SMPTE STANDARD

Academy Printing Density (APD) — Spectral Responsivities, Reference Measurement Device and Spectral Calculation

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Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Standards and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in Part XIII of its Administrative Practices.

SMPTE ST 2065-2 was prepared by Technology Committee 10E.

Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this standard. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

Academy Printing Density (APD) is an optical printing density metric suitable for use with motion picture color negative and internegative films. APD is defined by the spectral responsivities $\Pi_{APD.}$

Π_{APD} are based on the spectral sensitivities of contemporary motion picture print films such as those of the Kodak Vision® family, of the Fujifilm Eterna® family, and of Fujifilm F-CP®. Its definition is also based on the spectral power distribution of a Bell & Howell Model C® printer lamp house with dichroic filters and the spectral transmittance of an Eastman Kodak Wratten® Filter No. 2B.

The spectral responsivities associated with any printing density metric are the product of the spectral power distribution of a printer light source, the spectral transmittance, reflection, and absorbance of the optical components of the photographic printer, and the spectral sensitivities of the print medium onto which the sample is to be printed.

The spectral responsivities used to determine the APD values of a sample are the spectral product (Π_{APD}) of the relative spectral power distribution of the influx (S_{APD}) and the relative spectral response of the receiver (s_{APD}), which includes the photodetector and all intervening components between it and the plane of the sample to be measured.

1 Scope

This Standard defines Academy Printing Density (APD) by specifying the spectral responsivities Π_{APD} and the APD reference measurement device.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:".

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

ISO 5-1:1984, Photography — Density Measurements — Part 1: Terms, symbols, and notations, First Edition, March 1, 1984

ISO 5-2:2001(E), Photography — Density Measurements — Part 2: Geometric conditions for transmission density, Fourth Edition, June 15, 2001

ISO 5-3:1995(E), Photography — Density Measurements — Part 3: Spectral Conditions, Second Edition, November 15, 1995

4 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

4.1 Academy Printing Density (APD): printing densities defined by the spectral responsivities Π_{APD}.

4.2 densitometer: device for direc$_{tly}$ measuring tra$_{nsm}$ission or reflection optical densities.

4.3 influx spectrum: spectrum of the radiant flux incident on the specimen surface or sampling aperture. It is a function of the energy source and the optical system on the source side of the specimen.

4.4 optical density: negative logarithm to the base 10 of the ratio of the integration of the spectral responsivities of a detection system and the spectral transmittance or reflectance of the sample under examination and the integration of the spectral responsivities of the detection system alone.

4.5 printing density: optical density measured according to effective spectral responsivities defined by the spectral power distribution of a printer, including the light source, the spectral transmission, reflection and absorbance of its optical components, and the spectral sensitivity of a print medium.

4.6 spectral power distribution: power, or relative power, of electromagnetic radiation as a function of wavelength.

4.7 spectral product: wavelength-by-wavelength product of two or more spectral power distributions, spectral sensitivities, spectral responsivities, or spectral transmittances.

4.8 spectral responsivities: spectral condition that represents the responses of a detection system, such as a scanner or a densitometer, as a function of wavelength. Spectral responsivities are determined by the spectral power distribution of the illumination, the spectral filtration effects of various optical components, and the spectral sensitivity of the detector.

4.9 spectral sensitivity: response of a detector to monochromatic stimuli of equal radiant power.

4.10 spectral transmittance: fraction of the incident power transmitted as a function of wavelength.

5 Academy Printing Density

5.1 Notation

The spectral responsivities defined in this specification are specified as spectral products rather than discrete spectral components. The spectral product for any densitometric specification, film scanner, or densitometer may be denoted using Equation 1 as provided in ISO 5-3:1995(E).

$$\Pi = S(\lambda)s(\lambda)$$

Equation 1

where:

$S(\lambda)$ is the relative spectral power distribution of the influx.

and

$s(\lambda)$ is the relative spectral sensitivity of the receiver, which includes the photodetector and all intervening components between it and the plane of the sample to be measured.

ISO 5-1:1984 specifies functional notation of the form $D(G; S : g; s)$, where G and g symbolize the influx geometry and efflux geometry respectively. Since this standard is only concerned with spectral conditions, the notation is abbreviated to $D(S : s)$ where the subscripted symbol D_T is used to denote transmission density.

5.2 Specification

The following functional notation, consistent with the notation specified in ISO 5-1:1984, shall be used to denote spectral conditions associated with Academy Printing Density (APD).

By transmission:

$D_T(S_{APD} : s_{APD\_R})$, $D_T(S_{APD} : s_{APD\_G})$, and $D_T(S_{APD} : s_{APD\_R})$

5.2.1 Spectral Responsivities

The spectral responsivities used to calculate APD shall be known as Π_{APD} and conform to the values listed in Table A.1 found in Annex A. The subscripted symbols Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} shall be used to denote the spectral responsivities of the red, green, and blue components of Π_{APD} respectively. Π_{APD} are illustrated in Figure 1.

The subscripted symbol S_{APD} shall be used to denote the relative spectral power distribution of the influx spectrum used in the calculation of the spectral product Π_{APD}.

The subscripted symbol s_{APD} shall be used to denote the relative spectral sensitivities of the print material used in the calculation of the spectral product Π_{APD}. The subscripted symbols s_{APD_R}, s_{APD_G}, and s_{APD_B} shall be used to denote the spectral sensitivities of the red, green, and blue components of s_{APD} respectively.

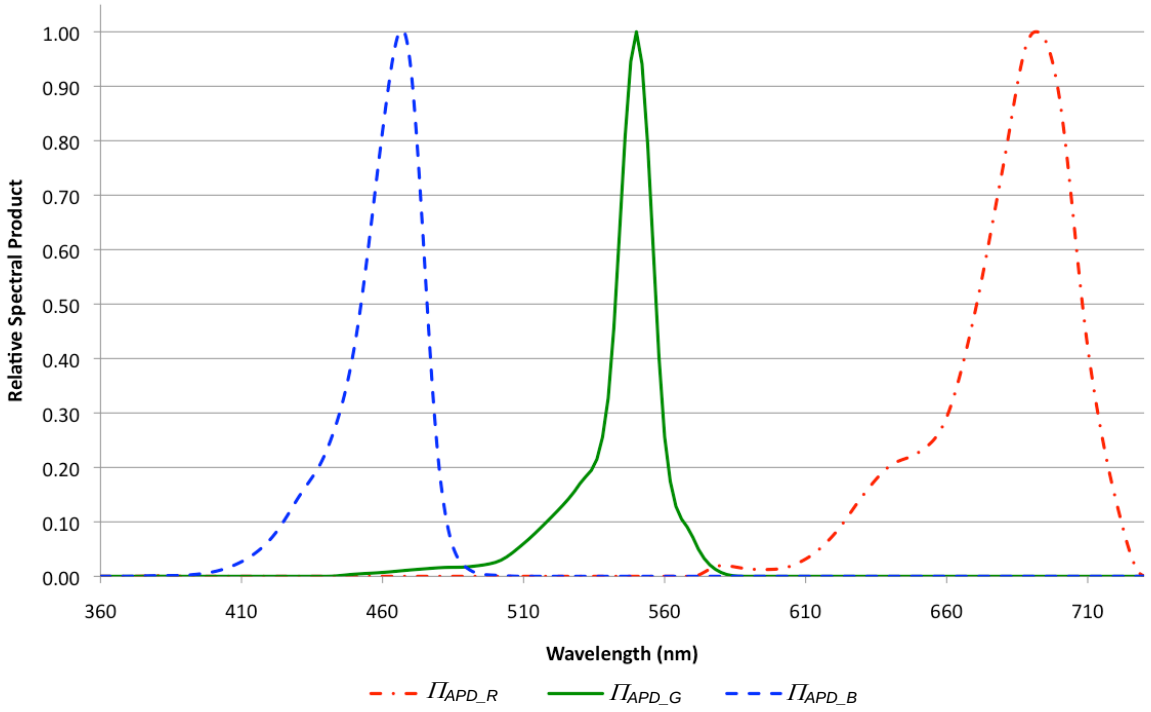

Figure 1 — Spectral Responsivities Π_{APD} (Peak Normalized)

5.2.2 Reference Measurement Device

This section specifies the conditions under which APD density measurements shall be made.

Note: The specifications in this section are intended to eliminate ambiguity in the determination of the APD values of a sample.

5.2.2.1 Spectral Responsivities

The reference measurement device shall have spectral responsivities equal to the spectral responsivities $\Pi_{APD.}$

5.2.2.2 Measurement Geometry

The reference measurement device geometry shall conform to the ISO standard diffuse transmission density specification found in ISO 5-2:2001(E).

5.2.2.3 Sample Conditions

The sample to be measured shall be at a temperature and relative humidity, consistent with the sample conditions specification for density measurements found in ISO 5-3:1995(E).

5.2.3 Spectral Calculation of APD Values

The spectral calculation of APD values requires the measurement of the spectral transmittance of the sample using a spectral measurement device. Measured sample transmittance spectra shall be converted into APD values using Equation 2.

$$APD_R = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{r}(\lambda)d\lambda\right)$$
$$APD_G = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{g}(\lambda)d\lambda\right)$$
$$APD_B = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{b}(\lambda)d\lambda\right)$$

Equation 2

where:

$\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$ are Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} normalized such that

$$\int_{360}^{730} \Pi_{APD\_R}(\lambda)d\lambda = \int_{360}^{730} \Pi_{APD\_G}(\lambda)d\lambda = \int_{360}^{730} \Pi_{APD\_B}(\lambda)d\lambda = 1$$

and

$T(\lambda)$ is the spectral transmittance of the sample, or $10^{-\text{density}(\lambda)}$

Note 1: In practice, it is common to calculate APD values using summations rather than integrals, as common spectral measurement devices typically return transmittance data as a series of spectral samples uniformly separated in wavelength rather than as a single continuous analytic function of wavelength.

Note 2: A densitometer with spectral responsivities equal to the spectral responsivities of Π_{APD} could measure APD values directly.

Note 3: Conversions between other density metric values (i.e. ISO Status M density, scanner density, etc.) and APD values are possible and can be particularly useful in process control efforts. These transformations are product specific: a separate transformation needs to be determined for each sample (e.g. color negative and internegative film products). The transformations can take many forms including 3 x 3 matrix transformations followed by an offset, polynomial conversions, and 3-dimensional LUTs. Each type transformation will likely be imperfect and care should be taken to when building such transformations to appropriately minimize the associated residual errors.

Note 4: Scanner density is the logarithm to the base 10 of the ratio of the integration of the spectral responsivities of a scanner and the spectral transmittance of the sample under examination and the integration of the spectral responsivities of the scanner alone.

Annex A Spectral Responsivities Π_{APD} (Normative)

Table A.1 — Π_{APD}

Wavelength λ, (nm)	Π_{APD_R}	Π_{APD_G}	Π_{APD_B}	Wavelength λ, (nm)	Π_{APD_R}	Π_{APD_G}	Π_{APD_B}
360	0.0000	0.0000	0.0000	436	0.0000	0.0000	0.1891
362	0.0000	0.0000	0.0000	438	0.0000	0.0000	0.2068
364	0.0000	0.0000	0.0000	440	0.0000	0.0000	0.2290
366	0.0000	0.0000	0.0000	442	0.0000	0.0003	0.2557
368	0.0000	0.0000	0.0001	444	0.0000	0.0010	0.2866
370	0.0000	0.0000	0.0001	446	0.0000	0.0020	0.3231
372	0.0000	0.0001	0.0003	448	0.0000	0.0030	0.3670
374	0.0002	0.0001	0.0005	450	0.0000	0.0039	0.4204
376	0.0005	0.0002	0.0007	452	0.0000	0.0046	0.4863
378	0.0009	0.0002	0.0010	454	0.0000	0.0052	0.5635
380	0.0013	0.0002	0.0012	456	0.0000	0.0058	0.6478
382	0.0013	0.0002	0.0013	458	0.0000	0.0064	0.7344
384	0.0010	0.0001	0.0013	460	0.0000	0.0071	0.8174
386	0.0006	0.0001	0.0014	462	0.0000	0.0079	0.8952
388	0.0002	0.0000	0.0016	464	0.0000	0.0089	0.9611
390	0.0000	0.0000	0.0020	466	0.0000	0.0099	1.0000
392	0.0000	0.0000	0.0028	468	0.0000	0.0108	0.9959
394	0.0000	0.0000	0.0037	470	0.0000	0.0117	0.9339
396	0.0000	0.0000	0.0050	472	0.0000	0.0126	0.8125
398	0.0000	0.0000	0.0065	474	0.0000	0.0134	0.6538
400	0.0000	0.0000	0.0083	476	0.0000	0.0142	0.4825
402	0.0000	0.0000	0.0107	478	0.0000	0.0150	0.3240
404	0.0000	0.0000	0.0138	480	0.0000	0.0158	0.2028
406	0.0000	0.0000	0.0175	482	0.0000	0.0163	0.1230
408	0.0000	0.0000	0.0219	484	0.0000	0.0165	0.0710
410	0.0000	0.0000	0.0268	486	0.0000	0.0166	0.0407
412	0.0000	0.0000	0.0325	488	0.0000	0.0167	0.0243
414	0.0000	0.0000	0.0392	490	0.0000	0.0174	0.0150
416	0.0000	0.0000	0.0471	492	0.0000	0.0184	0.0087
418	0.0000	0.0000	0.0562	494	0.0000	0.0196	0.0051
420	0.0000	0.0000	0.0667	496	0.0000	0.0211	0.0033
422	0.0000	0.0000	0.0790	498	0.0000	0.0230	0.0025
424	0.0000	0.0000	0.0935	500	0.0000	0.0256	0.0020
426	0.0000	0.0000	0.1095	502	0.0000	0.0296	0.0014
428	0.0000	0.0000	0.1265	504	0.0000	0.0356	0.0009
430	0.0000	0.0000	0.1434	506	0.0000	0.0430	0.0004
432	0.0000	0.0000	0.1591	508	0.0000	0.0514	0.0001
434	0.0000	0.0000	0.1738	510	0.0000	0.0600	0.0000

512	0.0000	0.0690	0.0000
514	0.0000	0.0787	0.0000
516	0.0000	0.0888	0.0000
518	0.0000	0.0990	0.0000
520	0.0000	0.1095	0.0000
522	0.0000	0.1201	0.0000
524	0.0000	0.1310	0.0000
526	0.0000	0.1427	0.0000
528	0.0000	0.1556	0.0000
530	0.0000	0.1704	0.0000
532	0.0000	0.1829	0.0000
534	0.0000	0.1944	0.0000
536	0.0000	0.2151	0.0000
538	0.0000	0.2556	0.0000
540	0.0000	0.3269	0.0000
542	0.0000	0.4552	0.0000
544	0.0000	0.6303	0.0000
546	0.0000	0.8082	0.0000
548	0.0000	0.9457	0.0000
550	0.0000	1.0000	0.0000
552	0.0000	0.9408	0.0000
554	0.0000	0.7932	0.0000
556	0.0000	0.5983	0.0000
558	0.0000	0.4023	0.0000
560	0.0000	0.2559	0.0000
562	0.0000	0.1744	0.0000
564	0.0000	0.1285	0.0000
566	0.0000	0.1051	0.0000
568	0.0000	0.0907	0.0000
570	0.0000	0.0718	0.0000
572	0.0023	0.0496	0.0000
574	0.0075	0.0330	0.0000
576	0.0133	0.0211	0.0000
578	0.0177	0.0129	0.0000
580	0.0197	0.0071	0.0000
582	0.0194	0.0033	0.0000
584	0.0181	0.0013	0.0000
586	0.0163	0.0003	0.0000
588	0.0146	0.0000	0.0000
590	0.0135	0.0000	0.0000
592	0.0128	0.0000	0.0000
594	0.0125	0.0000	0.0000
596	0.0125	0.0000	0.0000

598	0.0128	0.0000	0.0000
600	0.0134	0.0000	0.0000
602	0.0149	0.0000	0.0000
604	0.0176	0.0000	0.0000
606	0.0214	0.0000	0.0000
608	0.0262	0.0000	0.0000
610	0.0318	0.0000	0.0000
612	0.0383	0.0000	0.0000
614	0.0461	0.0000	0.0000
616	0.0553	0.0000	0.0000
618	0.0655	0.0000	0.0000
620	0.0766	0.0000	0.0000
622	0.0890	0.0000	0.0000
624	0.1028	0.0000	0.0000
626	0.1175	0.0000	0.0000
628	0.1323	0.0000	0.0000
630	0.1464	0.0000	0.0000
632	0.1597	0.0000	0.0000
634	0.1724	0.0000	0.0000
636	0.1843	0.0000	0.0000
638	0.1947	0.0000	0.0000
640	0.2033	0.0000	0.0000
642	0.2094	0.0000	0.0000
644	0.2138	0.0000	0.0000
646	0.2174	0.0000	0.0000
648	0.2215	0.0000	0.0000
650	0.2275	0.0000	0.0000
652	0.2348	0.0000	0.0000
654	0.2432	0.0000	0.0000
656	0.2544	0.0000	0.0000
658	0.2702	0.0000	0.0000
660	0.2923	0.0000	0.0000
662	0.3213	0.0000	0.0000
664	0.3560	0.0000	0.0000
666	0.3954	0.0000	0.0000
668	0.4386	0.0000	0.0000
670	0.4845	0.0000	0.0000
672	0.5337	0.0000	0.0000
674	0.5867	0.0000	0.0000
676	0.6418	0.0000	0.0000
678	0.6977	0.0000	0.0000
680	0.7527	0.0000	0.0000
682	0.8112	0.0000	0.0000

684	0.8727	0.0000	0.0000
686	0.9289	0.0000	0.0000
688	0.9721	0.0000	0.0000
690	0.9950	0.0000	0.0000
692	1.0000	0.0000	0.0000
694	0.9928	0.0000	0.0000
694	0.9928	0.0000	0.0000
696	0.9714	0.0000	0.0000
698	0.9336	0.0000	0.0000
700	0.8776	0.0000	0.0000
702	0.7997	0.0000	0.0000
704	0.7045	0.0000	0.0000
706	0.6028	0.0000	0.0000

708	0.5049	0.0000	0.0000
710	0.4203	0.0000	0.0000
712	0.3498	0.0000	0.0000
714	0.2876	0.0000	0.0000
716	0.2324	0.0000	0.0000
718	0.1834	0.0000	0.0000
720	0.1396	0.0000	0.0000
722	0.0984	0.0000	0.0000
724	0.0603	0.0000	0.0000
726	0.0289	0.0000	0.0000
728	0.0077	0.0000	0.0000
730	0.0000	0.0000	0.0000

Annex B Influx Spectrum S_{APD} (Informative)

Π_{APD} incorporate the influx spectrum S_{APD}, which models the lamp house of a Bell & Howell Model C® motion picture printer, filtered by an Eastman Kodak Wratten® Filter No. 2B. The tabulated values of S_{APD} are listed in Table B.1 and illustrated in Figure B.1.

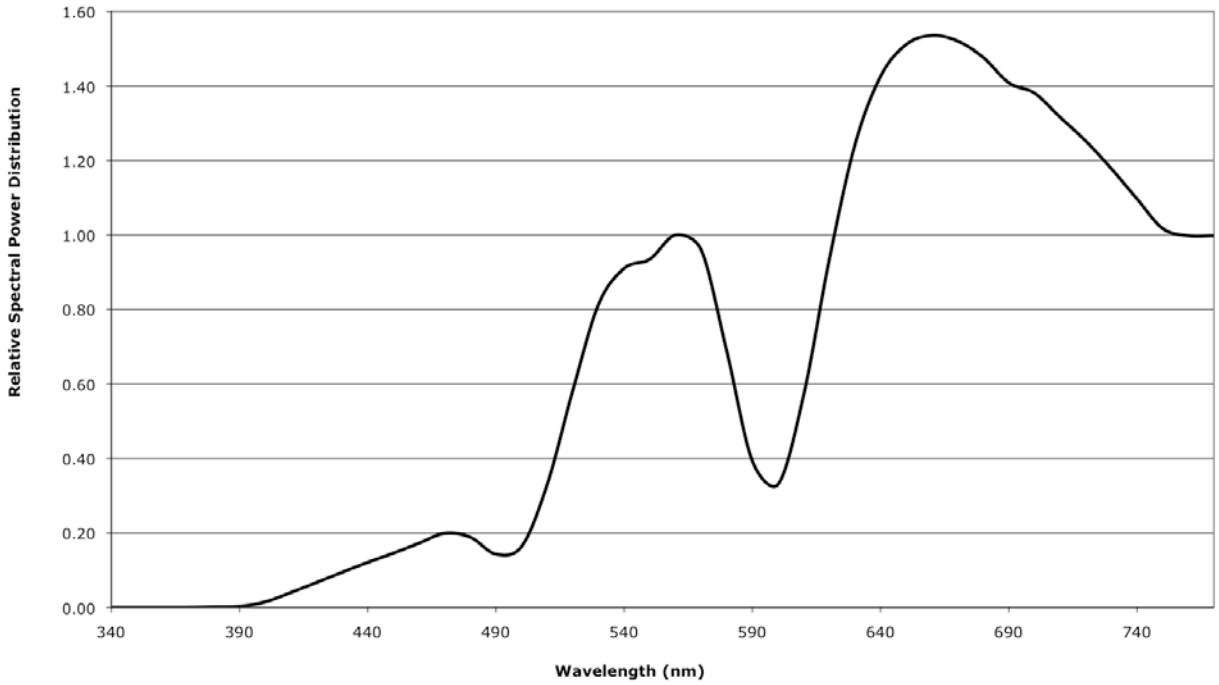

Figure B.1 — Influx Spectrum S_{APD} (Normalized to 1.0 at 560nm)

The basic light source for ISO densitometry, as specified in ISO 5-3:1995(E), is CIE Standard Illuminant A. The lamp house of the Bell & Howell Model C® motion picture printer uses a tungsten light source that is separated into red, blue, and green components with a set of dichroic mirrors; those components are then modulated by a series of light valves in order to precisely control the ratios of red, green, and blue light, and after modulation are filtered with a Eastman Kodak Wratten® Filter No. 2B. Use of SAPD in the calculation of the spectral responsivities associated with APD therefore meets the light source requirement of ISO 5-3:1995(E).

The specification of CIE Standard Illuminant A by ISO 5-3:1995(E) is motivated, in part, by the need to manage fluorescence in the sample to be measured.

Filtration of the light source is permitted and in fact suggested by ISO 5-3:1995(E) in order to protect the sample to be measured and optical elements from the heat of the light source.

Table B.1 — S_{APD}

Wavelength λ, (nm)	S_{APD}	Wavelength λ, (nm)	S_{APD}	Wavelength λ, (nm)	S_{APD}
360	0.0000	442	0.1261	524	0.6842
362	0.0000	444	0.1309	526	0.7325
364	0.0000	446	0.1357	528	0.7764
366	0.0000	448	0.1406	530	0.8137
368	0.0001	450	0.1456	532	0.8434
370	0.0001	452	0.1508	534	0.8669
372	0.0002	454	0.1562	536	0.8852
374	0.0005	456	0.1616	538	0.8993
376	0.0007	458	0.1671	540	0.9104
378	0.0010	460	0.1725	542	0.9179
380	0.0013	462	0.1787	544	0.9220
382	0.0014	464	0.1856	546	0.9248
384	0.0016	466	0.1921	548	0.9285
386	0.0018	468	0.1969	550	0.9352
388	0.0022	470	0.1989	552	0.9469
390	0.0030	472	0.1988	554	0.9621
392	0.0043	474	0.1981	556	0.9779
394	0.0061	476	0.1964	558	0.9915
396	0.0084	478	0.1933	560	1.0000
398	0.0113	480	0.1885	562	1.0036
400	0.0147	482	0.1802	564	1.0032
402	0.0189	484	0.1684	566	0.9969
404	0.0237	486	0.1563	568	0.9832
406	0.0290	488	0.1468	570	0.9602
408	0.0345	490	0.1428	572	0.9235
410	0.0399	492	0.1428	574	0.8728
412	0.0451	494	0.1439	576	0.8134
414	0.0505	496	0.1471	578	0.7502
416	0.0560	498	0.1534	580	0.6882
418	0.0614	500	0.1637	582	0.6252
420	0.0669	502	0.1825	584	0.5589
422	0.0724	504	0.2114	586	0.4947
424	0.0779	506	0.2476	588	0.4376
426	0.0834	508	0.2883	590	0.3930
428	0.0889	510	0.3307	592	0.3627
430	0.0944	512	0.3762	594	0.3436
432	0.0998	514	0.4265	596	0.3334
434	0.1052	516	0.4794	598	0.3297
436	0.1106	518	0.5325	600	0.3304
438	0.1159	520	0.5836	602	0.3467
440	0.1211	522	0.6338	604	0.3866

Wavelength λ, (nm)	S_{APD}
606	0.4423
608	0.5062
610	0.5705
612	0.6370
614	0.7101
616	0.7863
618	0.8623
620	0.9345
622	1.0029
624	1.0690
626	1.1317
628	1.1898
630	1.2424
632	1.2890
634	1.3303
636	1.3667
638	1.3985
640	1.4261
642	1.4499
644	1.4700
646	1.4867

Wavelength λ, (nm)	S_{APD}
648	1.5005
650	1.5118
652	1.5206
654	1.5273
656	1.5320
658	1.5348
660	1.5359
662	1.5355
664	1.5336
666	1.5305
668	1.5263
670	1.5212
672	1.5151
674	1.5079
676	1.4994
678	1.4892
680	1.4771
682	1.4631
684	1.4480
686	1.4332
688	1.4197

Wavelength λ, (nm)	S_{APD}
690	1.4088
692	1.4015
694	1.3965
696	1.3926
698	1.3880
700	1.3813
702	1.3714
704	1.3590
706	1.3450
708	1.3305
710	1.3163
712	1.3030
714	1.2904
716	1.2781
718	1.2656
720	1.2526
722	1.2387
724	1.2242
726	1.2091
728	1.1937
730	1.1782

Annex C Bibliography (Informative)

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