

174

TABLE 2.3.4

λ (nm)	SPECTRAL TRISTIMULUS VALUES $\bar{u}_{10}(\lambda)$	$\bar{v}_{10}(\lambda)$	$\bar{w}_{10}(\lambda)$	CHROMATICITY COORDINATES $u_{10}(\lambda)$	$v_{10}(\lambda)$	$w_{10}(\lambda)$
380	0.0001	0.0000	0.0003	0.2524	0.0411	0.7065
385	0.0004	0.0001	0.0012	0.2519	0.0408	0.7073
390	0.0016	0.0003	0.0044	0.2512	0.0404	0.7084
395	0.0048	0.0008	0.0137	0.2502	0.0398	0.7100
400	0.0127	0.0020	0.0365	0.2488	0.0391	0.7120
405	0.0289	0.0045	0.0836	0.2472	0.0385	0.7143
410	0.0565	0.0088	0.1654	0.2449	0.0380	0.7172
415	0.0938	0.0145	0.2797	0.2417	0.0373	0.7211
420	0.1363	0.0214	0.4161	0.2376	0.0373	0.7251
425	0.1765	0.0295	0.5531	0.2325	0.0389	0.7286
430	0.2098	0.0387	0.6774	0.2266	0.0418	0.7316
435	0.2385	0.0496	0.7948	0.2202	0.0458	0.7340
440	0.2558	0.0621	0.8849	0.2127	0.0516	0.7357
445	0.2578	0.0747	0.9323	0.2038	0.0591	0.7371
450	0.2471	0.0895	0.9462	0.1926	0.0697	0.7376
455	0.2286	0.1063	0.9383	0.1796	0.0835	0.7370
460	0.2015	0.1282	0.9138	0.1620	0.1031	0.7349
465	0.1694	0.1528	0.8795	0.1410	0.1271	0.7319
470	0.1304	0.1852	0.8388	0.1130	0.1604	0.7266
475	0.0882	0.2199	0.7788	0.0812	0.2023	0.7165
480	0.0537	0.2536	0.7262	0.0519	0.2454	0.7027
485	0.0274	0.2977	0.7110	0.0264	0.2873	0.6863
490	0.0108	0.3391	0.7082	0.0102	0.3205	0.6693
495	0.0034	0.3954	0.7417	0.0030	0.3467	0.6503
500	0.0025	0.4608	0.7985	0.0020	0.3652	0.6328
505	0.0103	0.5314	0.8689	0.0073	0.3767	0.6160
510	0.0250	0.6067	0.9474	0.0158	0.3842	0.6000
515	0.0476	0.6857	1.0339	0.0269	0.3880	0.5851
520	0.0785	0.7618	1.1141	0.0402	0.3898	0.5701
525	0.1153	0.8233	1.1700	0.0547	0.3904	0.5549
530	0.1577	0.8752	1.2098	0.0703	0.3903	0.5394
535	0.2028	0.9238	1.2439	0.0856	0.3897	0.5247
540	0.2512	0.9620	1.2614	0.1015	0.3887	0.5098
545	0.3011	0.9822	1.2515	0.1188	0.3875	0.4937
550	0.3532	0.9918	1.2247	0.1375	0.3859	0.4766
555	0.4107	0.9991	1.1912	0.1579	0.3841	0.4580
560	0.4701	0.9973	1.1434	0.1801	0.3820	0.4379
565	0.5292	0.9824	1.0767	0.2045	0.3796	0.4160
570	0.5858	0.9556	0.9940	0.2310	0.3769	0.3921
575	0.6341	0.9152	0.8972	0.2592	0.3741	0.3667
580	0.6761	0.8689	0.7963	0.2888	0.3711	0.3401
585	0.7162	0.8256	0.7013	0.3193	0.3681	0.3126
590	0.7457	0.7774	0.6068	0.3501	0.3650	0.2849
595	0.7562	0.7204	0.5134	0.3800	0.3620	0.2580
600	0.7493	0.6583	0.4255	0.4088	0.3591	0.2321
605	0.7261	0.5939	0.3463	0.4358	0.3564	0.2078
610	0.6870	0.5280	0.2767	0.4606	0.3539	0.1855
615	0.6338	0.4618	0.2174	0.4827	0.3517	0.1656
620	0.5709	0.3981	0.1689	0.5017	0.3498	0.1485
625	0.5033	0.3396	0.1319	0.5163	0.3484	0.1353

175

TABLE 2.34 (continued)

λ (nm)	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
	$\bar{u}_{10}(\lambda)$	$\bar{v}_{10}(\lambda)$	$\bar{w}_{10}(\lambda)$	$u_{10}(\lambda)$	$v_{10}(\lambda)$	$w_{10}(\lambda)$
630	0.4316	0.2835	0.1015	0.5286	0.3471	0.1243
635	0.3567	0.2283	0.0748	0.5407	0.3459	0.1134
640	0.2877	0.1798	0.0540	0.5517	0.3448	0.1035
645	0.2291	0.1402	0.0385	0.5618	0.3438	0.0943
650	0.1789	0.1076	0.0273	0.5701	0.3430	0.0869
655	0.1362	0.0812	0.0196	0.5746	0.3425	0.0828
660	0.1017	0.0603	0.0141	0.5775	0.3423	0.0803
665	0.0748	0.0441	0.0100	0.5802	0.3420	0.0779
670	0.0542	0.0318	0.0071	0.5822	0.3418	0.0760
675	0.0386	0.0226	0.0049	0.5837	0.3416	0.0746
680	0.0272	0.0159	0.0034	0.5848	0.3415	0.0737
685	0.0191	0.0111	0.0024	0.5854	0.3415	0.0731
690	0.0133	0.0077	0.0017	0.5858	0.3414	0.0728
695	0.0092	0.0054	0.0011	0.5861	0.3414	0.0725
700	0.0064	0.0037	0.0008	0.5863	0.3414	0.0724
705	0.0044	0.0026	0.0005	0.5862	0.3414	0.0724
710	0.0030	0.0018	0.0004	0.5859	0.3414	0.0727
715	0.0021	0.0012	0.0003	0.5856	0.3414	0.0730
720	0.0014	0.0008	0.0002	0.5851	0.3415	0.0734
725	0.0010	0.0006	0.0001	0.5846	0.3415	0.0739
730	0.0007	0.0004	0.0001	0.5840	0.3416	0.0744
735	0.0005	0.0003	0.0001	0.5834	0.3417	0.0750
740	0.0003	0.0002	0.0000	0.5827	0.3417	0.0756
745	0.0002	0.0001	0.0000	0.5819	0.3418	0.0763
750	0.0002	0.0001	0.0000	0.5812	0.3419	0.0770
755	0.0001	0.0001	0.0000	0.5803	0.3420	0.0777
760	0.0001	0.0000	0.0000	0.5795	0.3421	0.0785
765	0.0001	0.0000	0.0000	0.5786	0.3421	0.0793
770	0.0000	0.0000	0.0000	0.5777	0.3422	0.0801
775	0.0000	0.0000	0.0000	0.5767	0.3423	0.0810
780	0.0000	0.0000	0.0000	0.5757	0.3424	0.0819

Summation at 5 nm intervals:

$\Sigma\bar{u}_{10}(\lambda)$ = 15.5525

$\Sigma\bar{v}_{10}(\lambda)$ = 23.3324

$\Sigma\bar{w}_{10}(\lambda)$ = 34.9999

Summation at 10 nm intervals:

$\Sigma\bar{u}_{10}(\lambda)$ = 7.7760

$\Sigma\bar{v}_{10}(\lambda)$ = 11.6644

$\Sigma\bar{w}_{10}(\lambda)$ = 17.4963

176

TABLE 2.4

λ (nm)	CHROMATICITY COORDINATES			SPECTRAL TRISTIMULUS VALUES		
	r(λ)	g(λ)	b(λ)	$\bar{r}(\lambda)$	$\bar{g}(\lambda)$	$\bar{b}(\lambda)$
380	0.0272	-0.0115	0.9843	0.00003	-0.00001	0.00117
385	0.0268	-0.0114	0.9846	0.00005	-0.00002	0.00189
390	0.0263	-0.0114	0.9851	0.00010	-0.00004	0.00359
395	0.0256	-0.0113	0.9857	0.00017	-0.00007	0.00647
400	0.0247	-0.0112	0.9865	0.00030	-0.00014	0.01214
405	0.0237	-0.0111	0.9874	0.00047	-0.00022	0.01969
410	0.0225	-0.0109	0.9884	0.00084	-0.00041	0.03707
415	0.0207	-0.0104	0.9897	0.00139	-0.00070	0.06637
420	0.0181	-0.0094	0.9913	0.00211	-0.00110	0.11541
425	0.0142	-0.0076	0.9934	0.00266	-0.00143	0.18575
430	0.0088	-0.0048	0.9960	0.00218	-0.00119	0.24769
435	0.0012	-0.0007	0.9995	0.00036	-0.00021	0.29012
440	-0.0084	0.0048	1.0036	-0.00261	0.00149	0.31228
445	-0.0213	0.0120	1.0093	-0.00673	0.00379	0.31860
450	-0.0390	0.0218	1.0172	-0.01213	0.00678	0.31670
455	-0.0618	0.0345	1.0273	-0.01874	0.01046	0.31166
460	-0.0909	0.0517	1.0392	-0.02608	0.01485	0.29821
465	-0.1281	0.0762	1.0519	-0.03324	0.01977	0.27295
470	-0.1821	0.1175	1.0646	-0.03933	0.02538	0.22991
475	-0.2584	0.1840	1.0744	-0.04471	0.03183	0.18592
480	-0.3667	0.2906	1.0761	-0.04939	0.03914	0.14494
485	-0.5200	0.4568	1.0632	-0.05364	0.04713	0.10968
490	-0.7150	0.6996	1.0154	-0.05814	0.05689	0.08257
495	-0.9459	1.0247	0.9212	-0.06414	0.06948	0.06246
500	-1.1685	1.3905	0.7780	-0.07173	0.08536	0.04776
505	-1.3182	1.7195	0.5987	-0.08120	0.10593	0.03688
510	-1.3371	1.9318	0.4053	-0.08901	0.12860	0.02698
515	-1.2076	1.9699	0.2377	-0.09356	0.15262	0.01842
520	-0.9830	1.8534	0.1296	-0.09264	0.17468	0.01221
525	-0.7386	1.6662	0.0724	-0.08473	0.19113	0.00830
530	-0.5159	1.4761	0.0398	-0.07101	0.20317	0.00549
535	-0.3304	1.3105	0.0199	-0.05316	0.21083	0.00320
540	-0.1707	1.1628	0.0079	-0.03152	0.21466	0.00146
545	-0.0293	1.0282	0.0011	-0.00613	0.21487	0.00023
550	0.0974	0.9051	-0.0025	0.02279	0.21178	-0.00058
555	0.2121	0.7919	-0.0040	0.05514	0.20588	-0.00105
560	0.3164	0.6881	-0.0045	0.09060	0.19702	-0.00130
565	0.4112	0.5932	-0.0044	0.12840	0.18522	-0.00138
570	0.4973	0.5067	-0.0040	0.16768	0.17087	-0.00135
575	0.5751	0.4283	-0.0034	0.20715	0.15429	-0.00123
580	0.6449	0.3579	-0.0028	0.24526	0.13610	-0.00108
585	0.7071	0.2952	-0.0023	0.27989	0.11686	-0.00093
590	0.7617	0.2402	-0.0019	0.30928	0.09754	-0.00079
595	0.8087	0.1928	-0.0015	0.33184	0.07909	-0.00063
600	0.8475	0.1537	-0.0012	0.34429	0.06246	-0.00049
605	0.8800	0.1209	-0.0009	0.34756	0.04776	-0.00038
610	0.9059	0.0949	-0.0008	0.33971	0.03557	-0.00030
615	0.9265	0.0741	-0.0006	0.32265	0.02583	-0.00022
620	0.9425	0.0580	-0.0005	0.29708	0.01828	-0.00015

177

TABLE 2.4 (continued)

λ (nm)	CHROMATICITY COORDINATES			SPECTRAL TRISTIMULUS VALUES		
	r(λ)	g(λ)	b(λ)	$\bar{r}(\lambda)$	$\bar{g}(\lambda)$	$\bar{b}(\lambda)$
625	0.9550	0.0454	-0.0004	0.26348	0.01253	-0.00011
630	0.9649	0.0354	-0.0003	0.22677	0.00833	-0.00008
635	0.9730	0.0272	-0.0002	0.19233	0.00537	-0.00005
640	0.9797	0.0205	-0.0002	0.15968	0.00334	-0.00003
645	0.9850	0.0152	-0.0002	0.12905	0.00199	-0.00002
650	0.9888	0.0113	-0.0001	0.10167	0.00116	-0.00001
655	0.9918	0.0083	-0.0001	0.07857	0.00066	-0.00001
660	0.9940	0.0061	-0.0001	0.05932	0.00037	0.00000
665	0.9954	0.0047	-0.0001	0.04366	0.00021	0.00000
670	0.9966	0.0035	-0.0001	0.03149	0.00011	0.00000
675	0.9975	0.0025	0.0000	0.02294	0.00006	0.00000
680	0.9984	0.0016	0.0000	0.01687	0.00003	0.00000
685	0.9991	0.0009	0.0000	0.01187	0.00001	0.00000
690	0.9996	0.0004	0.0000	0.00819	0.00000	0.00000
695	0.9999	0.0001	0.0000	0.00572	0.00000	0.00000
700	1.0000	0.0000	0.0000	0.00410	0.00000	0.00000
705	1.0000	0.0000	0.0000	0.00291	0.00000	0.00000
710	1.0000	0.0000	0.0000	0.00210	0.00000	0.00000
715	1.0000	0.0000	0.0000	0.00148	0.00000	0.00000
720	1.0000	0.0000	0.0000	0.00105	0.00000	0.00000
725	1.0000	0.0000	0.0000	0.00074	0.00000	0.00000
730	1.0000	0.0000	0.0000	0.00052	0.00000	0.00000
735	1.0000	0.0000	0.0000	0.00036	0.00000	0.00000
740	1.0000	0.0000	0.0000	0.00025	0.00000	0.00000
745	1.0000	0.0000	0.0000	0.00017	0.00000	0.00000
750	1.0000	0.0000	0.0000	0.00012	0.00000	0.00000
755	1.0000	0.0000	0.0000	0.00008	0.00000	0.00000
760	1.0000	0.0000	0.0000	0.00006	0.00000	0.00000
765	1.0000	0.0000	0.0000	0.00004	0.00000	0.00000
770	1.0000	0.0000	0.0000	0.00003	0.00000	0.00000
775	1.0000	0.0000	0.0000	0.00001	0.00000	0.00000
780	1.0000	0.0000	0.0000	0.00000	0.00000	0.00000

178

TABLE 2.5

$\bar{\nu}$	SPECTRAL TRISTIMULUS VALUES			CHROMATICITY COORDINATES		
(cm^{-1})	$\bar{r}_{10}(\bar{\nu})$	$\bar{g}_{10}(\bar{\nu})$	$\bar{b}_{10}(\bar{\nu})$	$r_{10}(\bar{\nu})$	$g_{10}(\bar{\nu})$	$b_{10}(\bar{\nu})$
27750	0.000 000 079 100	-0.000 000 021 447	0.000 000 307 299	0.216 74	-0.058 77	0.842 03
27500	0.000 000 298 91	-0.000 000 081 25	0.000 001 164 75	0.216 22	-0.058 77	0.842 55
27250	0.000 001 083 48	-0.000 000 295 33	0.000 004 237 33	0.215 60	-0.058 77	0.843 17
27000	0.000 003 752 2	-0.000 001 027 1	0.000 014 750 6	0.214 71	-0.058 77	0.844 06
26750	0.000 012 377 6	-0.000 003 405 7	0.000 048 982 2	0.213 58	-0.058 77	0.845 19
26500	0.000 038 728	-0.000 010 728	0.000 154 553	0.212 15	-0.058 77	0.846 62
26250	0.000 114 541	-0.000 032 004	0.000 462 055	0.210 32	-0.058 77	0.848 44
26000	0.000 319 05	-0.000 090 06	0.001 303 50	0.208 19	-0.058 77	0.850 58
25750	0.000 832 16	-0.000 238 07	0.003 457 02	0.205 42	-0.058 77	0.853 35
25500	0.002 016 85	-0.000 588 13	0.008 577 76	0.201 55	-0.058 77	0.857 22
25250	0.004 523 3	-0.001 351 9	0.019 831 5	0.196 64	-0.058 77	0.862 13
25000	0.009 328 3	-0.002 877 0	0.042 505 7	0.190 54	-0.058 77	0.868 23
24750	0.017 611 6	-0.005 620 0	0.084 040 2	0.183 39	-0.058 52	0.875 13
24500	0.030 120	-0.010 015	0.152 451	0.174 55	-0.058 04	0.883 49
24250	0.045 571	-0.016 044	0.251 453	0.162 19	-0.057 10	0.894 91
24000	0.060 154	-0.022 951	0.374 271	0.146 19	-0.055 78	0.909 59
23750	0.071 261	-0.029 362	0.514 950	0.127 97	-0.052 73	0.924 76
23500	0.074 212	-0.032 793	0.648 306	0.107 60	-0.047 55	0.939 95
23250	0.068 535	-0.032 357	0.770 262	0.084 98	-0.040 12	0.955 14
23000	0.055 848	-0.027 996	0.883 628	0.061 27	-0.030 71	0.969 44
22750	0.033 049	-0.017 332	0.965 742	0.033 67	-0.017 66	0.983 99
22500	0.000 000	0.000 000	1.000 000	0.000 00	0.000 00	1.000 00
22250	-0.041 570	0.024 936	0.987 224	-0.042 83	0.025 69	1.017 14
22000	-0.088 073	0.057 100	0.942 474	-0.096 62	0.062 64	1.033 98
21750	-0.143 959	0.099 886	0.863 537	-0.175 67	0.121 89	1.053 78
21500	-0.207 995	0.150 955	0.762 081	-0.295 01	0.214 11	1.080 90
21250	-0.285 499	0.218 942	0.630 116	-0.506 60	0.388 50	1.118 10
21000	-0.346 240	0.287 846	0.469 818	-0.841 56	0.699 63	1.141 93
20750	-0.388 289	0.357 723	0.333 077	-1.283 55	1.182 51	1.101 04
20500	-0.426 587	0.435 138	0.227 060	-1.810 56	1.846 85	0.963 71
20250	-0.435 789	0.513 218	0.151 027	-1.907 54	2.246 46	0.661 08
20000	-0.438 549	0.614 637	0.095 840	-1.612 74	2.260 29	0.352 45
19750	-0.404 927	0.720 251	0.057 654	-1.085 66	1.931 08	0.154 58
19500	-0.333 995	0.830 003	0.029 877	-0.635 11	1.578 30	0.056 81
19250	-0.201 889	0.933 227	0.012 874	-0.271 28	1.253 98	0.017 30
19000	0.000 000	1.000 000	0.000 000	0.000 00	1.000 00	0.000 00
18750	0.255 754	1.042 957	-0.008 854	0.198 28	0.808 58	-0.006 86
18500	0.556 022	1.061 343	-0.014 341	0.346 86	0.662 09	-0.008 95
18250	0.904 637	1.031 339	-0.017 422	0.471 52	0.537 56	-0.009 08
18000	1.314 803	0.976 838	-0.018 644	0.578 44	0.429 76	-0.008 20
17750	1.770 322	0.887 915	-0.017 338	0.670 35	0.336 22	-0.006 57
17500	2.236 809	0.758 780	-0.014 812	0.750 41	0.254 56	-0.004 97
17250	2.641 981	0.603 012	-0.011 771	0.817 14	0.186 50	-0.003 64
17000	3.002 291	0.452 300	-0.008 829	0.871 30	0.131 26	-0.002 56
16750	3.159 249	0.306 869	-0.005 990	0.913 04	0.088 69	-0.001 73
16500	3.064 234	0.184 057	-0.003 593	0.944 38	0.056 73	-0.001 11
16250	2.717 232	0.094 471	-0.001 844	0.967 04	0.033 62	-0.000 66
16000	2.191 156	0.041 693	-0.000 815	0.981 69	0.018 68	-0.000 37

179

TABLE 2.5 (continued)

$\bar{\nu}$ (cm^{-1})	SPECTRAL TRISTIMULUS VALUES $\bar{r}_{10}(\bar{\nu})$	$\bar{g}_{10}(\bar{\nu})$	$\bar{b}_{10}(\bar{\nu})$	CHROMATICITY COORDINATES $r_{10}(\bar{\nu})$	$g_{10}(\bar{\nu})$	$b_{10}(\bar{\nu})$
15750	1.566 864	0.013 407	-0.000 262	0.991 68	0.008 49	-0.000 17
15500	1.000 000	0.000 000	0.000 000	1.000 00	0.000 00	0.000 00
15250	0.575 756	-0.002 747	0.000 054	1.004 70	-0.004 79	0.000 09
15000	0.296 964	-0.002 029	0.000 040	1.006 74	-0.006 88	0.000 14
14750	0.138 738	-0.001 116	0.000 022	1.007 95	-0.008 11	0.000 16
14500	0.060 220 9	-0.000 513 0	0.000 010 0	1.008 42	-0.008 59	0.000 17
14250	0.024 772 4	-0.000 215 2	0.000 004 2	1.008 59	-0.008 76	0.000 17
14000	0.009 763 19	-0.000 082 77	0.000 001 62	1.008 38	-0.008 55	0.000 17
13750	0.003 753 28	-0.000 030 12	0.000 000 59	1.007 93	-0.008 09	0.000 16
13500	0.001 419 08	-0.000 010 51	0.000 000 21	1.007 31	-0.007 46	0.000 15
13250	0.000 533 169	-0.000 003 543	0.000 000 069	1.006 56	-0.006 69	0.000 13
13000	0.000 199 730	-0.000 001 144	0.000 000 022	1.005 65	-0.005 76	0.000 11
12750	0.000 074 352 2	-0.000 000 347 2	0.000 000 006 8	1.004 60	-0.004 69	0.000 09
12500	0.000 027 650 6	-0.000 000 096 1	0.000 000 001 9	1.003 42	-0.003 49	0.000 07
12250	0.000 010 212 3	-0.000 000 022 0	0.000 000 000 4	1.002 12	-0.002 16	0.000 04

INTERNATIONAL COMMISSION ON ILLUMINATION

PART VI

RETROREFLECTION DEFINITION AND MEASUREMENT

LIST OF CONTENTS

1

1. FOREWORD

The results of the work carried out by the former CIE Committee W-3.3.5, Automobile Headlights and Signal Lights, were published in the Proceedings of the 14th Session of the CIE (CIE Publication No. 1, 1959, pages 566-571) under the title of General Recommendations for Reflex Reflector Photometry.

In 1974 a subgroup, Photometry, of the CIE Committee TC-4.7, Automobile Lighting, reconsidered these recommendations in order to bring them into better agreement with the prevailing practice. This subgroup proposed the introduction of another type of measuring goniometer, which was deemed to be of sufficient importance for a revision of the previous recommendations.

Also in 1974, CIE Committee TC-1.6, Visual Signalling, completed three draft documents on retroreflection. One of these documents, on Terminology, included a proposal for an intrinsic geometric system for describing retroflection. Thus in 1974 three geometric systems were under consideration by various CIE committees.

In 1975 a CIE Harmonizing Group on Retroreflection was established to make a more general study of the terminology and the definitions in the field of retroreflection for universal use by the CIE. This group prepared, in 1976, a document on names and units and another one on systems of angular reference. Apart from these documents the Harmonizing Group paid considerable attention to other important items, such as dimensional and physical specifications for the equipment, calibration techniques in measuring retroreflection and fundamentals of the colorimetry of retroreflectors.

Retroreflection at a macroscopic scale, if not at a microscopic one, may be considered as a particular kind of reflection. Therefore, in 1977, the study of retroreflection and of the corresponding measuring techniques was assigned to the CIE Committee TC-2.3 Materials whose terms of reference are : To study and develop methods for photometric and radiometric characterization of materials.

The process of retroreflection is widely used for increasing the visibility of objects and information for road traffic at night. The corresponding devices, or retroreflectors, may be divided into three broad categories, namely retroreflective signs, retroreflectors for road vehicles and retroreflective road markings. Since their application interests primarily three other CIE technical committees, TC-1.6, Visual Signalling, TC-4.7, Automobile Lighting, and TC-4.6, Road Lighting, coordination of the work and cooperation between these technical committees and TC-2.3 had to be established, respecting however the necessity for harmony concerning common fundamental questions.

The subcommittee, Retroreflection, was set up within the framework of TC-2.3 and studied the fundamental questions relating to retroreflection. These questions refer to :

Terminology and symbols
Instrumentation
Methods for photometry
Methods for colorimetry
Problems of accuracy.

This part of the work covered all categories of retroreflectors in order to secure the required harmonization for the basic parameters which are common to all types.

This subcommittee has also worked on and documented the special problems of the photometry at grazing incidence and view of flat horizontal retroreflective material such as road markings. However, this work is not contained in this report, since it will be further studied in a new subcommittee, Road Markings, of Committee TC-1.6.

It is the province of the relevant CIE technical committees to determine the performance requirements for the types of retroreflectors they have to deal with. This includes the selection of the most appropriate geometrical conditions under which the retroreflectors are to be tested.

The subcommittee, Retroreflection, his of the opinion that this technical report provides well defined measuring procedures and useful advice, which are important for persons who are working with these materials in test laboratories or for others who have an immediate interest in the results of tests.

The general improvement in accuracy of test data, which can result by following the contents of this report, should also lead to more correct assessment of product compliance with specified requirements.

2

2. TERMINOLOGY AND COORDINATE SYSTEM FOR RETROREFLECTION

This section contains definitions which describe the properties of retroreflectors. The general definitions define retroreflection as a phenomenon without regard to the luminosity function. The principle photometric terms are quantities recommended for the specification and description of retroreflectors used in visual signalling applications. Both the general definitions and the principle photometric terms appear in the International Lighting Vocabulary (4th edition, to be published).

2.1. GENERAL DEFINITIONS

2.1.1. Retroreflection

Reflection in which the reflected rays are preferentially returned in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays.

2.1.2. Retroreflector

A surface or device from which most of the reflected radiation is retroreflected.

2.1.3. Observation Angle α

Angle by which the direction of observation of the retroreflector departs from the direction of the incident light. (See 2.4.4.).

2.1.4. Entrance Angle β

Angle characterizing the angular position of the retroreflector with respect to the direction of the incident light. (See 2.4.7., 2.4.9. and 2.4.10.).
Note : For a plane retroreflector, the entrance angle corresponds generally to the angle of incidence.

2.2. PRINCIPAL PHOTOMETRIC TERMS

2.2.1. Coefficient of Luminous Intensity

The quotient of the luminous intensity (I) of the retroreflector in the direction of observation by the illuminance ($E_{\perp}$) at the retroreflector on plane perpendicular to the direction of the incident light.

Symbol R $$R = \frac{I}{E_{\perp}}$$

Note 1 : In the photometry of retroreflectors this coefficient is expressed in candelas per lux (cd lx^{-1}).

Note 2 : For accurate measurements of R, care must be taken that the angular extent of the retroreflector at the point of observation, of the source aperture at the retroreflector and of the aperture of the photometer head (the part of a physical photometer containing the detector and means for spectral and spatial corrections of the detector) at the retroreflector are each sufficiently restricted. The restriction needed depends upon both the distribution of the retroreflected light and the measurement geometry. (See Sections 3-1 to 3-3).

Note 3 : For accurate measurements of R the illuminance ($E_{\perp}$) must be sufficiently uniform over the useful area of the retroreflector. (See Section 3-6).

2.2.2. Coefficient of Retroreflection (of plane retroreflecting surface)

The quotient of the coefficient of luminous intensity (R) of a plane retroreflecting surface by its area (A).

Symbol R′ $$R' = \frac{R}{A} = \frac{I/E_{\perp}}{A}$$ (see 2.2.1)

Note 1 : The coefficient of retroreflection is expressed in candelas per lux per square metre (cd $lx^{-1}m^{-2}$).

Note 2 : This quantity is especially useful for describing materials in sheet form. For such materials the measurements are customarily made with the direction of illumination, the direction of observation, and the normal to the surface all in the same plane.

2.3. THE CIE ANGULAR REFERENCE SYSTEM FOR DESCRIBING, SPECIFYING AND TESTING RETROREFLECTORS

In this section an angular reference system is presented, the use of which is recommended when dealing with retroreflection. A retroreflector is usually illuminated with nearly collimated light and the reflected light of interest is directed nearly parallel to the direction of the incident light. These circumstances make it natural to regard the direction of illumination as the principal direction and to regard the direction of observation and the orientation of the retroreflector in terms of the direction of illumination. The CIE (angular reference) system for describing, specifying and testing retroreflectors has been developed from this basis (Venable and Johnson, 1980). It coincides with the way in which retroreflection is visualised. In the case of road vehicles, in which the retroreflectors are often considered as luminous sources, it can be regarded as describing the orientation of such a source in what is essentially the viewer's frame of reference.

In describing the angular quantities, the source of illumination, the retroreflector and the photometer head are all treated as points. Actual measurements involve light sources and photometer heads which subtend finite solid angles at the retroreflector and retroreflectors with finite physical dimensions. An indication of how these finite angles and dimensions affect the measurements and what restrictions must be placed on them is given in section 3 on the photometry of retroreflectors.

The angular reference system for retroreflectors uses no more reference points, planes, axes, and angles than are needed to fully describe the phenomena of retroreflection. Within the angular limits prescribed, the system is complete but not redundant. Each configuration of the source, retroreflector and photometer head can be described by one and only one set of four angles. (The four angles are α, β_1, β_2 and ϵ. The entrance angle β may always be derived from β_1 and β_2). The angular limits allow for all possible configurations of the retroreflector, source and photometer head. However, since most retroreflectors have one face only, the total allowable angular range is normally not used. The sign convention applied here is such that the positive direction of each axis and the positive sense of each angle are as indicated by the directions of the arrows in Figures 1 and 2. This system is completely defined in section 2.4.

2.4. GEOMETRIC DEFINITIONS

2.4.1. Reference Centre

A point on or near a retroreflector which is designated to be the centre of the device for the purpose of specifying its performance.

Note 1 : Designating the reference centre (2.4.1.), the reference axis (2.4.6.) and the datum mark (2.4.12.) establishes coordinates fixed with respect to the retroreflector by means of which its location and angular orientation can be specified. (For a retroreflective device, these geometrical parameters are usually designated by the manufacturer). This coordinate system is related to the intended use of the retroreflector. The location of the reference centre is chosen to be on or near the retroreflecting surface and central with respect to it. When symmetry exists, the reference axis usually coincides with the axis of symmetry of the retroreflector. When required, a datum mark not on the reference axis serves to indicate the orientation of the retroreflector about the reference axis.

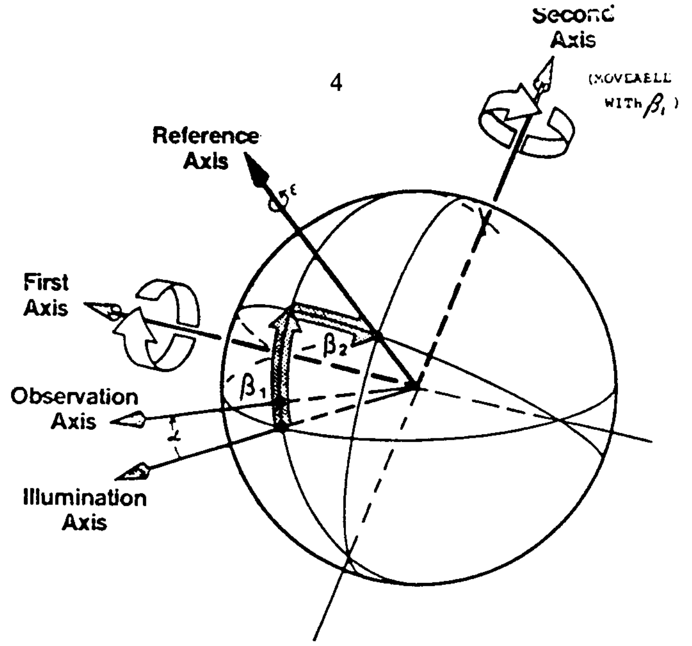


Figure 1. — The CIE angular reference system for specifying and measuring retroreflectors. The first axis is perpendicular to the plane containing the observation axis and the illumination axis. The second axis is perpendicular both to the first axis and to the reference axis. All axes, angles, and directions of rotation are shown positive.

Notes

a) The *principal fixed axis* is the Illumination Axis.

b) The First Axis is *fixed* perpendicular to the plane containing the Observation and Illumination Axis.

c) The Reference Axis is *fixed* in the retroreflector and moveable with β_1 and β_2.

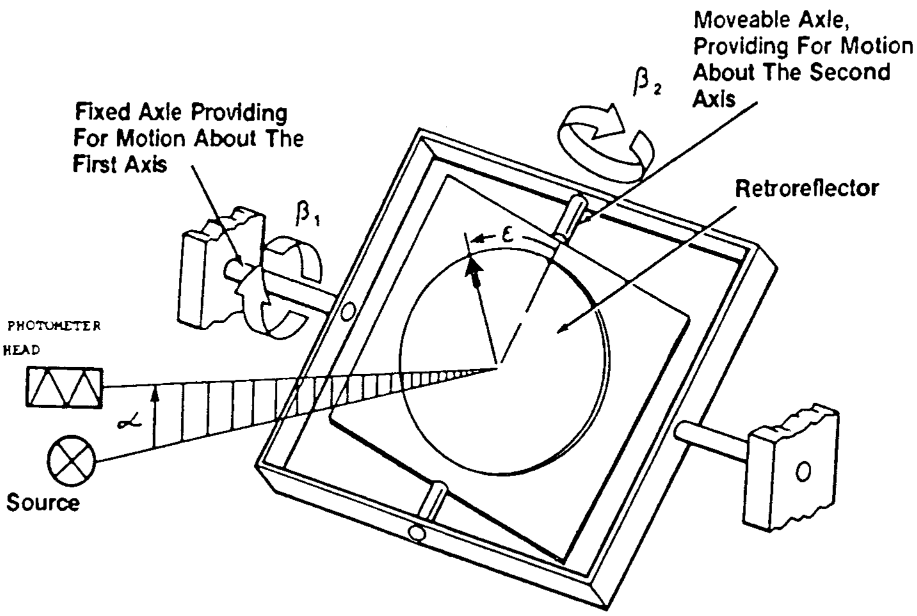


Figure 2. — A representation of a goniometer mechanism embodying the CIE angular reference system for specifying and measuring retroreflectors. All angles and directions of rotation are shown positive.

2.4.2. Illumination Axis

A line segment from the reference centre to the source of illumination.

2.4.3. Observation Axis

A line segment from the reference centre to the photometer head.

2.4.4. Observation Angle (Symbol α)

The angle between the illumination axis and the observation axis. The observation angle is always positive and in the context of retroreflection is restricted to small acute angles. Maximum range : $0 \leq \alpha < 180°$.

2.4.5. Observation Half-Plane

The half-plane which originates on the illumination axis and which contains the observation axis.

2.4.6. Reference Axis

A designated line segment originating on the reference centre which is used in describing the angular position of the retroreflector. (See Note 1, Section 2.4.1.).

2.4.7. Entrance Angle (Illumination Angle) (Symbol β)

The angle from the illumination axis to the reference axis. The entrance angle is usually not larger than 90°, but for completeness its full range is defined as $0 \leq \beta \leq 180°$. In order to completely specify the orientation, this angle is characterized by two components, β_1 and β_2.

2.4.8. First Axis

An axis throught the reference centre and perpendicular to the observation half-plane.

2.4.9. First Component of the Entrance Angle (Symbol β_1)

The angle from the illumination axis to the plane containing the reference axis and the first axis.
Range : $-180° < \beta_1 \leq 180°$

2.4.10. Second Component of the Entrance Angle. (Symbol β_2)

The angle from the plane containing the observation half-plane to the reference axis. Range : $-90° \leq \beta_2 \leq 90°$.

2.4.11. Second Axis

An axis through the reference centre and perpendicular to both the first axis and the reference axis. The positive direction of the second axis lies in the observation half-plane when $-90° < \beta_1 < 90°$ as shown in Figure 1.

2.4.12. Datum Mark

A mark on the retroreflector which is used to indicate the orientation of the retroreflector with respect to rotation about the reference axis. The datum mark must not lie on the reference axis. (See Note 1, Section 2.4.1.).

2.4.13. Rotation Angle (Symbol ϵ)

The dihedral angle from the half-plane originating on the reference axis and containing the positive part of the second axis to the half-plane originating on the reference axis and containing the datum mark. Range : $-180° < \beta \leq 180°$. (See Figure 2).

2.5. CONVENTIONS

2.5.1. If the retroflector has a datum mark and the rotation angle is unspecified, $\epsilon = 0$.

2.5.2. When the entrance angle β alone is specified without reference to components, $\beta_2 = 0$ and $\beta_1 = \beta$.

2.5.3. When $\beta_2 = \pm 90°$, the reference axis coincides with the first axis and motions about these axes are the same. To avoid redundancy in this special case, by convention the second axis will be chosen to lie in the observation half plane and be perpendicular to the illumination axis, β_1 is by convention set equal to zero, and by convention the orientation is represented by ϵ alone.

2.5.4. When $\alpha = 0$, the observation axis and the illumination axis coincide. In this special case, the definition of the observation half-plane can no longer be applied. Therefore by convention the half-plane originating on the illumination axis and containing the reference axis is used as if it were the observation half-plane. Also in this case allowing separate motions for β_1 and β_2 results in redundancy, therefore when $\alpha = 0$ only β_1 is used and its range is limited to $0 \leq \beta_1 \leq 180°$, $\beta_2 = 0$.

2.5.5. When $\alpha = 0$ and $\beta = 0$, the rotation angle can no longer be defined and by convention then $\epsilon = 0$.

2.6. GONIOMETER

A goniometer which can be used in making retroreflection measurements in the CIE geometry, as defined in Sections 2.3.-2.5. of this report, is illustrated in Figure 2. In this illustration the photometer head is arbitrarily shown to be vertically above the source. The first axis is shown to be fixed and horizontal and is situated perpendicular to the observation half-plane. Any arrangement of the components which is equivalent to the one shown can be used.

Some goniometers currently in use have an axis fixed perpendicular to the illumination axis in the observation half-plane. If it is not convenient to modify such apparatus so that it will coincide directly with the CIE angular system, the transformation given in Appendix B can be used to determine angular settings of such an apparatus to provide the values given for β_1, β_2 and ϵ.

7

3. DIMENSIONAL AND PHYSICAL SPECIFICATIONS FOR THE PHOTOMETRY OF RETROREFLECTORS

INTRODUCTION

In order to obtain an acceptable accuracy and compatible results between different laboratories when measuring the coefficient of luminous intensity of a retroreflector, the following aspects should be considered (see Figure 3).

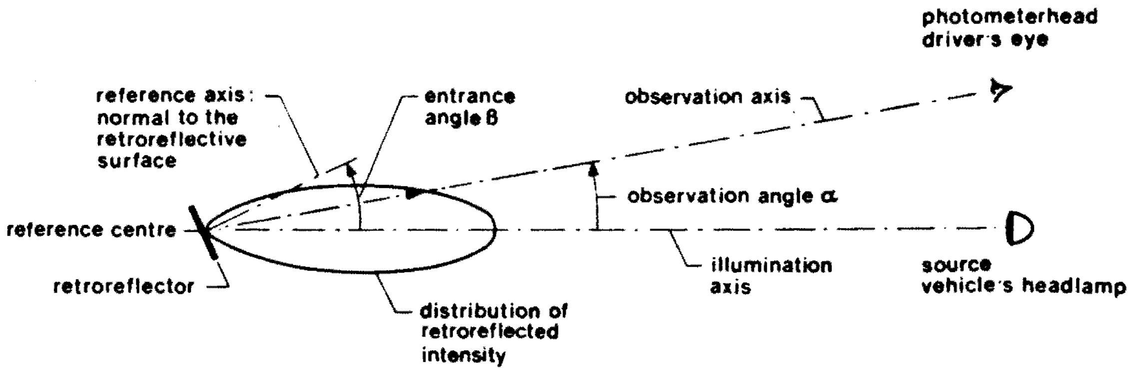


Figure 3. — Typical parameters involved with the effect of retroreflection.

For a retroreflector mounted in a fixed position the luminous distribution of the retroreflected beam in a plane through the illumination axis can, in general, be expressed by :

$$i_\alpha = C\ f(\alpha)$$

where i_α is the intensity reflected in that plane for an observation angle α. C is a parameter, which is a constant for the plane considered and f (α) is an analytical function of α, appropriate to the distribution concerned.

An example of the distribution of the beam from a corner cube retroreflector has been shown in Figure 4. The distribution was measured (see Figure 5) by using an optically plane glass, with its normal at 45° to the illumination axis, placed between the retroreflector and the (small) source of illumination and by moving the photometer head with a very small opening over a line parallel to the illumination axis in the plane containing both the illumination axis and the normal to the optical glass.

The distribution as given in Figure 4 has a half peak divergence of 38.5 minutes of arc. Measurements on a wide range of samples have shown that for such bell-shaped distributions the half peak divergence may vary from about 28 minutes of arc for very narrow beams up to about 13 degrees for very wide beams.

The important items to be considered in the photometry of retroreflectors are (see also Figure 6) :

(i) The angular aperture δ of the source of illumination, as seen from the reference centre of the retroreflector.

(ii) The angular aperture γ of the photometer head, as seen from the reference centre of the retroreflector.

(iii) The angular opening η of the retroreflector, as seen from the centre of the source (or from the centre of the photometer head).

(iv) The adjustment of the observation angle α and the required precision of the entrance and rotation angles.

(v) The measuring distance.

(vi) The illuminance at the retroreflector.

8

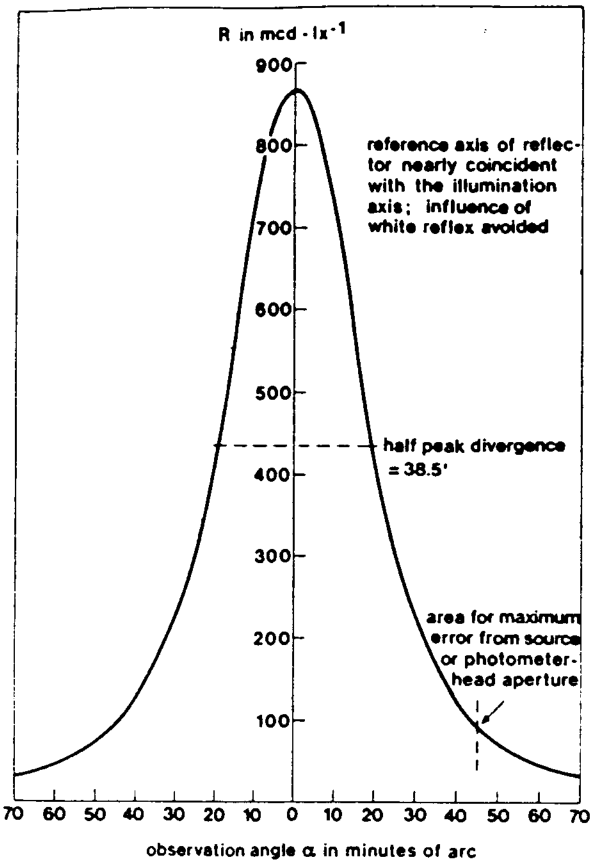


Figure 4. — Intensity distribution in a retroreflected beam from a corner-cube reflector of good quality, red in colour.

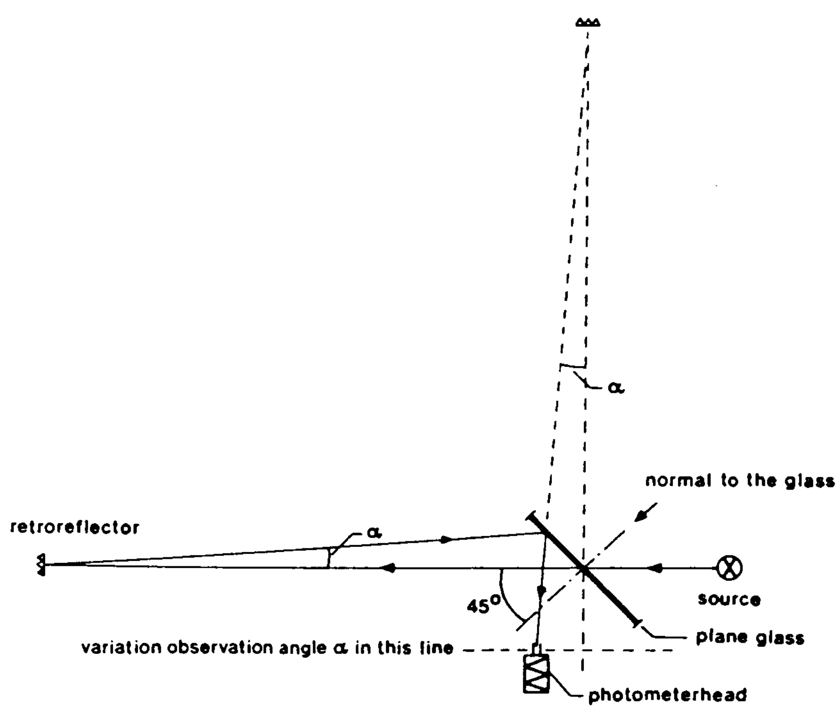


Figure 5. — Particular equipment used for the measurement of the intensity distribution in a retro-reflected beam, including the reflected intensities in the area around $\alpha = 0$.

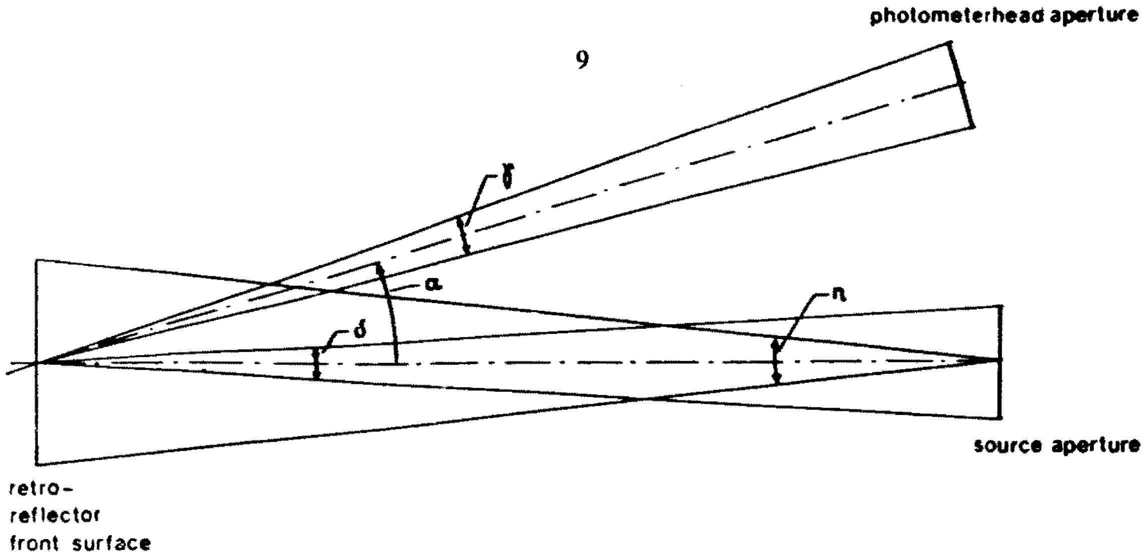


Figure 6. — Apertures and angles involved with retroreflection measurements.

(vii) The specification of the source.

(viii) The adaptation of the photometer head to the CIE Standard Photometric Observer.

(ix) The influence of a regular reflection, the colorless reflection from the front face of the reflector.

(x) The effect of residual reflections and stray light (see 4.2.1.).

With regard to the items (i), (ii), (iii) and (iv) calculations of the measuring error were made for strip-shaped source, photometer head and retroreflector configurations, with all strips in the same plane; this configuration was considered to be the most critical and, moreover, it is easy to apply a mathematical treatment to it (Moerman, 1977).

3.1. THE ANGULAR APERTURE δ OF THE SOURCE

For a limited size η of the retroreflector (see Figure 6 and section 3.3.) the relative error caused by the dimension δ of the source in the measurement of the reflected intensity can, in the general case (see Introduction), be calculated from the expression :

$$\text{Relative error} = \frac{f''(\alpha)}{f(\alpha)} \cdot \frac{\delta^2}{24}$$

where $f''(\alpha)$ represents the second derivative of $f(\alpha)$ with regard to α and α and δ are expressed in the same units.

The expression shows that large errors are to be expected at a large value of δ, especially when at the same time the ratio $f''(\alpha)/f(\alpha)$ reaches a large value. Particular attention should therefore be paid to the critical area in the distribution concerned (see Figure 4).

For bell-shaped distributions the error has a negative value for $\alpha = 0$, this indicates that the measured reflected intensity is too low. For narrower beams and larger values of δ the absolute value of this error increases rather quickly.

As the observation angle α is increased, the absolute error gradually decreases until zero is reached, while for still greater observation angles the error becomes positive and the measured reflected intensity is too high.

The area where the maximum positive error occurs is usually found near the bottom of the distribution. Experiments have shown that in many cases these positive errors are never greater than 3.5. times the absolute error at the observation angle $\alpha = 0$.

Note. See also the Notes 1 and 2 Section 3.2.

3.2. THE ANGULAR APERTURE γ OF THE PHOTOMETER HEAD.

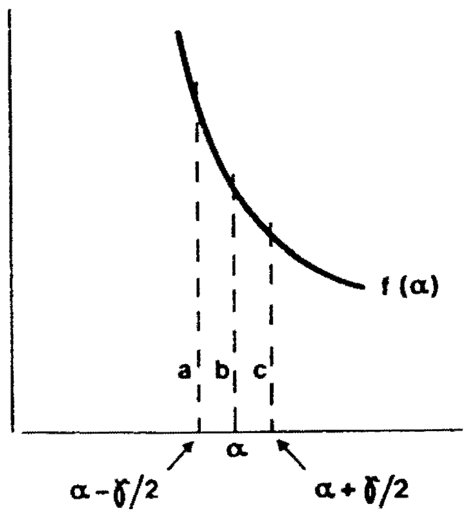
When the source dimension δ is sufficiently small but the dimension γ of the photometer head cannot be neglected, an extra error appears, which can be written for the general case (see Introduction) :

$$\text{Relative error} = \frac{f''(\alpha)}{f(\alpha)} \cdot \frac{\gamma^2}{24}$$

This expression has the same form as the relationship given in section 3.1. with δ replaced by γ; it therefore leads to similar conclusions.

Note 1 : The total relative error caused by the apertures of the source and the photometer head together is the sum of the relative errors calculated separately.

Note 2 : The error caused by the dimension of the photometer head can also be derived graphically from the distribution of reflected intensity, plotted on linear scales, by applying Simpson's rule to the curve over the angle-area bounded by the aperture of the photometer head (see Figure 7). Because the error caused by the source dimension is determined by an expression completely similar to that determining the error caused by the aperture of the photometer head, the same graphical method can be applied to estimate the influence of the aperture of the source on the measuring accuracy.



Simpson's rule says:

average height = $\frac{1}{6}(a + 4b + c)$

difference between average height and centre height is

$\frac{1}{6}(a - 2b + c)$

relative difference is therefore

$\frac{1}{6}\left(\frac{a+c}{b} - 2\right)$

Figure 7. — Graphical estimation of the error from the distribution curve $f(\alpha)$.

Note 3 : The validity of the theoretical analysis of the influence of aperture sizes was confirmed by experiment, combined with a computer integration technique, on four practical types of retroreflective material (Johnson and Stephenson, 1980).

Note 4 : For bell-shaped distributions the measuring errors as caused by the dimensions of the source and the photometer head can be derived from Table 3.1. which is reproduced from Moerman (1977). Table 3.2. gives further guidance on the aperture size to use for various categories of retroreflectors.

11

3.3. THE ANGULAR OPENING η OF THE RETROREFLECTOR

When, as for the example given in Figure 8, the influence of the entrance angle β on the intensity reflected in the direction of the photometer head can be described by an expression :

$$i_\beta = C' \, f(\beta)$$

where i_β is the intensity reflected in the position β. C' is a parameter, which is constant in the entrance plane considered. f (β) is an analytical function of β, appropriate to the characteristic concerned,

the error in the measurement of a retroflector, observed under an opening η, can be estimated from the value :

$$\text{Relative error} = \frac{f''(\beta) - 8 \tan\beta \, f'(\beta)}{f(\beta)} \cdot \frac{\eta^2}{24}$$

where f' (β) and f" (β) represent the first and the second derivatives of f (β) with respect to β and β and η are expressed in radians.

The expression makes it plausible that large errors are to be expected if a large value of η combines with a large value of the ratio f" (β)/f (β).

Most attention should therefore be paid to the critical area of the characteristic concerned (see Figure 8).

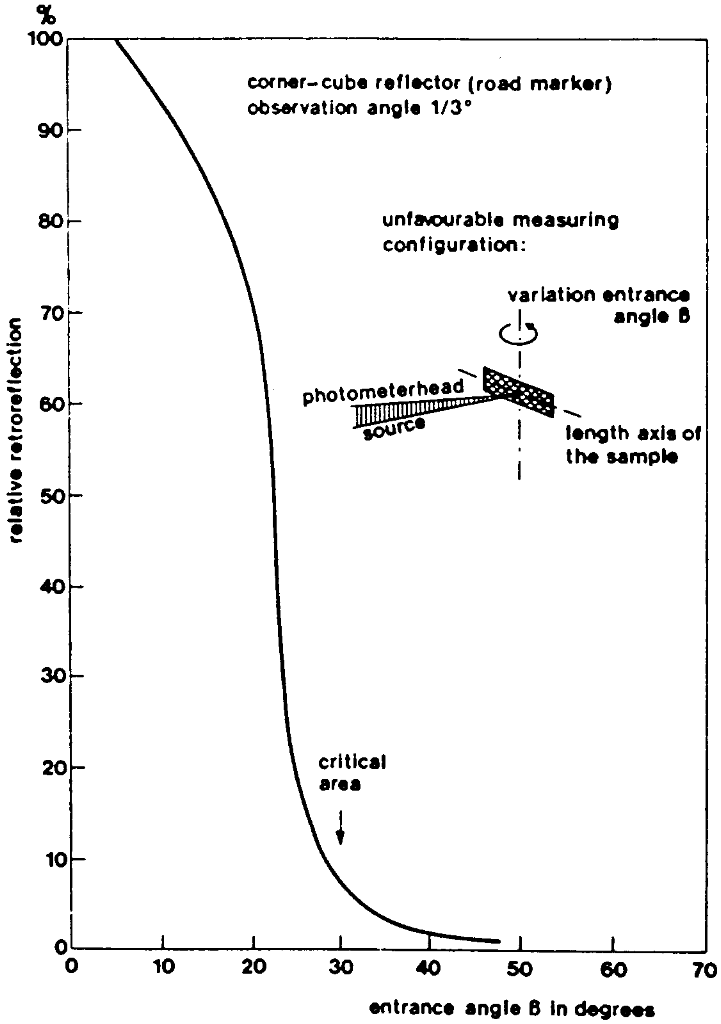


Figure 8. — Influence of the entrance angle β on the intensity reflected in the direction of the photometer head.

The effect is of special importance for the examination of large-size corner-cube retroreflectors, which may give rise to a relative error of 0.5 % when the retroreflector opening η corresponds to 80 minutes of arc and the entrance angle β chosen is about 30 degrees.

3.4. THE ADJUSTMENT OF THE OBSERVATION ANGLE α AND THE REQUIRED PRECISION OF THE ENTRANCE AND ROTATION ANGLES

Maladjustment of the observation angle α can lead to relatively large errors in the measured intensity; in the general case (see Introduction) where the intensity distribution in a certain plane throught the illumination axis follows the expression :

$$i_\alpha = C\ f(\alpha)$$

the relative error will be :

$$\text{Relative error} = \frac{f'(\alpha)}{f(\alpha)} \cdot \Delta\alpha$$

where $f'(\alpha)$ represents the first derivative of $f(\alpha)$ with respect to α and $\Delta\alpha$ is the error in the observation angle.

The expression shows that large values of $f'(\alpha)/f(\alpha)$, which appear in narrow beams for relatively large values of α, will increase the error caused by an inaccurate setting of the observation angle. With respect to the example of Figure 4, the error concerned with $\alpha = 20'$ and $\Delta\alpha = 1'$ will be 0.075 (7.5 %).

For a very narrow reflected beam, observed at not too small an observation angle, the adjustment of the observation angle should therefore be accurate within a fraction of a minute of arc.

It is evident that the position of both the centre of the aperture of the source and that of the photometer head should be clearly defined and recognized.

A similar discussion applies to errors associated with the rate of change of the angles β_1, β_2 and ϵ. Experience has shown that reflectors of cube-corner construction are most sensitive to errors in these angular settings. If one wishes to make accurate measurements on such a retroreflector in the areas where the coefficient of luminous intensity is heavily dependant on the setting of the angle concerned, an excellent quality goniometer with angle scales which can be read correctly to about $\pm$ 0.10° (or better) must be used. The accuracy in setting the angles β_1, β_2 or ϵ for a retroreflective sheeting is not so critical; for such a material an error of $\pm$ 0.2° in these angles can usually be tolerated.

3.5. THE MEASURING DISTANCE

The measuring distance must be chosen with particular regard to :

(i) the required accuracy

(ii) the practical dimensions of the source and the photometer head

(iii) the shape of the distribution in the reflected beam.

For a reasonably accurate measurement, with bell-shaped distributions, the total error at the observation angle $\alpha = 0$, caused by the apertures of the source and the photometer head together, should preferably not exceed 1 %; if this condition is fulfilled the errors appearing at much greater observation angles will usually not be greater than 3.5 %.

The narrower the beams the smaller will be the angular apertures required. Small angular apertures can be obtained by using a source and photometer head of small practical dimensions or by using a sufficiently long measuring distance.

For bell-shaped distributions the measuring errors, caused by the dimensions of the source and the photometer head, can be derived from Table 3.1.

Example

If both the source and the photometer head have a practical diameter of say 15 mm and the measuring distance in a conventional arrangement is chosen to be 10 m, the angular apertures of source and photometer head will be about 5.1 minutes of arc; for beams with a half peak divergence (h.p.d) not smaller than 40 minutes of arc the measuring error will then normally always be below 2.6 %.

For extremely narrow bell-shaped beams with an h.p.d down to 28 minutes of arc, the configuration just described may, especially with regard to larger observation angles, lead to greater errors of up to about 5.1 %. If such an error cannot be accepted and the source dimension has to be maintained, the diameter of the photometer head must be reduced to 7.5 mm, corresponding to an aperture of about 2.6 minutes of arc. This aperture combined with the source aperture of 5.1 minutes of arc will again guarantee a sufficiently accurate measurement, with errors not exceeding 3.2 % even for extremely narrow beams.

When the effective diameter of the photometer head is changed, the correction of the photometer head to the CIE Standard Observer must still be maintained (see 3.8).

Additional Comments

It is to be expected that when a longer measuring distance is used the adjustment of the observation angle can be carried out with a higher accuracy. For a 10 m measuring distance 1 minute of arc corresponds to 2.9 mm; at this distance the position of the centre of the aperture of the source and that of the photometer head should be known to within a fraction of a millimeter, in particular when very narrow beams have to be examined.

On the other hand it should be noted that a long test distance will significantly reduce the illuminance at the photometer head, which may result in supplementary errors from zero level instability and other random variations. The test distance should therefore be chosen as a compromise by which the observation angle can be set to an acceptable accuracy and the sensitivity of the photometer head is adequate to ensure that the signal is large enough to swamp any uncertainty in the zero or other instabilities.

The test distance should be measured accurately. Depending on the method of calibration (see sections 4.1.2. and 4.1.3.) a 1 % error in the measurement of the test distance may cause an error of 2 % or more in the photometric result.

The lateral displacement of the reflected beam, particularly from corner cube devices having individual retroreflective elements of large size requires special treatment and a large test distance is then needed for accurate measurement. Such devices are not considered further in this report.

3.6. THE ILLUMINANCE AT THE RETROREFLECTOR

The illuminance over the useful area of the retroreflector, measured perpendicular to the incident light shall be sufficiently uniform.

A check of this requirement needs a measuring element, the sensitive area of which is not greater than one tenth of the area to be examined. The variation in the value of the illuminance shall then comply with the condition :

$$\frac{\text{max. value}}{\text{min. value}} < 1.05$$

3.7. THE SPECIFICATION OF THE SOURCE

The source used for illuminating the retroreflector shall as faithfully as possible represent the CIE Standard Illuminant A in its spectral power distribution.

Experience has shown that a deviation of $\pm$ 50 K from the required distribution temperature may give rise to less accurate results when measuring coloured retroreflectors.

If for any reason a different light source is used this must be in accordance with the relevant specification.

3.8. THE PHOTOMETER HEAD

The photometer head shall be corrected to the CIE Standard Photometric Observer function, V (λ).

The device shall not show a perceptible change in local sensitivity within the area of its aperture; otherwise suitable provisions must be added, such as a diffusing window at a certain distance in front of the sensitive surface.

Experience has shown that non-linearity of photometer heads may be a problem with the very small light quantities which are the rule in the photometry of retroreflectors. A linearity check at comparable illuminance levels is recommended.

3.9. THE INFLUENCE OF A REGULAR REFLECTION

The amount and distribution of the regular reflection from the surface of the retroreflector depends on the flatness and the gloss of the surface. A regular reflection can seriously distort the measurement of retroreflection. In general, regular reflection is best avoided by placing the reference axis so that the regular reflection is directed on the opposite side of the source from the photometer head, for example with $\beta_1 = -5°$.

Table 3.1. — *Estimated relative error (in %) for an observation angle $\alpha = 0°$, for various values of the half peak divergence and of the source (δ) or photometer head (γ) apertures, for bell-shaped distributions (all data have been rounded off).*

Half peak divergence (minutes of arc)	Source (δ) or photometer head (γ) aperture (minutes of arc)							
	10	8	6	5.1	5	4	3	2.6
81	0.35	0.22	0.13	0.09	0.09	0.06	0.03	0.02
57	0.70	0.45	0.25	0.18	0.18	0.11	0.06	0.05
40	1.4	0.90	0.50	0.37	0.35	0.23	0.13	0.10
28	2.8	1.8	1.0	0.73	0.70	0.45	0.25	0.19

Note 1 : The total relative error caused by the apertures of the source and the photometer head together is found by summation of the relative errors determined separately for the dimensions concerned.

Note 2 : The maximum relative error which usually occurs in the measurement at a large observation angle will normally not be greater than 3.5 times the relative error at the observation angle $\alpha = 0$. If δ is chosen equal to γ, $\delta = \gamma = 0.15 \times$ h.p.d. (for maximum error $\leqslant 3.5$ %).

Table 3.2. — *Recommended aperture size for various categories of retroreflectors.*

Category	Beam Shape	Maximum Aperture Size (minutes of arc)	
		Source (δ)	Photometer Head (γ)
Corner-cube prisms	very narrow beam	4	4
Corner-cube prisms	narrow beam	6	6
Spherical lens retroreflective sheeting	narrow beam	6	6
Exposed lens systems on paint e.g. road marking material	wider beam	10	10

4. PHOTOMETRIC CALIBRATION TECHNIQUES AND MEASUREMENT PRECAUTIONS IN THE PHOTOMETRY OF RETROREFLECTION

4.1. CALIBRATION TECHNIQUES

4.1.1. General (Stephenson, 1978; Johnson, 1979)

The photometric properties of a retroreflector depend, apart from the measurement geometry, on its spectral reflection characteristic and on the spectral power distribution of the light source.

Because all current test specifications refer to measurement using CIE Standard Illuminant A with the photometer head corrected to the CIE Standard Photometric Observer V (λ) function, most laboratories use simplified measuring equipment to avoid spectral analysis and computation (see 4.1.5.). The calibration techniques applicable to such simplified equipment are given below.

The photometric calibration consists essentially of determining, for one geometric arrangement, the luminous intensity of the retroreflector in the direction of observation and also the illuminance falling on the retroreflector in a plane perpendicular to the direction of the incident light. The quotient of these two quantities gives, for this geometric arrangement, the value of the Coefficient of Luminous Intensity (R) of the retroreflector in the unit of candela per lux (cd lx^{-1}), from which a scale factor may be derived for the instrument reading.

This scale factor is used to convert readings made at other measurement geometries directly into R values, provided the photometer response is linear and that throughout the test both the illuminance at the retroreflector and the responsivity of the photometer remain unchanged.

It is also necessary for the apparatus to be so designed that the illuminance over the sample area and the responsivity across the area of the photometer head are sufficiently uniform. In addition, the centroids of the light source aperture and of the photometer head must be well defined and symmetric. For the light source, this requirement infers that at its exit aperture light is emitted symmetrically with respect to the axis of illumination and, hence, also about the centroid. The distribution temperature of the light source must also be known (see section 3.7.).

For measurements on coloured retroreflectors it is strongly recommended that special attention should be given to obtaining the best possible correction to the CIE Standard Photometric Observer V (λ) function. With many commercially available photometer heads the correction is not adequate for measuring retroreflectors and measurement uncertainties occur.

An earlier commonly used technique was to calibrate with colour filters of known transmission, similar in colour to the retroreflector under test. Experience has shown that because the choice is limited of available colour filters having suitable spectral transmission curve shapes close to the spectral reflectance characteristics of many retroreflectors, the method may frequently fail to compensate sufficiently for an inadequate correction of the photometer head to the V (λ) function.

For the measurement of the photometric performance of, for example, retroreflective road markings a different measuring technique may be used involving luminance measurements (Morren, 1980 and 1982). This matter is currently being studied by CIE Technical Committee TC-1.6 in a subcommittee on Road Markings.

4.1.2. Conventional Calibration Techniques

The calibration procedure generally follows one of of two methods, either the relative method or a direct method.

The relative method has the advantage that it avoids the use of calibrated reference lamps and illuminance meters. It uses the same photometer head for determining both the illuminance at the retroreflector and also its luminous intensity, so that the photometer head does not need to be calibrated. The photometer head is moved to the position of the retroreflector and the illuminance falling on it is measured, giving an arbitrary scale reading M_1. Then with the photometer head placed at the correct distance and observation angle, the illuminance falling on it from the retroreflector is measured in the same scale units, giving a reading M_2. The value of the Coefficient of Luminous Intensity in candelas per lux is given by the formula

$$R = \frac{M_2 \times D^2}{M_1} \text{ cd.lx}^{-1}$$

where D is the distance in metres between the retroreflector and the photometer head.

The Scale Factor for use in subsequent measurements which, when multiplied by any photometer head reading M, will convert M to an R value in candelas per lux is :

Scale Factor = D^2/M_1 cd lx^{-1} per unit of photometer head reading.

This method is self calibrating and its use restricts photometric calibration errors to the linearity of the photometer head and, for measurements on coloured retroreflectors, to the quality of the correction of the photometer head to the CIE Standard Photometric Observer (see section 4.1.1.).

In the method, the range of illuminances to be measured is large, so that the linearity must be checked over the full range used and where necessary, appropriate corrections made to the measured values. The linearity checking method given in CIE Publication No. 25, 1970 (Procedures for the Measurement of Luminous Flux of Discharge Lamps and for their Calibration as Working Standards) is recommended.

In the direct method, the illuminance at the retroreflector in lux is measured by a separate illuminance meter, the calibration of which must be known. The luminous intensity of the retroreflector is determined by placing a suitable calibrated reference lamp of known luminous intensity at the retroreflector to calibrate the scale of the photometer head. When measuring coloured retroreflectors, unless a well corrected photometer head is used, a colour filter of known transmission and having a similar spectral characteristic to the retroreflector may be placed in the front of the reference lamp to compensate for errors in the correction of the photometer head to the CIE Standard Photometric Observer (see section 4.1.1.). The overall accuracy of the method is limited by the combined errors in the calibration of both the illuminance meter and the reference lamp. Such errors can be minimised by using the reference lamp itself to calibrate the illuminance meter.

4.1.3. Calibration Method using an Auxiliary Lamp and Photometer Head

In some laboratories a calibration technique is used which employs an auxiliary lamp of unknown but stable luminous intensity and an auxiliary photometer head, which is uncalibrated but is known to have a linear response.

The auxiliary lamp is used at convenient distances from the photometer head in the apparatus and from the auxiliary photometer head, to determine both their responses per unit of illuminance in arbitrary units. The illuminance falling on the test sample from the light source in the apparatus is measured in the same arbitrary units using the auxiliary photometer head. The illuminance, falling on the photometer head in the apparatus from the test sample, is recorded, again in arbitrary units. From the four readings and the known distances, the R value for the test sample can be derived; see Appendix C.

It is also possible to arrange in the calibration that by altering the responsivity of the photometer head in the apparatus, its reading will indicate the R value of test sample either directly or in convenient powers of 10 (Artom, 1981).

It should be noted that any errors present in each of the four stages of the calibration may be additive and hence may limit the overall accuracy obtainable using this method.

4.1.4. Substitution Method

An alternative calibration method is sometimes used where a previously calibrated retroreflecting device is available as a reference standard. This is interchanged with the test sample under test so that the calibration is made by a direct substitution. The ratio of the reading on the sample to that on the reference standard when multiplied by the known photometric value assigned to the reference standard, gives the R value for the test sample.

This technique is used especially with certain short range reflex photometer designs, such as those using a collimating lens or fibre optics. It is recommended that where the photometric calibration facilities in a laboratory are inadequate for applying the methods described in Sections 4.1.2. and 4.1.3., substitutional calibration should be made with reference standards previously calibrated by a reputable laboratory.

4.1.4.1. Calibrated Reference Standards

Reference standards should be stable and have been calibrated at one or more measuring geometries by a conventional technique (see section 4.1.2.) or, with some allowance for the overall accuracy, by the method using an auxiliary lamp (see section 4.1.3.). The calibration of the reference standard must be checked periodically.

The type of retroreflector chosen as a reference standard should be one having a smooth retroreflected light distribution, so that its mounting position and orientation are not critical. For this reason corner-cube constructions are not recommended.

A diffusely reflecting reference surface, such as one of barium sulphate or magnesium oxide, should not be used because such surfaces are themselves retroreflective at small observation angles and their reflectance is then heavily dependent on the observation angle (Meacock *et al.*, 1962).

Devices using a good quality retroreflective sheet material are much better suited as reference standards, assuming however that these materials are sufficiently stable with time, are handled and stored with care and are calibrated and used at a fixed entrance angle, which avoids regular reflections in the direction of observation. In the case of the photometer in an equipment not being completely corrected to the CIE Standard Photometric Observer function, the use of a sheet material similar in colour to the retroreflector under test is recommended.

Concave or convex mirrors (Chandler and Reid, 1961) are not recommended for calibration purposes, because small imperfections in such mirrors may cause large local variations in the R value.

4.1.5. The Spectroradiometric Method of Measuring the Coefficient of Luminous Intensity (Blaise, 1980; Rennilson, 1980).

The procedure uses a monochromator of good quality to measure the spectral coefficient of luminous intensity $R(\lambda)$ for wavelengths throughout the visible spectrum.

This is effected, for the selected measurement geometry, by substituting the monochromator for the photometer head and analysing the spectral distribution of the light received at the sample and that in the retroreflected beam. Wavelength intervals of 10 nanometers are suggested.

The coefficient of luminous intensity R, referring to a particular arbitrary light source (usually CIE Standard Illuminant A), is calculated using the measured R (λ) values, the relative spectral power distribution of the light source $S(\lambda)$ and the CIE Standard Photometric Observer function $V(\lambda)$, as follows :

$$R = \frac{\sum_{380}^{780} R(\lambda)\, S(\lambda)\, V(\lambda)}{\sum_{380}^{780} S(\lambda)\, V(\lambda)}$$

When determining $R(\lambda)$ experimentally neither the spectral distribution of the light source nor the spectral sensitivity of the photometer in the monochromator is critical. However, they must be sufficiently stable throughout the two measurements required to calculate $R(\lambda)$.

A high luminance source such as a short-arc Xenon lamp may be an advantage to ensure an adequate signal level. This will provide more flux at the shorter wavelengths than that given by a filament lamp.

The procedure has the advantage of not requiring a specified illuminant and not needing a $V(\lambda)$ corrected photometer head. It has the disadvantage of being a much more lengthy procedure than that using conventional equipment. However, with the recent introduction of the microprocessor controlled spectroradiometer, the time required for measurement and for the calculation is significantly reduced. It is expected that in the future the use of such devices will become more widespread.

In addition, it should be noted that an extension of the calculation will also provide the chromaticity coordinates; see section 5.

4.1.6. Calibration for the Measurement of Coefficient of Retroreflection

A reflex photometer measures the Coefficient of Luminous Intensity of the test sample. To derive the Coefficient of Retroreflection for material in the sheet form it is necessary to measure a known area of the sample and calculate the R value per unit area. If a substitution method of calibration is used (see section 4.1.4.) employing a reference standard where its Coefficient of Retroreflection is known, it is convenient to measure an area of the test sample equal to that of the reference standard. No correction for area is then needed.

4.2. GENERAL MEASUREMENT PRECAUTIONS

4.2.1. Residual and Stray Light

Since very low light levels are to be measured special precautions are needed to minimise errors due to stray light. The background to the sample and the framework of the sample holder should be matt black and the field of view of the photometer head and the spread of light from both the sample and the source should each be restricted as much as possible.

Reflections from the floor and walls which occur over the relatively long test distances used must be screened from both the sample and the photometer head by baffles. The importance of looking from the photometer head to check for sources of stray light cannot be over emphasised.

A valuable aid to reducing the amount of stray light in the laboratory is to use a slide projector type of optical system for the light source. With this, an iris diaphragm or suitable sized apertures may be used in the optical system to restrict the illuminated area at the sample to the minimum size needed to provide uniform illuminance over the sample.

Residual stray light should always be allowed for by measuring it when the sample is covered by an opaque matt black surface, zig-zag folded black paper of the same size and shape or a specular black surface suitably oriented with a light trap. This value should be subtracted from that measured on the retroreflector.

4.2.2. Stability of the Apparatus

The light source and photometer head should remain stable throughout the period of the test. Since the responsivity and the correction to the V(λ) function of most photometer heads change with temperature, the laboratory ambient temperature should not vary significantly during this period. Sufficient time should always be allowed for the apparatus to stabilise before commencing measurements.

The power supply to the light source should be adequately stabilised so that the luminous intensity of the lamp can be maintained throughout the test to within the required accuracy for the work.

A useful check on the overall stability of the reflex photometer during a series of tests is to make periodic measurements of the R value of a stable reference standard selected in line with the criteria given in Section 4.1.4.1.

Another technique is to incorporate in the apparatus an auxiliary detector to check or monitor the output of the light source. Although the output from the auxiliary detector can be checked for any change in reading, a useful refinement is to use the output to alter electronically the responsivity of the main reflex photometer head and compensate automatically for changes in the light output of the source.

4.2.3. Check on Goniometer Angle Scales

The index marks on both the goniometer angle scales of the sample holder need to be checked to ensure that with zero angle settings on both scales the axis representing the reference axis coincides with the direction of the incident light. This is effected by placing a good quality plane mirror on the sample holder, perpendicular to and symmetric with the axis representing the reference axis, and tilting the goniometer so that the reflected image of the light source is central on the source aperture. The index marks should now be adjusted to read zero degrees. Additional checks may be required depending on the system used for angle measurement.

4.2.4. Check on the Observation Angle Scale

An initial check must be made to determine the centroid of the light pattern emitted at the exit aperture of the light source and, for the photometer head aperture, the centroid of responsivity to light received from the retroreflector under test, see Section 4.1.1. For work of high accuracy it will be necessary to find these centroids by experiment using small diameter probes e.g. a fibre optic.

The observation angle setting scale must now be checked using these centroids either by a direct measurement of the distance between them or by optical means e.g. a theodolite or similar optical sighting device looking from the centre of the sample holder. It is essential that the scale is so checked that the observation angle can be set to within a fraction of a minute of arc.

5. COLORIMETRY OF RETROREFLECTORS

5.1. GENERAL

Colorimetry of retroreflective materials requires special measurement conditions, because these materials exhibit different spectral distributions of reflected light when illuminated by day and by night. The purpose of this section is to summarize the techniques of measurement for both daytime and nighttime colorimetry. The section states the precision of measurement and the criteria required for instrumentation to determine the colour of retroflective material. In addition, recommended measurement geometry is given for colorimetric specification. It is necessary that the colours of retroreflective material be measured under geometric and spectral conditions that simulate those of actual use.

The practical daytime use of retroreflective material uses an illumination that is a combination of diffuse light from the sky and direct light from the sun. These illuminating conditions vary throughout the day and from day to day. Light from a retroreflective device thus reaches an observer by a combination of diffuse reflection and retroreflected light incident from areas behind the observer. The correlated colour temperature of the incident daylight varies from 5,000 K to 15,000 K depending upon whether the light is omnidirectional, such as an overcast sky, or unidirectional from the sun. Most of the skylight incident on a retroreflective material never reaches the observer, a part is retroreflected, a part specularly reflected and the remainder diffusely reflected. Sunlight is specularly and diffusely reflected by the surface of the retroflective material away from the observer and it is only when the sun is directly behind the observer and low in the sky, that the retroreflective component dominates in the daytime.

At night the light from a source near the observer, a vehicle headlamp usually, illuminates the retroreflective material with a distribution temperature approaching that of CIE Standard Illuminant A (see section 3.7.). The entrance and observation angles change as the observer approaches the retroreflective material.

5.2. MEASUREMENT TECHNIQUES

The basic instrumentation for both daytime and nighttime measurement of chromaticity may follow either a spectral or a tristimulus method. However, a spectral technique is generally to be preferred, since the measurement yields ratios of spectral quantities from which the chromaticity may be computed using a source spectral power distribution and tristimulus data from CIE Publication No. 15, 1971, Colorimetry.

Colorimeters and telecolorimeters require that their filter-detector combinations are closely matched to the CIE colour matching functions, and care should be exercised in choosing instruments to ensure their performance meets the required accuracy. In addition, for daytime colorimetry it is customary to specify the chromaticities on the basis of the spectral power distribution of CIE Standard Illuminant D 65. Some instruments provide a practical source approximating D 65 in the visible region, using filtered Tungsten Halogen lamps and some use a filtered Xenon lamp which also simulates the UV region of D 65, which is more applicable to retroreflective materials which exhibit fluorescence.

5.2.1 Daytime colour measurement (Asher *et al.*, 1978)

In daytime the greatest use of retroreflective materials is for traffic signs. Since these are mounted vertically the illumination on them is incident from only half of the sky and they are usually seen by an observer in directions near to the normal to the sign. The geometry is therefore neither d/O nor 45/0, the optimum lying somewhere between the two. However, tests with different instruments have shown that those with 45/0 geometry are in better agreement for measuring retroreflectors, because the results of colour measurements with sphere instruments (d/O or O/d geometry) depend strongly on the sizes of apertures and gloss traps. Accordingly, a 45/0 geometry is recommended (as in CIE Publicaiton No. 39, 1978, Surface Colours for Visual Signalling) to exclude both the specular component of reflectance and retroreflected radiation. Some modern spectrophotometers have illuminating and viewing geometries of 45/0 and these conditions correspond with those commonly used in colorimeters. It is important that the apertures of the illuminating and viewing beams be limited to not greater than ± 4°, because the instrument geometry is critical.

Calibration of the instrument can normally be made using a barium sulphate plaque. However, with tristimulus instruments where the filters do not provide a sufficiently close match to the CIE colour matching functions, it is necessary to calibrate the instrument using reference standards having spectral and geometrical characteristics closely similar to that of the samples being tested. In addition, when the source is not a satisfactory approximation to CIE Standard Illuminant D 65, reference standards are necessary. These reference standards need to be calibrated for CIE Standard Illuminant D 65.

There is evidence that some retroreflective materials exhibit a small amount of fluorescence. Where this is present the sample should be illuminated with polychromatic D 65 radiation for measurement.

The measurement of the daytime colour of road marking materials presents special problems and is excluded from this report.

5.2.2. Nighttime colour measurement (Blaise, 1980; Rennilson, 1980; Stephenson, 1976).

Chromaticity measurements are made under illuminating and viewing conditions which simulate those occurring at night. The measurement geometry is similar to that utilized in the photometric measurement of the Coefficient of Luminous Intensity. The illuminating source together with the test method is similar to that described earlier and should be followed in the measurement of the colour.

Studies have been made on the effect that the angular subtense of the photometer head has on the accuracy of the chromaticity measurements. The chromaticity change is small for small entrance angles and close observation angles. The change of chromaticity with geometry under nighttime conditions thus indicates that angular subtenses as large as about ten minutes of arc may be satisfactorily used without influencing the colour measurement.

5.2.2.1. Spectroradiometers

The colorimetry of retroreflective material using a spectroradiometer may follow one of two methods. In each of these methods, the spectroradiometer is usually equipped with collection optics such that the field of view is limited to a size slightly in excess of the retroreflector.

The use of these methods does not require that the source be at the designated distribution temperature or that the intensity scale of the spectroradiometer be absolutely calibrated. However, the spectroradiometer must be linear, and its wavelength scale must be calibrated.

In the first method, the spectroradiometer is placed at the position of the sample and measures the relative spectral power distribution of the source. This is followed by a measurement of the retroreflection at a position close to that of the source.

The second technique uses the radiation of the source reflected from a barium sulphate plaque. This method has the advantage that the detector signal from the source and the signal from the retroreflector can be adjusted to be approximately the same magnitude by properly choosing the distance between the source and the barium sulphate plaque. However, in both methods, the responsivity and angular acceptance of the spectroradiometer must be held constant during the series of measurements of the retroreflection and the source.

The chromaticity coordinates x and y are obtained from the tristimulus values X, Y, and Z for the particular geometry (α, β_1, β_2 and ϵ) which are calculated using the following equations :

$$X = \text{Constant} \cdot \sum_{380}^{780} [m_2(\lambda)/m_1(\lambda)] \cdot S(\lambda)\, [\beta\,(BaSO_4)\,(\lambda)]\, \bar{x}(\lambda)\, \Delta\lambda$$

$$Y = \text{Constant} \cdot \sum_{380}^{780} [m_2(\lambda)/m_1(\lambda) \cdot S(\lambda)\, [\beta(BaSO_4)\,(\lambda)]\, \bar{y}(\lambda)\, \Delta\lambda$$

$$Z = \text{Constant} \cdot \sum_{380}^{780} [m_2(\lambda)/m_1(\lambda)] \cdot S(\lambda)[\beta(BaSO_4)\,(\lambda)]\, \bar{z}(\lambda)\Delta\lambda$$

where $m_2(\lambda)$ is the spectroradiometric reading of the sample and $m_1(\lambda)$ equals the spectroradiometric reading of the incident radiation either directly or reflected from a barium sulphate plaque. $S(\lambda)$ is the spectral power distribution of the prescribed illuminant, usually CIE Standard Illuminant A. For the first method the term $[\beta(BaSO_4)\,(\lambda)]$ is equal to unity because the barium sulphate plaque is not used.

For the second method, because the reflectance of barium sulphate is not constant but varies slightly with wavelength, the radiance factor [$\beta(BaSO_4)$ (λ)] for the particular barium sulphate used has to be included. The functions $\bar{x}$ (λ), $\bar{y}$ (λ) and $\bar{z}$ (λ) are the CIE colour matching functions and the constant in the equations is simply a proportionality factor and is eliminated by self-division when the chromaticity coordinates are computed; see CIE Publication No. 15, 1971, Colorimetry.

5.2.2.2. Telecolorimeters

The telecolorimeter is equipped with tristimulus filters. The trimming of the output of the photometer head in combination with each of the filters should be such that the tristimulus values have the proper relative values. A means of focusing the retroreflective material on a field stop is required and the stop should be of such a size that the field of view of the telecolorimeter is slightly in excess of the retroreflective sample. The source must be adjusted as close as possible to the prescribed illuminant, usually CIE Standard Illuminant A. The calibration of the telecolorimeter may be accomplished by focusing the telecolorimeter on a barium sulphate plaque, or on a reference colour standard, illuminated by the source and measuring the response of the respective tristimulus filters. The responsivity and angular acceptance of the telecolorimeter must not be altered during the measurement sequence.

5.3. MEASUREMENT PRECAUTIONS AND TOLERANCES

5.3.1. Spectrophotometers and spectroradiometers

Both these instruments are similar in that they possess dispersive elements to separate the radiation into its wavelength components. Abridged spectrophotometers consisting of narrow band interference filters also separate the radiant flux in a similar manner. The most serious errors in spectrophotometers or spectroradiometers arise from the deviations of linearity of the photometric scale and wavelength position. The upper end of the photometric scale for a spectrophotometer is normally set, for reflectance measurement, by the selection of an appropriate standard. The lower end point of the scale, for reflectance measurement, should be set not by blocking the light beam, but rather by the use of a highly efficient light trap at the sample. For nighttime colorimetry using a spectroradiometer, a black trap with the same size as the sample should be used in the sample position, to measure the stray light present when the retroreflective sample is removed from the photometer.

Secondary standards, such as filters with known transmittance or reflectance standards with known reflectance factors, are used widely to check the linearity of the photometric scale. Addition of flux techniques, such as light addition method may be used as well. Wavelength dependent errors must also be taken into account and the wavelength scale should be periodically checked using emission line sources so that position and the slit width errors, if significant, are recognized and corrected for. The illuminating source should contribute negligible amounts of polarization to the retroreflective sample, and the spectrophotometers and spectroradiometers should be as insensitive to polarized light as possible to minimize the effect of any polarized light coming from the retroreflective sample. The use of diffusers or integrating cavities is suggested. In general, retroreflective material does not depolarize light in a predictable manner.

The wavelength reproducibility of spectrophotometers and spectroradiometers for colorimetry of retroreflective material should be within accepted tolerance limits; see CIE Publication, Spectroradiometry of Light Sources (in preparation). The photometer head should be stable and linear. For a discussion of errors, see CIE Publication No. 53, 1982, Methods of Characterizing the Performance of Radiometers and Photometers.

For referee purposes it is recommended that the integration range be 380 to 780 nm at 10 nm intervals using a triangular bandpass of 10 nm. Other bandpasses and integration ranges may be used provided they agree sufficiently closely with the referee method to satisfy the users.

5.3.2. Tristimulus colorimeters and telecolorimeters

If the tristimulus filters are not of high quality, these instruments should be used with reference standards and correction factors should be computed for the master standards. In some instruments this is performed automatically. When making measurements for nighttime colour, it is recommended that correction factors for specific reference standards of the retroreflective material be computed and used when measuring samples of the same colour. The same care for stray light and polarization insensitivity is important in colorimeters and telecolorimeters.

The overall errors and calibration factors together with the repeatability of the system should be sufficient to allow measurements of the chromaticity coordinates to be within accepted tolerances.

5.3.3. Variation between different instruments

Variations between instruments of the same kind are usually smaller than between different kinds of instruments. The deviation between different kinds of instruments is usually larger than the stability and linearity error of one instrument.

In colorimeters another error occurs which is caused by the filtering in the instrument, but nevertheless a good colorimeter can give better results than a spectroradiometer with poor linearity and stability.

A deviation of $\pm$ 0.010 in both x and y can expected for measurements of retroreflective materials with different types of instruments. The measurement deviations will vary with the colour of the retroreflective material.

5.4. RECOMMENDED GEOMETRY FOR THE COLORIMETRY OF RETROREFLECTORS

5.4.1. Daytime

Daytime measurements of retroflectors should be made at a geometry of 45/0 (0/45). For additional information, see also CIE Publication No. 15, 1971, Colorimetry and CIE Publication No. 39, 1978, Surface Colours for Visual Signalling.

5.4.2. Nighttime

The colour of retroreflective material can change significantly with illuminating and viewing geometries. It is recommended that the same geometry should be used in the nighttime colour measurement of retroreflectors as in the measurement of the coefficient of luminous intensity, R, or the coefficient of retroflection, R′. That is, for most applications, an observation angle of 20′ and an entrance angle β_1 of $-$ 5°, with a maximum aperture for the source and photometer head of 10′. Also, for specific applications where the variation of chromaticity as a function of the geometry is important, additional angles, such as 2° for observation angle and 30° for entrance angle, may be used.

APPENDIX A

RELATIONSHIP BETWEEN THE NEW CIE ANGULAR REFERENCE SYSTEM FOR RETROREFLECTORS AND CURRENTLY USED OR PROPOSED SPECIFICATION SYSTEMS

In the interest of promoting international uniformity in measurement, the writers of several of the most widely used specifications and test methods for retroreflectors have expressed their intention to use the new CIE angular reference system in their documents. These documents are expected to be available before or soon after the publication of this report. Conversions to the new CIE system from two other systems currently used, which are not expected to be changed immediately, and from a system as proposed in 1975 (Blaise, 1975) under the name Intrinsic System, follow.

A.1. E.C.E. Reg. 3 dated 23rd September 1964 and Reg. 27 dated 7 June 1972

These documents refer to a CIE recommendation by Committee W-3.3.5. appearing in Proccedings of the 14th Session of the CIE (CIE Publication No. 7, 1959). In this recommendation, the entrance angle is defined by two spherical coordinates giving the position of the (moveable) reference axis, vertical (V) and horizontal (H), analogous to latitude and longitude in a system in which the equator (containing the fixed illumination axis) is horizontal and the observation plane vertical. However, for determining the signs of these coordinates, the ECE Reg. 3 refers to the position of the illumination axis with respect to the reference axis when looking at the reflector, so that the sign of V is always opposite to that of β_1 and the sign of H always opposite to that of β_2.

In order to secure, in every respect, the same orientation of the reflector with respect to the illumination and observation axes, the following equations apply :

CIE angle		ECE Regulations
α	=	α
β	=	β
$\tan \beta_1$	=	$-\dfrac{\tan V}{\cos H}$
$\sin \beta_2$	=	$-\cos V \sin H$

when $-90° < V < +90°$ and $-90° < H < +90°$

ϵ (according to Figure 2) $=$ $-\epsilon$ (according to ECE) $+$ a correction $\Delta\epsilon$

Note 1 : When looking at the retroreflectors, the positive direction of the rotation angle is clockwise according to ECE Regulation 3, but counter-clockwise according to Figure 2. For maintaining the orientation corresponding to the ECE Regulation when using a goniometer as illustrated in Figure 2, an additional rotation about the reference axis becomes necessary as soon as both coordinates differ from zero. The value $\Delta\epsilon$ of this additional rotation is given by

$$\tan \Delta\epsilon = \tan H \sin V = \tan \beta_1 \sin \beta_2$$

Note 2 : For the inverse transformation see Appendix B.

A.2. United States SAE Specification J594f

This system describes measurements on the basis of a goniometer with a horizontal and a vertical axis but since only one of the two axes is involved at any one time, the difference between the two systems is immaterial.

CIE angle		SAE J594f angle
α	=	Observation Angle
$\beta_1 > 0$	=	"down" entrance angle
$\beta_1 < 0$	=	"up" entrance angle
$\beta_2 > 0$	=	"right" entrance angle
$\beta_2 < 0$	=	"left" entrance angle
ϵ	=	Negative of SAE rotation angle

24

A.3. The intrinsic system as proposed to the 9th Conference of the International Association of Lighthouse Authorities (Blaise, 1975).

CIE angle		Angle(s) according to the Intrinsic System
α	=	α
β	=	β
$\tan\beta_1$	=	$\tan\beta\cos\delta$
$\sin\beta_2$	=	$\sin\beta\sin\delta$
$\cos\epsilon$	=	$\dfrac{\sin\gamma\cos\beta\sin\delta - \cos\gamma\cos\delta}{[\cos^2\delta + \sin^2\delta\cos^2\beta]^{1/2}}$
$\sin\epsilon$	=	$\dfrac{\cos\gamma\cos\beta\sin\delta + \sin\gamma\cos\delta}{[\cos^2\delta + \sin^2\delta\cos^2\beta]^{1/2}}$

where $\beta < 90°$.

For the inverse transformation the following expressions can be used.

$$\cos\beta = \cos\beta_1\cos\beta_2$$

$$\cos\gamma = \frac{\sin\epsilon\cos\beta_1\sin\beta_2 - \cos\epsilon\sin\beta_1}{[\sin^2\beta_2 + \cos^2\beta_2\sin^2\beta_1]^{1/2}}$$

$$\sin\gamma = \frac{\cos\epsilon\cos\beta_1\sin\beta_2 + \sin\epsilon\sin\beta_1}{[\sin^2\beta_2 + \cos^2\beta_1\sin^2\beta_1]^{1/2}}$$

$$\cos\delta = \frac{\sin\beta_1\cos\beta_2}{[\sin^2\beta_2 + \cos^2\beta_2\sin^2\beta_1]^{1/2}}$$

$$\sin\delta = \frac{\sin\beta_2}{[\sin^2\beta_2 + \cos^2\beta_2\sin^2\beta_1]^{1/2}}$$

except when both $\beta_1 = 0$ and $\beta_2 = 0$, then δ is undefined. If, in this case, γ is measured relative to the observation plane, then one convention is to let $\delta = 0$ and $\cos\gamma = -\cos\epsilon$; $\sin\gamma = \sin\epsilon$.

In the above expressions the angular parameters of the intrinsic system are :

- α – observation angle
- β – entrance angle
- γ – angle of orientation
- δ – angle of presentation

Note : The Harmonising Group document (unpublished) referred to in the Foreword uses the symbol γ for the angle of presentation and ω for the angle orientation.

25

APPENDIX B

ANGULAR TRANSFORMATION TO BE USED WITH THE ALTERNATIVE GONIOMETER AS RECOMMENDED BY THE CIE IN 1959 AND AS FURTHER DEFINED IN ECE REGULATION No. 3

The new CIE angular reference system for specifying and measuring retroreflectors was chosen to coincide with the type of goniometer arrangement shown in Figure 2, which is the most commonly used arrangement for measuring retroreflectors. A second type of goniometer is sometimes used in which the fixed axis lies in the observation plane. If it is not possible to alter the arrangement of such apparatus to conform with the new CIE angular reference system, or if it is not convenient to do so, the following transformation can be used to set the angles in such an apparatus to provide specified components of the entrance angle in the new CIE system. In the transformation, the angle H ($-90° < H < +90°$) represents rotation about an axis fixed in the observation half-plane and perpendicular to the illumination axis, and the angle V ($-90° < V < +90°$) represents rotation about an axis perpendicular to both the reference axis and the axis about which H is measured, then

$$\tan H = -\frac{\tan \beta_2}{\cos \beta_1}$$

$$\sin V = -\cos \beta_2 \cdot \sin \beta_1$$

When : $-90° < \beta_1 < +90°$ and $-90° < \beta_2 < +90°$

ϵ (according to ECE) = $-\epsilon$ (according to Figure 2) + a correction $\Delta\epsilon$

Note : This is the inverse transformation to that given in Appendix A, Section A.1. As soon as the coordinates β_1, β_2 and thus the corresponding ones V, H both differ from zero, an additional rotation $\Delta\epsilon$ must be made about the reference axis in order to re-establish the same position of the retroreflector referring to its orientation. The value of this additional rotation is given by

$$\tan \Delta\epsilon = \tan \beta_1 \sin \beta_2 = \tan H \sin V$$

26

APPENDIX C

CALIBRATION OF A REFLEX PHOTOMETER USING THE AUXILIARY LAMP AND AUXILIARY PHOTOMETER HEAD METHOD

The auxiliary lamp is used as a reference light source and is operated at a stable voltage such that its colour temperature is approximately that of CIE Standard Illuminant A. Its luminous intensity I does not need to be known. The lamp is usually mounted near to the sample holder of the reflex photometer.

The auxiliary photometer head, usually containing a photovoltaic detector, may be uncalibrated but the overall response must have been checked for linearity.

In the following the numerical values of the parameters are given with luminous intensities expressed in cd, illuminance in lx, dimensions in m and coefficient of luminous intensity in cd lx^{-1}. Preliminary measurements are made using the auxiliary lamp to determine the responses per unit of illuminance of the photometer head in the reflex photometer and of the auxiliary photometer head as follows :

(a) With the auxiliary lamp placed at a distance 'D' from the photometer head in the reflex photometer (see Figure C1), record the reading R_D in arbitrary scale units.

The illuminance at the photometer head = I/D^2

Hence the reading per unit of illuminance is :

$$\frac{R_D \, . \, D^2}{I} \qquad \text{(C1)}$$

(b) With the auxiliary photometer head placed at a distance 'd' from the auxiliary lamp (see Figure C1), record the reading R_d.

The illuminance at the auxiliary photometer head = I/d^2.

Hence the reading per unit of illuminance is :

$$\frac{R_d \, . \, d^2}{I} \qquad \text{(C2)}$$

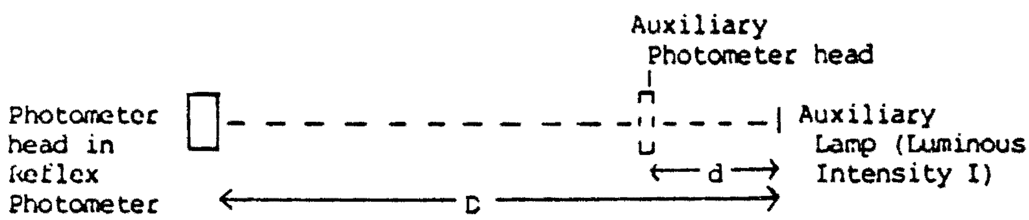


Figure C1

The next step is to measure the illuminance falling on the sample holder from the light source in the reflex photometer. The auxiliary photometer head is placed in the position of the sample and normal to the direction of the incident light (see Figure C2). If the reading is R_L then the illuminance E_s, using equation C2, is given by :

$$E_s = R_L \, . \, \frac{I}{R_d \, . \, d^2} \qquad \text{(C3)}$$

27

The final step in the calibration is to determine the luminous intensity I_s of the sample under test. The sample is placed in the sample holder in the required orientation and the reading R_s recorded from the photometer head in the reflex photometer. Using equation 1, the illuminance falling on the photometer head is given by :

$$R_s \cdot \frac{I}{R_D \cdot D^2}$$

The luminous intensity of the sample in the direction measured is then :

$$I_s = R_s \cdot \frac{I \cdot T^2}{R_D \cdot D^2} \qquad \text{(C4)}$$

where T is the test distance of the reflex photometer (see Figure C2).

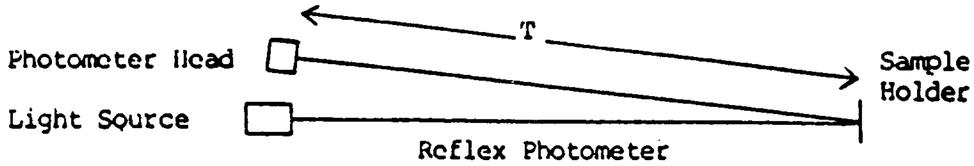


Figure C2

The coefficient of luminous intensity (R) of the sample using equations C3 and C4 is :

$$R = \frac{I_s}{E_s}$$
$$= \frac{R_s \cdot R_a \cdot d^2 \cdot T^2}{R_L \cdot R_D \cdot D^2}$$

The R value of the sample is therefore determined from the four photometric readings and the three distances, the luminous intensity of the auxiliary lamp cancelling out in the final formula.

Notes on the calibration procedure

(i) The two readings taken using the auxiliary lamp must be in the same direction from the lamp so that the luminous intensity directed towards the photometer heads is identical.

(ii) It is assumed that the linearities of the auxiliary photometer head and of the photometer head in the reflex photometer are adequate. If not, corrections should be made to the readings.

(iii) When coloured retroreflectors are measured it is assumed that the correction to the CIE Standard Photometric Observer of the photometer head in the reflex photometer is adequate. If not, suitable corrections must be applied for each colour tested; see section 4.1.1.

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