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CORRECTION FUNCTION OF PHOTOMULTIPLIER FOR SPECTROSCOPIC MEASUREMENTS

LUBOMÍR DVOŘÁK, ZDENĚK KUPKA

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In the measurement of emission spectra by different spectrophotometers it is necessary to solve the problem how to determine the right correction function to errors of the measuring apparatus. Calibrating lamps are mostly used for such corrections which method, however, entails one drawback in the time instability of the lamp. To determine the corrections of errors with the aid of an absolutely black body proved to be uneasy for the generality of working sites due to the difficulty of realizing such a body. This article presents the determination of a correction function by emission of platinum acting here as a grey radiator.

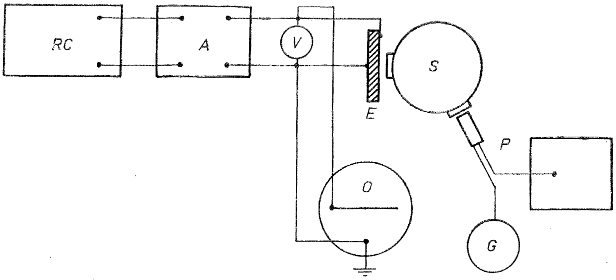

Fig. 1. Block diagram of measure apparatus. *RC* sine-voltage generator, *A* amplifier, *S* spectrophotometer, *P* photomultiplier with a voltage source, *O* oscillograph.

A prismatic spectro-photometer Zeiss type *VSU 1* with a registrating photomultiplier in an arrangement as shown in figure *1* was used to yield the desired measurement of luminescent emission spectra. Measuring of spectra such-wise is loaded with systematic errors having their origin especially in the dispersion of the spectro-photometer and in the spectral sensitivity of the photomultiplier. Thereto the spectral absorption of the individual optical elements of the measuring apparatus or the adjustment of the slit-width may have some effect, too.

A platinum shim in dimensions of 10 × 25 mm heated by electric current in an atmosphere of pure argon was used as a source of light with a known spectrum to determine the correction function. Its black temprature was kept at 1 700 °K. The input slit of the spectro-photometer was adjusted to the centre of the platinum shim

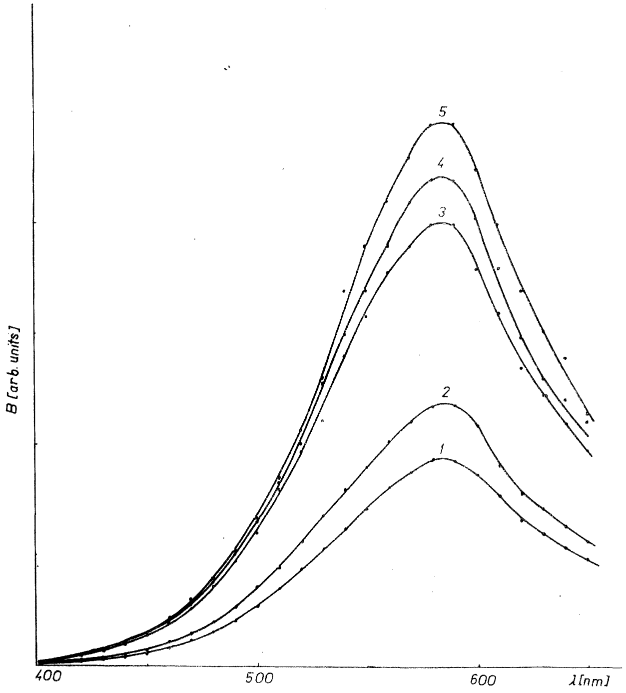

Fig. 2. Emission of platinum. 1 voltage of photomultiplier $U_p = 975$ *V*, width of output slit $d = 0{,}15$ *mm*. 2 $U_p = 1\,600$ *V*, $d = 0{,}01$ *mm*, 3 $U_p = 1\,100$ *V*, $d = 0{,}15$ *mm*, 4 $U_p = 1\,350$ *V*, $d = 0{,}10$ *mm*, 5 $U_p = 1\,350$ *V*, $d = 0{,}05$ *mm*.

and the temperature was measured by an optical pyrometer, whereby we assumed that in the given spectral interval, platinum is emitting as an ideal grey radiator.

It is essential for our measurement to determine the correction functions for the visible and near infrared interval. We used as a comparative parameter the ratio $H_{\lambda}/H_{\lambda-10nm}$. Besides that, for the visible interval the ratio H_{λ}/H_{500nm} and for the near infrared interval the ratio H_{λ}/H_{900nm}, where H_{λ} denotes the spectral ratio intensity of radiation falling on the interval $\Delta\lambda$ in the surrounding of the wavelength λ. The ratios for emission of the absolutely black body at temperature of 1 700 °K were calculated by Plank's law on the ODRA computer and can be seen in table 1.

For the measurement in the interval ranging from 400 to 600 nm the photo-multipliers Zeiss type M12 FS35 were employed. Measuring was effected for different widths of the input slit and output slit of the spectro-photometer, for different voltages on the photomultiplier, and for different photomultipliers of an equal type. The outcomes of the spectral measurement on the platinum shim for one of the photomultiplier are given in figure *2*. We used as a comparative parameter the ratio H_{λ}/H_{500nm}. Under the comparison of the theoretical value and the measured value of this ratio the correction function was determined. It is evident that in the margin of measuring accuracy, which is up to 2 %, the correction function is independent on

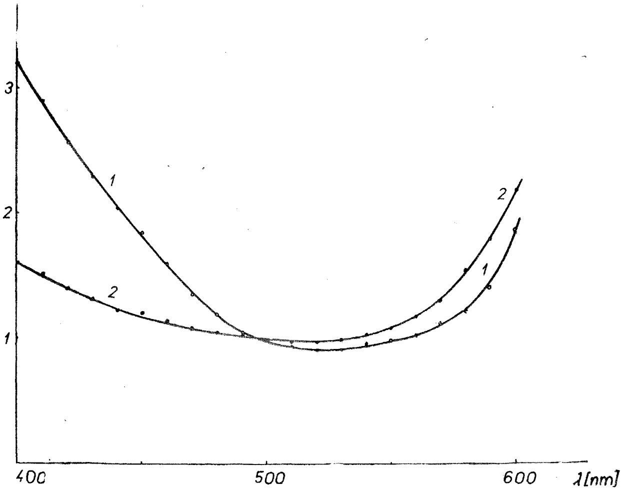

Fig. 3. Correction functions of photomultipliers.

Table I

Wavelength [nm]	H_λ	$H_\lambda/H_{500\,\mathrm{nm}}$	$H_\lambda/H_{900\,\mathrm{nm}}$	$H_\lambda/H_{\lambda-10\,\mathrm{nm}}$
400	$3,7594967.10^{6}$	$4,4332067.10^{-2}$	$4,5267629.10^{-4}$	1,5158023
405	$4,5877630.10^{6}$			
410	$5,5671929.10^{6}$	$6,5648461.10^{-2}$	$6,7033873.10^{-4}$	1,4808346
415	$6,7193537.10^{6}$			
420	$8,0679328.10^{6}$	$9,5137241.10^{-2}$	$9,7144970.10^{-4}$	1,4491923
425	$9,6388198.10^{6}$			
430	$1,1460184.10^{7}$	$1,3513874.10^{-1}$	$1,3799064.10^{-3}$	1,4204610
435	$1,3562542.10^{7}$			
440	$1,5978813.10^{7}$	$1,8842251.10^{-1}$	$1,9239888.10^{-3}$	1,3942894
445	$1,8744356.10^{7}$			
450	$2,1897014.10^{7}$	$2,5821007.10^{-1}$	$2,6365921.10^{-3}$	1,3703780
455	$2,5477120.10^{7}$			
460	$2,9527497.10^{7}$	$3,4818889.10^{-1}$	$3,5553689.10^{-3}$	1,3484714
465	$3,4093467.10^{7}$			
470	$3,9222817.10^{7}$	$4,6251632.10^{-1}$	$4,7227704.10^{-3}$	1,3283489
475	$4,4965731.10^{7}$			
480	$5,1374803.10^{7}$	$6,0581281.10^{-1}$	$6,1859758.10^{-3}$	1,3098193
485	$5,8504916.10^{7}$			
490	$6,6413178.10^{7}$	$7,8314566.10^{-1}$	$7,9967277.10^{-3}$	1,2927189
495	$7,5158809.10^{7}$			
500	$8,4803095.10^{7}$	$9,9999996.10^{-1}$	$1,0211035.10^{-2}$	1,2769016
505	$9,5409200.10^{7}$			
510	$1,0704210.10^{8}$	1,2622427	$1,2888805.10^{-2}$	1,2622428
515	$1,1976832.10^{8}$			
520	$1,3365598.10^{8}$	1,5760743	$1,6093350.10^{-2}$	1,2486301
525	$1,4877449.10^{8}$			
530	$1,6519440.10^{8}$	1,9479760	$1,9890851.10^{-2}$	1,2359671
535	$1,8298728.10^{8}$			
540	$2,0222544.10^{8}$	2,3846469	$2,4349713.10^{-2}$	1,2241665
545	$2,2298193.10^{8}$			
550	$2,4533014.10^{8}$	2,8929384	$2,9539895.10^{-2}$	1,2131517
555	$2,6934374.10^{8}$			
560	$2,9509647.10^{8}$	3,4797840	$3,5532196.10^{-2}$	1,2028545
565	$3,2266185.10^{8}$			
570	$3,5211317.10^{8}$	4,1521262	$4,2397506.10^{-2}$	1,1932138
575	$3,8352312.10^{8}$			
580	$4,1696368.10^{8}$	4,9168449	$5,0206075.10^{-2}$	1,1841752
585	$4,5250600.10^{8}$			
590	$4,9021991.10^{8}$	5,7806839	$5,9026766.10^{-2}$	1,1756897
595	$5,3017425.10^{8}$			
600	$5,7243625.10^{8}$	6,7501809	$6,8926334.10^{-2}$	1,1677132
605	$6,1707156.10^{8}$			
610	$6,6414404.10^{8}$	7,8316011	$7,9968753.10^{-2}$	1,1602061
615	$7,1371565.10^{8}$			

Table 1

Wavelength [nm]	H_λ	$H_\lambda/H_{500\,nm}$	$H_\lambda/H_{800\,nm}$	$H_\lambda/H_{\lambda-10\,nm}$
620	$7,6584607.10^{8}$	9,0308737	$9,2214567.10^{-2}$	1,1531325
625	$8,2059303.10^{8}$			
630	$8,7801174.10^{8}$	$1,0353534.10^{1}$	$1,0572030.10^{-1}$	1,1464598
635	$9,3815495.10^{8}$			
640	$1,0010728.10^{9}$	$1,1804672.10^{1}$	$1,2053792.10^{-1}$	1,1401588
645	$1,0668128.10^{9}$			
650	$1,1354193.10^{9}$	$1,3388889.10^{1}$	$1,3671441.10^{-1}$	1,1342025
655	$1,2069341.10^{9}$			
660	$1,2813960.10^{9}$	$1,5110250.10^{1}$	$1,5429129.10^{-1}$	1,1285664
665	$1,3588406.10^{9}$			
670	$1,4393005.10^{9}$	$1,6972263.10^{-1}$	$1,7330437.10^{-1}$	1,1232285
675	$1,5228050.10^{9}$			
680	$1,6093805.10^{9}$	$1,8977850.10^{1}$	$1,9378349.10^{-1}$	1,1181685
685	$1,6990492.10^{9}$			
690	$1,7918311.10^{9}$	$2,1129312.10^{1}$	$2,1575215.10^{-1}$	1,1133670
695	$1,8877427.10^{9}$			
700	$1,9867967.10^{9}$	$2,3428350.10^{1}$	$2,3922770.10^{-1}$	1,1088080
705	$2,0890028.10^{9}$			
710	$2,1943675.10^{9}$	$2,5876029.10^{1}$	$2,6422104.10^{-1}$	1,1044751
715	$2,3028936.10^{9}$			
720	$2,4145815.10^{9}$	$2,8472798.10^{1}$	$2,9073674.10^{-1}$	1,1003542
725	$2,5294266.10^{9}$			
730	$2,6474229.10^{9}$	$3,12118469.10^{1}$	$3,1877288.10^{-1}$	1,0964313
735	$2,7685605.10^{9}$			
740	$2,8928262.10^{9}$	$3,4112270.10^{1}$	$3,4832158.10^{-1}$	1,0926952
745	$3,0202040.10^{9}$			
750	$3,1506748.10^{9}$	$3,7152826.10^{1}$	$3,7936881.10^{-1}$	1,0891338
755	$3,2842163.10^{9}$			
760	$3,4208036.10^{9}$	$4,0338191.10^{1}$	$4,1189468.10^{-1}$	1,0857368
765	$3,5604094.10^{9}$			
770	$3,7030016.10^{9}$	$4,3665876.10^{1}$	$4,4587378.10^{-1}$	1,0824946
775	$3,8485477.10^{9}$			
780	$3,9970119.10^{9}$	$4,7132853.10^{1}$	$4,8127521.10^{-1}$	1,0793979
785	$4,1483557.10^{9}$			
790	$4,3025383.10^{9}$	$5,0735626.10^{1}$	$5,1806325.10^{-1}$	1,0764387
795	$4,4595161.10^{9}$			
800	$4,6192439.10^{9}$	$5,4470226.10^{1}$	$5,5619738.10^{-1}$	1,0736090
805	$4,7816737.10^{9}$			
810	$4,9467559.10^{9}$	$5,8332254.10^{1}$	$5,9563269.10^{-1}$	1,0709016
815	$5,1144397.10^{9}$			
820	$5,2846690.10^{9}$	$6,2316933.10^{1}$	$6,3632038.10^{-1}$	1,0683100
825	$5,4573899.10^{9}$			
830	$5,6325452.10^{9}$	$6,6419097.10^{1}$	$6,7820772.10^{-1}$	1,0658274
835	$5,8100759.10^{9}$			

Table 1

Wavelength [nm]	H_λ	$H_\lambda/H_{500\,\mathrm{nm}}$	$H_\lambda/H_{900\,\mathrm{nm}}$	$H_\lambda/H_{\lambda-10\,\mathrm{nm}}$
840	5,9899219.10^{9}	7,0633291.10^{1}	7,2123900.10^{-1}	1,0634485
845	6,1720214.10^{9}			
850	6,3563113.10^{9}	7,4953763.10^{1}	7,6535549.10^{-1}	1,0611676
855	6,5427271.10^{9}			
860	6,7312038.10^{9}	7,9374503.10^{1}	8,1049583.10^{-1}	1,0589796
865	6,9216745.10^{9}			
870	7,1140721.10^{9}	8,3889294.10^{1}	8,5659652.10^{-1}	1,0568796
875	7,3083292.10^{9}			
880	7,5043740.10^{9}	8,8491743.10^{1}	9,0359229.10^{-1}	1,0548634
885	7,7021386.10^{9}			
890	7,9015524.10^{9}	9,3175280.10^{1}	9,5141604.10^{-1}	1,0529263
895	8,1025446.10^{9}			
900	8,3050438.10^{9}	9,7933259.10^{1}	9,9999993.10^{-1}	1,0510648
905	8,5089784.10^{9}			
910	8,7142760.10^{9}	1,0275893.10^{2}	1,0492751	1,0492751
915	8,9208648.10^{9}			
920	9,1286721.10^{9}	1,0764550.10^{2}	1,0991720	1,0475537
925	9,3376259.10^{9}			
930	9,5476536.10^{9}	1,1258614.10^{2}	1,1496210	1,0548973
935	9,7586826.10^{9}			
940	9,9706431.10^{9}	1,1757404.10^{2}	1,2005527	1,0443030
945	1,0183458.10^{10}			
950	1,0397059.10^{10}	1,2260235.10^{2}	1,2518969	1,0427672
955	1,0611375.10^{10}			
960	1,0826334.10^{10}	1,2766436.10^{2}	1,3035853	1,0412880
965	1,1041865.10^{10}			
970	1,1257899.10^{10}	1,3275340.10^{2}	1,3555496	1,0398626
975	1,1474366.10^{10}			
980	1,1691189.10^{10}	1,3786286.10^{2}	1,4077225	1,0384884
985	1,1908324.10^{10}			
990	1,2125679.10^{10}	1,4298627.10^{2}	1,4600378	1,0371631
995	1,2343195.10^{10}			
1 000	1,2560805.10^{10}	1,4811729.10^{2}	1,5124308	1,0358847
1 005	1,2778445.10^{10}			
1 010	1,2996049.10^{10}	1,5324969.10^{2}	1,5648380	1,0346510
1 015	1,3213554.10^{10}			
1 020	1,3430899.10^{10}	1,5837746.10^{2}	1,6171978	1,0334602
1 025	1,3648017.10^{10}			
1 030	1,3864851.10^{10}	1,6349463.10^{2}	1,6694493	1,0323099
1 035	1,4081339.10^{10}			
1 040	1,4297423.10^{10}	1,6859553.10^{2}	1,7215348	1,0311992
1 045	1,4513045.10^{10}			
1 050	1,4728147.10^{10}	1,7367464.10^{2}	1,7733978	1,0301260
1 055	1,4942674.10^{10}			

Table 1

Wavelength [nm]	H_λ	$H_\lambda/H_{500\ \mathrm{nm}}$	$H_\lambda/H_{900\ \mathrm{nm}}$	$H_\lambda/H_{\lambda-10\ \mathrm{nm}}$
1 060	$1{,}5156571 . 10^{10}$	$1{,}7872662 . 10^{2}$	1,8249838	1,0290888
1 065	$1{,}5369784 . 10^{10}$			
1 070	$1{,}5582259 . 10^{10}$	$1{,}8374634 . 10^{2}$	1,8762403	1,0280860
1 075	$1{,}5793945 . 10^{10}$			
1 080	$1{,}6004793 . 10^{10}$	$1{,}8872887 . 10^{2}$	1,9271171	1,0271164
1 085	$1{,}6214751 . 10^{10}$			
1 090	$1{,}6423773 . 10^{10}$	$1{,}9366949 . 10^{2}$	1,9775659	1,0261784
1 095	$1{,}6631810 . 10^{10}$			
1 100	$1{,}6838816 . 10^{10}$	$1{,}9856369 . 10^{2}$	2,0275408	1,0252709
1 105	$1{,}7044748 . 10^{10}$			
1 110	$1{,}7249560 . 10^{10}$	$2{,}0340719 . 10^{2}$	2,0769979	1,0243927
1 115	$1{,}7453213 . 10^{10}$			
1 120	$1{,}7655660 . 10^{10}$	$2{,}0819593 . 10^{2}$	2,1258959	1,0235426
1 125	$1{,}7856863 . 10^{10}$			
1 130	$1{,}8056783 . 10^{10}$	$2{,}1292599 . 10^{2}$	2,1741947	1,0227193
1 135	$1{,}8255383 . 10^{10}$			
1 140	$1{,}8452625 . 10^{10}$	$2{,}1759376 . 10^{2}$	2,2218575	1,0219220
1 145	$1{,}8648473 . 10^{10}$			
1 150	$1{,}8842894 . 10^{10}$	$2{,}2219582 . 10^{2}$	2,2688493	1,0211498
1 155	$1{,}9035852 . 10^{10}$			
1 160	$1{,}9227316 . 10^{10}$	$2{,}2672894 . 10^{2}$	2,3151371	1,0204015
1 165	$1{,}9417255 . 10^{10}$			
1 170	$1{,}9605638 . 10^{10}$	$2{,}3119011 . 10^{2}$	2,3606903	1,0196762
1 175	$1{,}9792435 . 10^{10}$			
1 180	$1{,}9977620 . 10^{10}$	$2{,}3557653 . 10^{2}$	2,4054802	1,0189732
1 185	$2{,}0161164 . 10^{10}$			
1 190	$2{,}0343043 . 10^{10}$	$2{,}3988561 . 10^{2}$	2,4494803	1,0182916
1 195	$2{,}0523230 . 10^{10}$			
1 200	$2{,}0701703 . 10^{10}$	$2{,}4411494 . 10^{2}$	2,4926661	1,0176306
1 205	$2{,}0878438 . 10^{10}$			
1 210	$2{,}1053413 . 10^{10}$	$2{,}4826231 . 10^{2}$	2,5350151	1,0169894
1 215	$2{,}1226608 . 10^{10}$			
1 220	$2{,}1398002 . 10^{10}$	$2{,}5232571 . 10^{2}$	2,5765066	1,0163674
1 225	$2{,}1567581 . 10^{10}$			
1 230	$2{,}1735318 . 10^{10}$	$2{,}5630335 . 10^{2}$	2,6171225	1,0157639
1 235	$2{,}1901201 . 10^{10}$			
1 240	$2{,}2065214 . 10^{10}$	$2{,}6019349 . 10^{2}$	2,6568448	1,0151779
1 245	$2{,}2227341 . 10^{10}$			
1 250	$2{,}2387569 . 10^{10}$	$2{,}6399471 . 10^{2}$	2,6956592	1,0146092
1 255	$2{,}2545884 . 10^{10}$			
1 260	$2{,}2702273 . 10^{10}$	$2{,}6770571 . 10^{2}$	2,7335523	1,0140571
1 265	$2{,}2856725 . 10^{10}$			
1 270	$2{,}3609229 . 10^{10}$	$2{,}7132534 . 10^{2}$	2,7705125	1,0135209
1 275	$2{,}3159775 . 10^{10}$			

Table 1

Wavelength [nm]	H_λ	$H_\lambda/H_{500\text{ nm}}$	$H_\lambda/H_{900\text{ nm}}$	$H_\nu/H_{\lambda-10\text{ nm}}$
1 280	$2,3308354.10^{10}$	$2,7485262.10^{2}$	2,8065297	1,0130002
1 285	$2,3454956.10^{10}$			
1 290	$2,3599576.10^{10}$	$2,7828672.10^{2}$	2,8415954	1,0124943
1 295	$2,3742205.10^{10}$			
1 300	$2,3882838.10^{10}$	$2,8162695.10^{2}$	2,8757026	1,0120028
1 305	$2,4021469.10^{10}$			
1 310	$2,4158093.10^{10}$	$2,8487277.10^{2}$	2,9088458	1,0115252
1 315	$2,4292707.10^{10}$			
1 320	$2,4425307.10^{10}$	$2,8802376.10^{2}$	2,9410207	1,0110611
1 325	$2,4555891.10^{10}$			
1 330	$2,4684456.10^{10}$	$2,9107965.10^{2}$	2,9722245	1,0106099
1 335	$2,4811002.10^{10}$			
1 340	$2,4935527.10^{10}$	$2,9404029.10^{2}$	3,0024556	1,0101712
1 345	$2,5058023.10^{10}$			
1 350	$2,5178516.10^{10}$	$2,9690561.10^{2}$	3,0317136	1,0097447
1 355	$2,5296981.10^{10}$			
1 360	$2,5413433.10^{10}$	$2,9967576.10^{2}$	3,0599997	1,0093301
1 365	$2,5527864.10^{10}$			
1 370	$2,5640283.10^{10}$	$3,0235078.10^{2}$	3,0873144	1,0089264
1 375	$2,5750692.10^{10}$			
1 380	$2,5859095.10^{10}$	$3,0493102.10^{2}$	3,1136613	1,0085339
1 385	$2,5965497.10^{10}$			
1 390	$2,6069902.10^{10}$	$3,0741686.10^{2}$	3,1390443	1,0081521
1 395	$2,6172315.10^{10}$			
1 400	$2,6272742.10^{10}$	$3,0980875.10^{2}$	3,1634680	1 0077806
1 405	$2,6371189.10^{10}$			
1 410	$2,6467662.10^{10}$	$3,1210725.10^{2}$	3,1869381	1,0074191
1 415	$2,6562168.10^{10}$			
1 420	$2,6654714.10^{10}$	$3,1431297.10^{2}$	3,2094607	1,0070672
1 425	$2,6745308.10^{10}$			
1 430	$2,6833957.10^{10}$	$3,1642661.10^{2}$	3,2310432	1,0067247
1 435	$2,6920671.10^{10}$			
1 440	$2,7005458.10^{10}$	$3,1844896.10^{2}$	3,2516934	1,0063912
1 445	$2,7088327.10^{10}$			
1 450	$2,7169287.10^{10}$	$3,2038083.10^{2}$	3,2714198	1,0060665
1 455	$2,7248347.10^{10}$			
1 460	$2,7325519.10^{10}$	$3,2222312.10^{2}$	3,2902316	1,0057503
1 470	$2,7474235.10^{10}$	$3,2397679.10^{2}$	3,3081383	1,0054424
1 475	$2,7545802.10^{10}$			
1 480	$2,7615522.10^{10}$	$3,2564284.10^{2}$	3,3251505	1,0051425
1 485	$2,7683407.10^{10}$			
1 490	$2,7749467.10^{10}$	$3,2722233.10^{2}$	3,3412786	1,00448504
1 495	$2,7813716.10^{10}$			
1 500	$2,7876164.10^{10}$	$3,2871634.10^{2}$	3,3565340	1,0045657

the input and output slit of the spectro-photometer or on the voltage of the photomultiplier. Yet, the correction function is different for each photomultiplier and must be determined individually. A correction function for two photomultipliers of type M12 FS35 is shown in figure *3*. The application of the correction function in a certain interval is restricted to the required accuracy of the measurement. Upon multiplying through by a large correction factor the resulting error of measuring for the given wavelength increases, which applies especially to the endpoints of the measured spectral interval. The correction functions accuracy was verified by measuring of the same spectra on a grid spectrograph DFS-8-1 using the spectral photographic plates WT 2 Total.

The final outcome of the above determination of correction curves by means of platinum (platinum acting as a grey radiator), is the conviction that this method is well-suited and sufficiently precise for the visible interval of the spectrum. The smooth course of the correction function and the comparative measurements on the grid spectrograph make clear evidence of that as well.

Shrnutí

KOREKČNÍ FUNKCE FOTONÁSOBIČŮ PRO SPEKTRÁLNÍ MĚŘENÍ

LUBOMÍR DVOŘÁK, ZDENĚK KUPKA

V předložené práci je popsána metoda stanovení korekční funkce spektrofotometrické soustavy sestávající z hranolového spektrofotometru s registrací pomocí fotonásobiče. Korekce na dispersi spektrofotometru, spektrální citlivost fotonásobiče a absorpci optických prvků měřící aparatury byla určena pomocí vyzařování platiny.

Zusammenfassung

KOREKTIONSFUNKTION DES PHOTOMULTIPLIER FÜR DIE SPEKTRALMESSUNG

LUBOMÍR DVOŘÁK, ZDENĚK KUPKA

In dieser Arbeit ist die Methode der Bestimmung der Korrektionsfunktion des Spektrophotometers beschrieben. Die Registration der gemessenen Werte wird mittels Photomultiplier durchgeführt. Die Korrektion an die Dispersion des Spektrophotometers, die Spektralempfindlichkeit des Photomultipliers und an die Absorption der Apparatur ist mit Hilfe der Platin-Ausstrahlung festgesetzt.