On a new method for the determination of absolute declinations

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On a new method for the determination of absolute declinations,

by *C. Sanders* and *J. J. Raimond Jr.*

1. *The principle.*

On page 333 of NEWCOMB's Compendium of Spherical Astronomy the variability of the zero point of a divided circle, be it the zenith, the nadir, the equator or the pole, is mentioned as "one of the most troublesome problems with which the observer has to deal". The only way to avoid these changes is to do away with the zero point itself. In azimuth work as well as in the determination of right ascensions there seems to be no way of doing this. Zenith distances however may succesfully be measured without a knowledge of the zenith point by using a theodolite in its two positions or, for more refined astronomical work, by a vertical circle, as is done by BONSDORFF [1]).

In meridian circle work it is impossible to reverse the instrument on each star; absolute determinations of declinations being hitherto made by using the nadir as the zero point, whereas differential determinations depend on the equator point derived from the circle readings of fundamental stars. The variability of both these points, even when freed from temperature and other, more or less plausible, effects, is the cause of constant trouble, detracting much of the precision of the measurements themselves. As long as the meridian circle is considered as an instrument complete in itself, nothing can remove this defect. The question assumes quite a different aspect if we call to its aid another instrument, of at least the same precision, by which simultaneously with the meridian circle the necessary observations are made to cancel the effect of the varying zero point or rather to eliminate any observation of such a point.

In fact two stars culminating, the one north and the other south of the zenith, intercept on the meridian an arc equal to the sum of their apparent meridian zenith distances. This arc may be measured without any knowledge of the zero point in any position of the circle and changes of the zero point by any cause will scarcely affect the results, if the stars have nearly the same right ascension. If, in addition, the zenith distances do not differ more than 20′, the differences of the zenith distances may be measured with great precision with the zenith telescope. Introducing the latitude of the zenith telescope, we may also consider the quantity 2φ minus the difference just mentioned as being equal to the *sum* of the declinations of the observed stars. The arc measured with the meridian circle corrected for refraction and flexure resulting in the *difference* of those declinations, the declinations themselves can be readily computed.

This is the principle, which guided our efforts. The observations discussed below were undertaken as a practical test of this principle, which had been in the mind of the senior of us for some time.

2. *The observations.*

During 5 nights, from May 31 to June 6 of the present year, we have simultaneously observed some TALCOTT pairs with the zenith telescope (observer SANDERS) and with the meridian circle (observer RAIMOND).

Indicating the north and south stars by the indices n and s respectively, we have for the zenith telescope:

$$\delta_n + \delta_s = 2\,\varphi + (z'_n - z'_s) + (\rho_n - \rho_s)$$

and for the meridian circle:

$$\delta_n - \delta_s = (z'_n + z'_s) + (\rho_n + \rho_s) + 2f$$

where: δ = declination,
z' = apparent zenith distance,
ρ = refraction,
f = flexure,
φ = latitude,

$(z'_n - z'_s)$ being corrected for the errors of the micrometer screw and $(z'_n + z'_s)$ for division errors and run of the microscopes.

1) *Vierteljahrschrift* 1913, p. 240 and *Resultate der absoluten Deklinationsbestimmungen* 1915, by I. BONSDORFF.

TABLE 1. Provisional results of declinations determined from combined observations of meridian circle and zenith telescope (epoch 1928·42).

pair	name [1])	mag.	$\alpha_{1928\cdot0}$	date	$\delta_{1928\cdot0}$	
			h m		° ′ ″	° ′ ″
1	Grw 1600 (Boss 3598)	6·7	13 50·3	June 2	79 21 3·51	24 54 36·87
	CbrE 6693	7·3	59·6	3	3·55	36·29
					3·53	36·58
2	Grw 2241	7·8	14 5·3	June 1	77 19 24·58	27 7 42·52
	CbrE 6788	7·8	14·9	2	23·78	42·90
				3	24·04	41·73
					24·13	42·38
3	Grw 1923	7·2	14 27·8	June 1	78 49 4·95	25 39 49·93
	CbrE 6814	6·1	19·9	2	4·34	49·89
				3	4·64	49·70
				6	5·03	49·86
					4·74	49·84
4	Grw 1313	6·5	14 35·6	June 1	79 58 18·17	24 23 50·06
	BerlB 5160	7·0	44·4	2	17·41	50·68
				3	17·77	50·29
				6	18·50	49·75
					17·96	50·20
5	Grw 1067	7·2	14 53·7	May 31	81 2 32·55	23 11 6·15
	BerlB 5239	7·5	15 4·1	June 1	32·60	6·19
				2	32·58	6·14
				3	32·10	6·43
				6	32·73	6·12
					32·51	6·21
6	Grw 1932	7·8	15 20·5	May 31	78 39 9·81	25 45 17·95
	CbrE 7221	7·4	26·9	June 1	10·04	17·03
				2	10·66	16·47
				6	10·35	17·22
					10·22	17·17
7	Grw 2261 (Boss 3982)	5·4	15 33·5	May 31	77 35 23·40	26 31 21·88
	CbrE 7301 (Boss 3998)	3·8	39·7	June 1	23·14	22·56
				2	22·95	22·76
				6	22·87	22·32
					23·09	22·38
8	Grw 1939 (Boss 4035)	4·4	15 46·6	May 31	78 1 0·66	26 22 21·41
	CbrE 7443	7·8	58·1	June 1	0·54	21·40
				2	0·27	21·47
				6	0·09	21·60
					0·39	21·47
9	Grw 1330	7·6	16 5·5	May 31	80 49 22·85	23 18 2·97
	BerlB 5556 (Boss 4142)	6·5	13·2	June 1	22·41	3·19
				2	23·02	2·21
				6	22·57	2·66
					22·71	2·76

[1]) Grw = Greenwich second nine-year cat., Part II, 1900·0.

In order to get an idea of the accuracy of the method we adopted for φ the value $+52°9'19''\cdot80$, for f the values given in Leiden Annals XIII, 4, page 18, and computed the refraction from the tables of ALBRECHT. The results, reduced to 1928·0, are given in Table 1. They are valid for the epoch of observation 1928·42 and the equinox 1928·0.

To avoid useless complications the meridian circle remained during all these observations in the position clamp west. Thus the two microscopes were always read at the same divisions. In each of the (diametrically opposite) microscopes two divisions were read off. For these zenith distances and this state of the meridian circle the correction for flexure amounts to $+''\cdot32$.

As to the internal agreement the results show that the method is reliable and capable of a precision which at present is only slightly surpassed by that of BONSDORFF's vertical circle observations, the mean error of one declination computed from the residuals of separate observations with the mean per star being $\pm''\cdot35$, against BONSDORFF's $\pm''\cdot28$ for the same zenith distances and computed in the same manner, where one declination is the mean of 8 pointings with a movable thread, whereas in the present observations the meridian circle was pointed once on each star with the slow motion.

The quality of the air on respective nights was: May 31: perfect, June 1: good, June 2: fairly good, June 3: poor, June 6: fairly good.

Notwithstanding these not extremely favourable circumstances the mean error has a value which is only 2/3 of the m.e. of that of differential measurements with the meridian circle, which, as far as the observation goes, are best comparable with our observations.

Our mean error ε contains the m. e. ε_1 of one pointing and reading with the meridian circle and the m. e. ε_2 of the measured difference $(z'_n - z'_s)$ in the following manner:

$$''\cdot35 = \pm \tfrac{1}{2} \sqrt{2\,\varepsilon_1^2 + \varepsilon_2^2}.$$

Adopting for ε_2 the value $\pm''\cdot28$ we find: $\varepsilon_1 = \pm''\cdot45$. ε_1 contains: **1°**. the error of the pointing of the horizontal wire on the star with the aid of the slow motion, **2°**. that of the readings of the microscopes and **3°**. the uncertainty of the computed refraction, and, which is perhaps the most dangerous, that of the adopted flexure. In a more extensive programme also the errors of the assumed division errors will enter into ε_1.

From the residuals it appears that the mean error of the south stars is somewhat larger than that of the north stars. Probably the pointings on the north stars are more accurate than those on the south stars, but in the reductions the errors of the measured arcs are distributed equally among both declinations; the present material however is too small to settle this point. At present our main aim is to give a rough idea of what may be obtained.

To illustrate the variation of the zero point we have computed the equator points from the mean of the circle readings corrected for $\frac{1}{2}(z'_n - z'_s)$ and the latitude. They are tabulated in Table 2 and also shown in the diagram of fig. 1. The table shows the aspect familiar to every meridian astronomer.

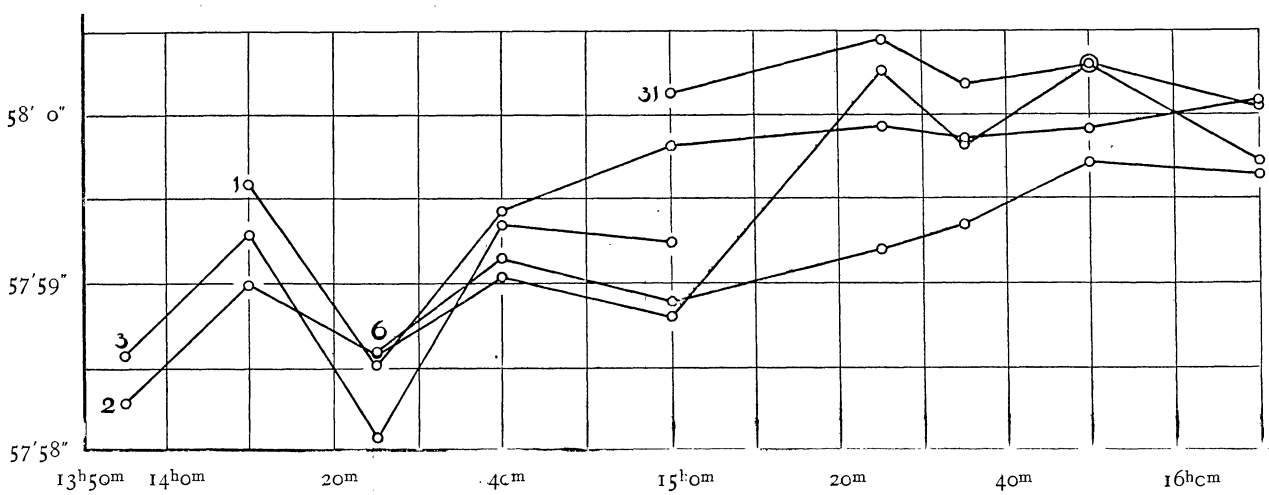

FIGURE 1.

Equator points May 31—June 6.

Quite interesting was a comparison with other catalogues, especially with the *P. G. C.* (see Table 3).

As the pairs were chosen from an existing programme for the zenith telescope, which was used by the first

TABLE 2. Equator points computed from the measured sum and difference of zenith distances.

pair	May 31	June 1	June 2	June 3	June 6
1			127° 57′ 58″·28	127° 57′ 58″·56	
2		127° 57′ 59″·52	58·99	59·28	
3		58·52	58·58	58·09	127° 57′ 58″·59
4		59·43	59·03	59·35	59·14
5	127° 58′ 0″·12	59·81	58·79	59·24	58·88
6	0·44	59·93	58 0·26		59·20
7	0·19	59·86	57 59·84		59·35
8	0·29	59·92	58 0·30		59·72
9	57 59·72	58 0·08	0·05		59·63
mean	127° 58′ 0″·15	127° 57′ 59″·63	127° 57′ 59″·35	127° 57′ 58″·90	127° 57′ 59″·22

of us, only 5 stars are contained in the *P. G. C.* The respective columns of Table 3 contain the δ's as given in:
BOSS' *P. G. C.*,
Publ. of the U. S. Naval Observatory, vol. XI, second series, Catalogue of 2499 stars for 1910·0,
Resultate der absoluten Deklinationsbestimmungen 1915, by BONSDORFF,
Greenwich catalogue of stars 1925.

TABLE 3. Comparison with other catalogues.

star	P. G. C.	Wash. 1910	Pulk. 1915	Grw. 1925	*S* and *R*
	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
BOSS 3598	79 21 3·33				79 21 3·53
BOSS 3982	77 35 22·87	{ 77 35 22·87 22·99	77 35 22·82	77 35 22·90	77 35 23·09
BOSS 3998	26 31 21·16		26 31 21·51	26 31 21·68	26 31 22·38
BOSS 4035	78 1 0·32	{ 78 1 0·22 0 59·93	78 1 0·08	78 1 0·49	78 1 0·39
BOSS 4142	23 18 1·76	23 18 1·73	23 18 2·17	23 18 1·91	23 18 2·76

Taking into account that our declinations still contain the variation of latitude, the north stars are in sufficient agreement with the *P. G. C.* As to the south stars the deviations are larger, bu tnot extremely large. It will be readily granted by all who are engaged in fundamental astronomy that near the equator the declinations of the *P. G. C.* may be subject to large systematic errors. Possibly it is not a mere accident that these few declinations of ours deviate from BOSS in the expected sense. Assuming the north declinations of the *P. G. C.* to be correct and that only the south stars need a correction, it seems that our latitude is about ″·2 too high, which may possibly be confirmed by observations for the latitude variation.

There is another proof that our results are possibly more reliable than the declinations of the *P. G. C.*. BOSS 3982 and 3998 form a TALCOTT pair and so the difference measured with the zenith telescope combined with the declinations from the *P. G. C.* give us a value of the latitude of the zenith telescope; in this case they give:

May 31:	52° 9′ 19″·16
June 1:	19 ·01
2:	19 ·01
6:	19 ·22
mean :	52° 9′ 19″·10,

which is undoubtedly too small even when the possibility of a large latitude variation is allowed for.

TABLE 4.

meridian circle	BOSS	obs.-BOSS
51° 4′ 7″·01	51° 4′ 7″·19	— ″·18
6·14 [1])	7·28	— 1·14
5·82 [1])	7·34	— 1·52
6·45 [1])	7·61	— 1·16
mean		— 1″·00

[1]) With grating reducing $2^m·5$.

In addition we have the arcs measured with the meridian circle (see Table 4). Comparing these with the differences of declination according to BOSS we find an average difference of — 1·″00, which is in fair agreement with the difference in the latitude found by the zenith telescope.

Taking for granted that the declination of the north star will be about right, there is a strong probability that the declination of the south star according to BOSS is about 1″ too far south. The good agreement between meridian circle and zenith telescope in this case cannot be easily attributed to mere accident. It would also be very strange if on four different nights the same kind of refraction anomaly should affect the observations of the south star.

We venture to think that this sort of check upon the exactness of our declinations is one of the most important advantages of this method.

Some other south stars occurred in the Greenwich catalogue of stars for 1910·0. The comparison is given in Table 5.

TABLE 5. Comparison with Grw. 1910·0.

A. G. C.	Grw. 1910·0	*S* and *R*
CbrE 6788	27° 7′ 43″·04	42″·38
CbrE 6814	25 39 50·32	49·84
BerlB 5160	24 23 49·09	50·20
CbrE 7221	25 45 16·81	17·17
CbrE 7443	26 22 21·67	21·47

For the moment it is useless to make further comparisons.

3. In this paragraph we wish to make a few remarks about the conditions to be fulfilled for the performance of this sort of observations in a larger programme.

It is not necessary that both instruments have the same latitude, as was the case with the present observations; only the latitude of the zenith telescope and its variation, the principal aim of the zenith telescope, must be known as accurately as possible. In order to avoid waste of time it should be possible for one meridian circle to work with two zenith telescopes, each in its own place and with its own programme, or with one zenith telescope with two or three different programmes to be used alternately so as to avoid a superfluity of observations on one and the same pair.

A very important point concerning the limitation of the programme, is the optical capacity of both instruments, which must not differ too much. It would be desirable to have for example a transit instrument of rather large dimensions, capable of quick reversal, and provided with one or two TALCOTT levels and a movable declination wire.

Concluding, we may add some general remarks. In this fundamental method no observations are made independent of the star observations (such as e.g. the determination of nadir point by the mercury horizon). If the measurements with the zenith telescope may be considered free from systematic errors, there remain the systematic errors (of unknown origin) of the circle used; such as are found in the differences between the ERTEL and the REPSOLD's vertical circles at Pulkowa [1]).

Although it may seem superfluous we yet may once again lay stress on the importance of varying methods for fundamental work. We may just quote two sentences. The first was pronounced by the late Sir DAVID GILL on occasion of a discussion with Prof. TURNER [2]). "..... I quite agree that those who see their way to a probability of improving our methods should devote at least part of their time to making such experiments as seem likely to lead to that end."

The other concludes OORT's investigation of the constant of refraction [3]). "In general the discussions in this paper show again that it is eminently important to determine declinations fundamentally at many different observatories and, *if possible, by different methods.*"

Additional note.

After finishing the preceding paper we have made a few more observations on four nights, viz. Sept. 5, 6, 7 and 8. During the nights of Sept. 5 and 6 the position of the meridian circle was clamp east, and clamp west on Sept. 7 and 8. On Sept. 6, 7 and 8 two diametrically opposite microscopes were read off at both circles, one observer (RAIMOND) made the pointings with the slow motion and read the microscopes on the west pier, and a second (G. VAN HERK) read those on the east pier as well as the thermometers.

The reductions were made for both circles separately. Table 6 contains the resulting declinations. Both circles are in fair agreement, the agreement between the different nights however is far worse than in the former series; the m. e. being ± ″·66 for each circle, as against ± ″·35 for the series treated above.

Although this error (as well as that in the preceding paper) computed from some sixty residuals has only the character of a rough estimate and may be subject to accidental uncertainties, there is some evidence that it is caused by atmospheric anomalies. In fact

[1]) BONSDORFF, *l. c.*
[2]) *Observatory*, April 1911, page 147.
[3]) *B. A. N.* **143**, page 141.

TABLE 6. Provisional results of declinations from combined observations of meridian circle and zenith telescope (epoch 1928·7).

pair	name	mag.	$\alpha_{1928\cdot0}$	date	$\delta_{1928\cdot0}$ circle A	$\delta_{1928\cdot0}$ circle B	$\delta_{1928\cdot0}$ circle A	$\delta_{1928\cdot0}$ circle B
			h m		° ′ ″	″	° ′ ″	″
1	Grw 2689 (Boss 4911)	5·2	19 11·8	Sept. 5	76 26 —	29·92	27 48 —	26·08
	Cbr E 10049 (Boss 4986)	3·2	27·8	6	28·75	28·63	27·09	27·12
				7	29·32	—	26·53	—
				8	29·21	28·84	26·56	26·95
					29·09	29·13	26·73	26·72
2	Grw 1242 (Boss 2034) L. C.	6·5	7/19 44·6	Sept. 5	80 26 —	59·92	4 48 —	20·79
	Alb 6825	7·4	19 41·0	8	58·13	58·59	19·50	19·96
					58·13	59·26	19·50	20·38
3a	Grw 2899 L. C.	6·5	8/20 13·2	Sept. 6	75 2 47·89	47·83	— 0 54 38·88	38·94
	Nic 5056 (Boss 5142)	6·2	20 0·7	7	47·67	48·43	39·47	38·72
				8	46·44	46·90	40·89	40·42
					47·33	47·72	39·75	39·36
3b	Grw 2899 L. C.	6·5	8/20 13·2	Sept. 5	75 2 —	45·87	— 0 53 —	12·25
	Nic 5067 (Boss 5159)	6·5	20 4·4	7	47·72	48·39	10·65	9·98
				8	45·99	46·61	12·44	11·81
					46·86	46·96	11·54	11·35
4	Grw 891 (Boss 5377)	5·9	20 47·9	Sept. 5	82 15 —	57·39	22 2 —	47·87
	BerlB 8024 (Boss 5397)	5·6	55·1	6	56·96	56·91	48·66	48·71
				7	57·30	57·60	48·42	48·22
				8	57·74	57·71	48·13	48·16
					57·33	57·40	48·40	48·24
5	Grw 2915 L. C.	6·3	9/21 20·6	Sept. 5	75 24 —	35·83	— 0 12 —	23·08
	Nic 5401	6·5	21 11·0	6	35·61	35·52	22·32	22·41
				7	35·56	36·06	22·63	22·13
				8	34·00	34·77	23·69	22·92
					35·06	35·54	22·88	22·64
6	Grw 5800 (Boss 2591) L. C.	6·0	9/21 36·2	Sept. 5	69 34 —	0·36	— 5 53 —	18·86
	Wien-Ott. 7728 (Boss 5527)	2·9	21 27·8	6	0·20	0·05	19·12	19·27
				7	33 59·94	0·19	20·00	19·73
				8	58·81	58·96	19·82	19·67
					33 59·65	59·89	19·65	19·38
7	Grw 3732 (Boss 2656) L. C.	6·2	9/21 52·1	Sept. 5	73 13 —	23·37	— 2 30 —	12·76
	Strb 7695 (Boss 5663)	4·7	21 59·6	6	24·53	24·34	11·59	11·77
				7	23·34	23·68	12·66	12·32
				8	23·15	23·38	13·04	12·81
					23·67	23·69	12·43	12·42

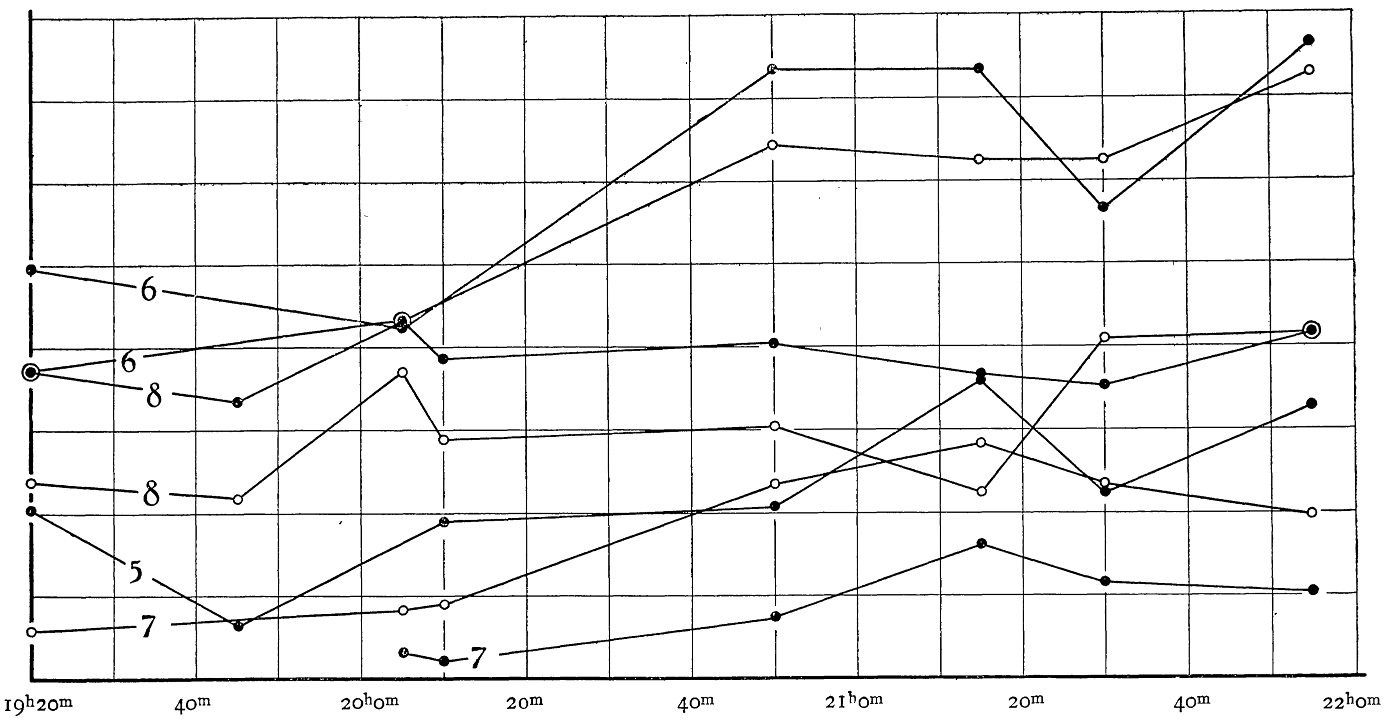

FIGURE 2. Equator points Sept. 5—8.

(Full dots refer to circle *B*, open circles to circle *A*. Same scale as Fig. 1).

the zenith (or equator) points, which depend only on the readings of the circles and on the measured differences of zenith distances, without any correction for refraction, show a much better agreement. The m. e. computed from the residuals from the mean for each night is ± ″·47, and when a linear rate is derived, this error becomes ± ″·30 (for the former observations these errors were ± ″·56 and ± ″·33 respectively). From this may be concluded that the pointings with the slow motion were not far in error, but that refraction anomalies may have affected the results. Just in this case, where only one pointing was made, such anomalies or fluctuations may enter fully into the results. On these nights the definition was rather poor and the images were in constant, perhaps rather slow, motion [1]). It is evident that the mean of three or four pointings with a movable wire will be far more trustworthy in such a case. It remains however still remarkable that these anomalies must have been symmetrical with respect to the zenith, otherwise the zenith point should have been affected.

In ordinary meridian work the zenith point is determined two or three times during a night, and is interpolated by a linear formula. In the method used here we have a determination of the zenith point for each pair of stars from the simultaneous observations with the zenith telescope. The instantaneous zenith point thus derived is used to compute the declinations. It is interesting to investigate the agreement of the declinations of the same stars on different nights if, instead of the instantaneous zenith points, the values derived by a linear interpolation formula are used. We have therefore for each of these nights derived a formula of the form $a + bt$ for the zenith points and computed the declinations from these interpolated zenith points. The mean errors were derived from the deviations of the declination

[1]) See the irregularities in photographic star trails, measured by Prof. F. SCHLESINGER, *M. N.* **87**, p. 510, May 1927.

TABLE 7. Comparison with the *P. G. C.*

P. G. C. N°	P. G. C.	*S* and *R*
4911	76° 26′ 28″76	29″11
4986	27 48 26·31	26·72
2034 (L. C.)	80 26 58·50	58·70
5142	— 0 54 40·75	39·56
5159	— 0 53 11·64	11·44
5377	82 15 57·98	57·36
5397	22 2 47·36	48·32
5527	— 5 53 19·77	19·52
2591 (L. C.)	69 33 59·43	59·77
2656 (L. C.)	73 13 22·69	23·68
5663	— 2 30 13·18	12·42

of each star on the several nights from the mean in the same way as above. We find:

	m. e. of one declination derived with		mean difference instant-aneous—inter-polated
	instantaneous equator points	interpolated equator points	
first period	± ″·35	± ″·41	± ″·26
second period:			
circle A	·66	·63	·16
circle B	·66	·71	·23

Since the uncertainty of each of these mean errors is of the order of 10°/₀ of its amount, no conclusions can be drawn as to whether the instantaneous or the interpolated zenith point is the better.

The last column gives the mean differences between the final declinations determined by the two methods, derived as if the differences were errors of independent observations (which, of course, they are not). They can be taken, however, as a measure of the uncertainty in the final declinations due to the method of reduction.