A mean relation between magnitude and galvanometer reading in photographic photometry with a Schilt photometer (Errata: 8 XI)

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A mean relation between magnitude and galvanometer reading in photographic photometry with a Schilt photometer, by *A. J. Wesselink*.

Let (m, g) be the relation for the stellar images of a photographic plate between magnitude and galvanometer reading as determined by means of a Schilt photometer. Suppose the reading to be zero when all light is cut off and let the reading of the fog be reduced to a fixed value, e.g. 25 cm.

It was pointed out in *B.A.N.* No. 190, 195 that for any pair of plates the relation between the magnitudes, corresponding to the same value of the galvanometer reading, is practically linear under these conditions.

Stated otherwise: the relation between the magnitudes m_1 and m_2 corresponding to the same value of the galvanometer reading, as derived from (m_1, g) and (m_2, g) by the elimination of g, is approximately linear. In still other words: apart from an insignificant constant, depending on the arbitrary zeropoints in the magnitudes of each plate, the relations (m, g) differ only by a constant factor, which may be regarded as a measure of the relative gradation of the two plates.

Hertzsprung suggested that it would be more convenient to operate with provisional magnitudes than with the galvanometer readings. These provisional magnitudes are given by the relation (m_{pr}, g), which is merely a mean (m, g) relation derived from a number of plates. Such a table of provisional magnitudes was derived at the Leiden Observatory several years ago from six plates of the Pleiades taken with a coarse grating in front of the objective of the 13-inch photographic refractor. This table has been applied in numerous investigations issued from the astrophysical department of this observatory.

The table mentioned above was derived from a number of slightly out of focus exposures on ordinary blue sensitive photographic plates taken with the 13-inch refractor and measured with the original Schilt photometer. However, it was found that the table could be used under much more general conditions than those present in the photographs and measures used for the construction of the table.

Thus the normal table appeared to be valid also for:

1°. Orthochromatic plates in combination with a yellow filter for use in photovisual photometry.

2°. Observations made either with instruments of large focal length, thus fuzzy images (Yale refractor, $f = 1096$ cm; the 26-inch refractor of the Union Observatory, $f = 1070$ cm; both in Johannesburg), or of short focal length, giving sharp images (Zeiss double camera with moving plateholders at Leiden, $f = 51$ cm; the Franklin-Adams camera at Johannesburg, $f = 113$ cm).

3°. Measures made with the new Schilt photometer.

As the material suitable for the determination of a normal table has increased considerably since the first table was made, a more accurate one has been constructed. This new table forms the subject of this paper and is shown on page 333.

Dr. P. Th. Oosterhoff and Mr. C. J. Kooreman were kind enough to put at my disposal their measures on a number of plates taken with objective grating. The material consists of six exposures of h and χ Persei, nine exposures of the Pleiades and two exposures of NGC 1502.

The exposures of NGC 1502 were taken and measured by the writer. All observations were made with the 13-inch photographic refractor. The seventeen (m, g) relations were all derived in the same manner, which is not essentially different from that proposed by Schwarzschild[1]. This derivation is performed by means of the (g_c, g_s) curve, g_c and g_s being the galvanometer reading for the central and first order images respectively.

Then for each of the seventeen (m, g) relations the magnitude was read off at every centimetre of the galvanometer reading. This reading varies from zero to twenty-five centimetres. Then the weighted mean of the magnitudes was taken at each centimetre. For each (m, g) relation these weights were chosen according to the following consideration. The weight of a (g_c, g_s) curve may be taken proportional to the number of stars from which it has been derived.

[1]) *A.N.* No. 4109, Bd. **172**, p. 65, 1906.

This does not hold true for the weights of the (m, g) relations as a consequence of the additional uncertainty which is introduced at its construction out of the (g_c, g_s) curves. These weights vary less strongly than proportional to the number of stars and were taken proportional to the square roots of these numbers.

In order to compute the normal table the observed mean values of m at each cm galvanometer reading were smoothed by means of a suitable interpolation formula. As it is practical to have the table with constant intervals in m this formula should allow the computation of g from m. The mean (m, g) relation proved to have no point of symmetry. The point of inflexion was found to be at the reading $13\frac{1}{2}$ cm. The constants in the following two interpolation formulae were derived from leasts quares solutions.

$$m(g) - m(13{\cdot}5) = 2{\cdot}397 \text{ tg } [3^\circ{\cdot}910\,(g - 13{\cdot}5)] \qquad 4 \leq g \leq 13{\cdot}5$$

$$m(g) - m(13{\cdot}5) = 1{\cdot}889 \text{ tg } [4^\circ{\cdot}915\,(g - 13{\cdot}5)] \qquad 13{\cdot}5 \leq g \leq 23.$$

In these formulae the products $2{\cdot}397 \times 3{\cdot}910$ and $1{\cdot}889 \times 4{\cdot}915$ are practically equal, as they must be if the first derivative at $13{\cdot}5$ cm shall be continuous. In these solutions less weight was assigned to the extreme readings. The normal table as published has been computed by means of the interpolation formulae from 4 to 23 cm. The interpolation formulae do not represent the observations beyond this interval. This may be seen from Table 1, which shows the agreement between formulae and observations.

TABLE 1.

Comparison between mean (m, g) relation as observed and as computed from the interpolation formulae.

g	O	C	$O—C$
	m	m	m
4	·666	·685	—·019
5	·929	·925	+·004
6	1·160	1·155	+·005
7	1·365	1·365	·000
8	1·561	1·555	+·006
9	1·738	1·745	—·007
10	1·913	1·915	—·002
11	2·082	2·085	—·003
12	2·250	2·255	—·005
13	2·417	2·415	+·002
14	2·582	2·585	—·003
15	2·748	2·745	+·003
16	2·916	2·915	+·001
17	3·090	3·085	+·005
18	3·270	3·265	+·005
19	3·463	3·465	—·002
20	3·670	3·675	—·005
21	3·905	3·915	—·010
22	4·177	4·185	—·008
23	4·536	4·505	+·031

TABLE 2. Residuals of the least squares solutions $m = a + b\, m_{pr}$; unit ·01 m_{pr}.

Plate no.		1120	1213	1215	1218	1625	1635	1643	1644	1648	2024	2036	2045*	2045	2056	2067	2825	2831
number of stars		100	52	92	70	62	53	41	42	31	31	40	15	12	28	15	20	29
relative gradation		1·14	·77	·94	·87	·97	·83	·92	1·03	1·04	·88	·99	·90	·76	1·02	·73	1·00	·83
relative weight	g																	
1	2	—3	—2	—3	—2	+6	+8	—3	+22	+14	—4	—10	+4	—6	—13	—4	—18	+5
3	3	0	0	—1	—2	+4	+6	—2	+13	+9	—2	—5	+2	—5	—13	—1	—14	+5
7	4	+1	0	0	—2	+3	+4	—1	+7	+4	—3	—3	0	—5	—10	—2	—5	+3
11	5	0	+3	0	—1	+2	+4	—1	+3	0	—2	—3	—1	—3	—5	—1	—2	+2
16	6	0	+3	0	—1	+1	+3	—2	+1	—1	—2	+2	—1	—2	—3	—1	—1	+2
21	7	0	+4	+1	+1	0	—3	—2	0	—2	—1	0	—2	0	—2	0	+1	+2
25	8	—1	+2	+1	0	—1	+2	—2	—1	—2	0	+1	—1	—1	—1	+1	+2	+2
30	9	—1	+1	+1	—3	0	+1	0	—1	—1	0	0	—1	—1	0	+3	+4	+1
33	10	—1	—1	0	+1	—1	0	+2	—2	—1	+1	0	0	0	+1	+2	+2	—1
36	11	—1	—2	0	+1	0	0	0	—2	—1	+1	0	+1	+1	+2	+1	+1	—1
38	12	—1	—2	0	+1	0	—1	+1	—2	0	+1	+1	+1	+1	+2	0	+1	—1
39	13	—1	—1	—1	+1	0	—2	+1	—1	0	+1	+2	+1	+1	+2	—1	0	—1
39	14	0	—2	0	+1	—1	—2	+1	—1	+1	+1	+1	+1	+1	+2	—1	0	—2
38	15	0	—2	0	+1	—1	—2	+2	—1	+2	+1	+1	0	+2	+3	—1	—1	—2
36	16	0	—3	—1	0	—1	—3	+2	0	+2	+1	+2	+1	+1	+4	—1	0	—2
33	17	+2	—2	—1	0	0	—2	+1	+1	+2	0	+2	0	0	+3	—3	—2	—3
30	18	+2	—2	—1	—1	+2	—1	0	+2	+2	0	0	—1	0	+2	—3	—2	—2
25	19	+2	—1	0	—1	+1	0	—2	+3	+2	—2	0	—1	0	+1	—3	—1	0
21	20	+2	+1	+2	—1	+1	+1	—3	+3	+1	—3	—2	—1	—2	—1	—3	0	+1
16	21	+1	+2	+2	—3	+2	+1	—3	+4	—1	—2	—2	—1	—3	—4	+1	0	+2
11	22	0	+3	+1	—2	+1	+3	—3	+3	—3	0	—3	0	—3	—8	+6	0	+4
7	23	—6	+7	+1	0	—2	+10	0	—4	—4	—1	—3	0	—5	—12	+8	+2	+7
3	24	—20	+17	—3	+10	+1	+16	+5	—14	—12	+2	—2	+3	—5	—20	+15	+4	+12

*) The two exposures on this plate showed different gradations. Therefore two (m, g) relations have been derived.

Relation between galvanometer reading g and provisional magnitude m_{pr}; fog reading = 25 cm.

g	m_{pr}	g	m_{pr}	g	m_{pr}	g	m_{pr}	g	m_{pr}	g	m_{pr}	g	m_{pr}
2·640	·21	4·542	·82	7·399	1·44	10·840	2·06	14·608	2·68	18·170	3·30	21·014	3·92
·667	·22	·583	·83	·451	1·45	·899	2·07	·669	2·69	·222	3·31	·054	3·93
·694	·23	·625	·84	·502	1·46	·959	2·08	·730	2·70	·274	3·32	·093	3·94
·721	·24	·666	·85	·553	1·47	11·018	2·09	·791	2·71	·326	3·33	·132	3·95
·748	·25	·707	·86	·605	1·48	·077	2·10	·852	2·72	·378	3·34	·170	3·96
·775	·26	·749	·87	·656	1·49	·137	2·11	·913	2·73	·430	3·35	·209	3·97
·802	·27	·791	·88	·708	1·50	·197	2·12	·974	2·74	·481	3·36	·248	3·98
·829	·28	·833	·89	·761	1·51	·256	2·13	15·034	2·75	·532	3·37	·286	3·99
·856	·29	·875	·90	·813	1·52	·315	2·14	·094	2·76	·582	3·38	·324	4·00
·883	·30	·918	·91	·865	1·53	·375	2·15	·155	2·77	·632	3·39	·361	4·01
·910	·31	·960	·92	·918	1·54	·435	2·16	·215	2·78	·683	3·40	·399	4·02
·937	·32	5·003	·93	·971	1·55	·495	2·17	·276	2·79	·733	3·41	·436	4·03
·965	·33	·046	·94	8·023	1·56	·555	2·18	·336	2·80	·783	3·42	·473	4·04
·992	·34	·089	·95	·076	1·57	·615	2·19	·396	2·81	·833	3·43	·510	4·05
3·020	·35	·132	·96	·130	1·58	·675	2·20	·456	2·82	·883	3·44	·547	4·06
·047	·36	·175	·97	·183	1·59	·735	2·21	·516	2·83	·932	3·45	·583	4·07
·075	·37	·219	·98	·236	1·60	·796	2·22	·576	2·84	·981	3·46	·620	4·08
·102	·38	·262	·99	·290	1·61	·857	2·23	·636	2·85	19·030	3·47	·656	4·09
·130	·39	·306	1·00	·344	1·62	·917	2·24	·696	2·86	·079	3·48	·692	4·10
·157	·40	·350	1·01	·398	1·63	·977	2·25	·755	2·87	·128	3·49	·728	4·11
·185	·41	·395	1·02	·452	1·64	12·038	2·26	·815	2·88	·176	3·50	·764	4·12
·214	·42	·439	1·03	·506	1·65	·098	2·27	·874	2·89	·224	3·51	·799	4·13
·244	·43	·483	1·04	·561	1·66	·159	2·28	·933	2·90	·272	3·52	·835	4·14
·273	·44	·528	1·05	·615	1·67	·220	2·29	·991	2·91	·320	3·53	·870	4·15
·303	·45	·573	1·06	·670	1·68	·281	2·30	16·050	2·92	·367	3·54	·905	4·16
·332	·46	·618	1·07	·725	1·69	·341	2·31	·109	2·93	·414	3·55	·940	4·17
·361	·47	·663	1·08	·780	1·70	·402	2·32	·167	2·94	·461	3·56	·974	4·18
·390	·48	·709	1·09	·835	1·71	·463	2·33	·226	2·95	·508	3·57	22·008	4·19
·420	·49	·754	1·10	·890	1·72	·523	2·34	·284	2·96	·554	3·58	·042	4·20
·450	·50	·800	1·11	·945	1·73	·584	2·35	·343	2·97	·601	3·59	·076	4·21
·480	·51	·846	1·12	9·000	1·74	·645	2·36	·401	2·98	·647	3·60	·110	4·22
·513	·52	·891	1·13	·056	1·75	·706	2·37	·459	2·99	·693	3·61	·144	4·23
·546	·53	·937	1·14	·113	1·76	·767	2·38	·516	3·00	·739	3·62	·177	4·24
·579	·54	·984	1·15	·169	1·77	·828	2·39	·574	3·01	·784	3·63	·211	4·25
·612	·55	6·031	1·16	·224	1·78	·889	2·40	·632	3·02	·830	3·64	·244	4·26
·645	·56	·077	1·17	·280	1·79	·950	2·41	·689	3·03	·875	3·65	·277	4·27
·678	·57	·124	1·18	·337	1·80	13·011	2·42	·746	3·04	·920	3·66	·309	4·28
·711	·58	·171	1·19	·393	1·81	·072	2·43	·803	3·05	·965	3·67	·342	4·29
·744	·59	·219	1·20	·449	1·82	·133	2·44	·860	3·06	20·009	3·68	·375	4·30
·777	·60	·266	1·21	·506	1·83	·194	2·45	·916	3·07	·054	3·69	·407	4·31
·810	·61	·313	1·22	·563	1·84	·256	2·46	·972	3·08	·098	3·70	·439	4·32
·839	·62	·361	1·23	·620	1·85	·317	2·47	17·029	3·09	·141	3·71	·471	4·33
·868	·63	·408	1·24	·677	1·86	·379	2·48	·085	3·10	·184	3·72	·503	4·34
·897	·64	·456	1·25	·734	1·87	·439	2·49	·141	3·11	·228	3·73	·534	4·35
·926	·65	·504	1·26	·791	1·88	·500	2·50	·197	3·12	·271	3·74	·565	4·36
·955	·66	·553	1·27	·848	1·89	·562	2·51	·253	3·13	·314	3·75	·596	4·37
·984	·67	·601	1·28	·906	1·90	·624	2·52	·308	3·14	·357	3·76	·628	4·38
4·013	·68	·650	1·29	·964	1·91	·685	2·53	·363	3·15	·400	3·77	·659	4·39
·042	·69	·699	1·30	10·021	1·92	·747	2·54	·418	3·16	·442	3·78	·689	4·40
·062	·70	·748	1·31	·079	1·93	·809	2·55	·473	3·17	·485	3·79	·720	4·41
·101	·71	·797	1·32	·137	1·94	·871	2·56	·528	3·18	·527	3·80	·751	4·42
·140	·72	·846	1·33	·195	1·95	·932	2·57	·583	3·19	·568	3·81	·781	4·43
·180	·73	·896	1·34	·253	1·96	·994	2·58	·637	3·20	·610	3·82	·811	4·44
·219	·74	·945	1·35	·311	1·97	14·055	2·59	·691	3·21	·651	3·83	·841	4·45
·259	·75	·995	1·36	·370	1·98	·116	2·60	·745	3·22	·693	3·84	·871	4·46
·299	·76	7·045	1·37	·428	1·99	·178	2·61	·798	3·23	·734	3·85	·900	4·47
·340	·77	·095	1·38	·486	2·00	·239	2·62	·852	3·24	·775	3·86	·930	4·48
·380	·78	·145	1·39	·545	2·01	·301	2·63	·906	3·25	·815	3·87	·959	4·49
·420	·79	·196	1·40	·603	2·02	·362	2·64	·959	3·26	·855	3·88	·989	4·50
·461	·80	·247	1·41	·662	2·03	·424	2·65	18·012	3·27	·895	3·89	23·018	
·501	·81	·297	1·42	·722	2·04	·485	2·66	·065	3·28	·935	3·90		
4·542		·348	1·43	·781	2·05	·546	2·67	·118	3·29	·975	3·91		
		7·399		10·840		14·608		18·170		21·014			