Astronomy. — *"Determination of the geographical latitude and longitude of Mecca and Jidda executed in* 1910—'11." By Mr. N. SCHELTEMA. Part I. (Communicated by Prof. E. F. VAN DE SANDE BAKHUYZEN).

(Communicated in the meeting of May 25, 1912).

I. *Introduction.*

Mecca as we know is the holy city and the meeting-place for Mohammedan believers. Yearly some 200.000 gather there from different parts of the world in order to make their pilgrimages and many of them stay there for a couple of years to gain a thorough knowledge of the doctrines of their religion.

From an economical and political point of view as well as for the history of religion Mecca is a place of great significance. Moreover it forms an important starting-point for the geography of the interior of Arabia. Hence it is not surprising that constant efforts have been made to obtain closer and the most accurate possible knowledge about this centre of the Islam; but great and peculiar difficulties are connected with these endeavours on account of the fact that entrance into the "holy domain" is strictly prohibited to non-Mohammedans. Only now and again a few Eurepeans succeeded in stealthily penetrating into it and spending there some time.

It is well known that among these stands first our compatriot the present professor Dr. C. SNOUCK HURGRONJE, who spent some eight months in Mecca and put down his exhaustive researches in his standardwork about this town. It stands to reason that my position as Consul of the Netherlands at Jidda, the harbour of Mecca, often brought me into contact with this scholar, and it was he who in the course of our talks drew my attention to the fact that so much scientific work might be done in the Hedjaz. In particular he pointed out that even the geographical position of Mecca was not accurately known and he raised the question if I might not supply this deficiency.

Others had succeeded in making fairly accurate plans of the town but its absolute position had not yet been determined with sufficient exactness. Lack of good instruments, which are not easily transportable and the necessity of taking care that no attention was drawn in the vicinity had generally prevented astronomical observations.

The only person by whom direct determinations of the latitude and the longitude of Mecca have been published is ALI BEY EL ABASSI, or at any rate the man who under that name travelled in many oriental countries from 1803 to 1807 and in the latter year also visited Arabia and Mecca. His "Travels" were published in London in 1816[1]). He made his astronomical observations with a reflecting-circle of 10inch diameter with 4 verniers by Troughton and an achromatic telescope by Dollond of 2½ feet, with the aid of two chronometers by Brooksbanks and Pennington (see Vol. **1**, p. XVII, Vol. **2**, p. IX). The latitudes were determined by meridian altitudes of the sun and stars, the longitudes by the transporting of chronometers, by lunar distances and by observations of eclipses of the satellites of Jupiter. Of his determination of the position of Mecca it is mentioned in particular that it was accomplished by means of altitudes of the sun and of lunar distances (**2**, 94)[2]); in the meantime the chronometer by Brooksbanks had been broken, while probably shortly afterwards, that of Pennington was stolen at Mina in the neighbourhood of Mecca, so that the determinations of longitude could not be continued. ALI BEY's results, especially his longitudes such as they have been published can only be of little accuracy. Taking, however, into account the good instruments he had at his disposal, it is probable that a renewed calculation might amend matters, but his original observations are not likely to have been preserved.

Besides from direct observations the position of Mecca might also be derived from that of Jidda by means of journeys between the two places with noted directions and distances, as the latter place has at present been accurately determined by the observations of the English hydrography. Of these itineraries HUBER's[3]) seems to stand first; it has been accurately calculated and discussed by J. J. HESS. Yet HESS[4]) himself must attribute to his results for the longitude and latitude of Mecca mean errors of resp. $\pm 3'.2$ and $\pm 3'.8$,

So even after this last investigation the position of Mecca was very unsatisfactorily determined and Prof. SNOUCK HURGRONJE's proposition to try and obtain greater accuracy attracted me greatly. In the summer of 1909 I therefore applied to the director of the Leyden observatory, Prof. E. F. VAN DE SANDE BAKHUYZEN, who was much

1) *Travels of* ALI BEY *in Morocco, Tripoli, Cyprus, Egypt, Arabia, Syria and Turkey between the years 1803 and 1807, written by himself.* London 1816 2 vols.

2) Erroneously J. J. HESS says in his *Geographische Lage Mekkas* that ALI BEY's longitude of Mecca is based on eclipses of the satellites of Jupiter.

3) CHARLES HUBER, *Journal d'un voyage en Arabie.* Paris 1891.

4) J. J. HESS, *Die geographische Lage Mekkas und die Strasse von Gidda nach Mekka.* Freiburg 1900.

interested in my plans and kindly promised me help and advice. The execution of the work was now rendered possible and by the kind dispensation of His Excellency the Minister of Foreign Affairs, to whom I here respectfully render thanks, I received a royal commission to execute astronomical observations in the Hedjaz.

Let me say first of all in what way I intended to set about the proposed plan. As it was quite impossible for me to enter Mecca and make observations, the help would be asked of Mr. A. SALIM, Pupil-Secretary-Interpreter of the consulate. As a Mohammedan be was perfectly free in his movements within the holy domain and having finished the 5 years' course of the Secondary School at Batavia, he was sufficiently well-grounded to successfully make the astronomical observations. Let me add that Mr. SALIM showed an eager interest, when I communicated my plans to him.

According to the consultations with Prof. BAKHUYZEN a more detailed plan was now made out for the execution of the observations. For the determination of the latitude of Mecca circummeridian-altitudes of stars were to be observed and the same was to be done also at Jidda, partly for practice, partly for the examination of the instrument and of the employed method of observation and finally to mutually control the results obtained by the English hydrographers and by ourselves. Secondly the difference of longitude between Jidda and Mecca was to be determined by transporting some chronometers to and fro between the two places, if possible a couple of times, while during the stay in each place as many determinations of time as possible would be made by altitudes of stars in the east and in the west. All the observations at Mecca having to be accomplished by Mr. SALIM, also the corresponding determinations of time at Jidda wanted for the derivation of the difference of longitude were to be executed by him. All the observations were to be made with a small altazimuth.

First of all I now tried to use the rest of my furlough to practise making observations at the Leyden observatory. The exceedingly unfavourable summer of 1909 gave, however, only very rare opportunities for observations and so I had to leave again for Jidda at the end of July without having acquired sufficient skill in observing.

Consequently the observations I accomplished after my arrival at Jidda left much to be wished for in arrangement as well as in accuracy. Besides, other circumstances, among which an extremely busy time at the consulate, concurred in impeding the work. Owing to all this the material collected in the winter of 1909—10 has so little value that we can henceforth leave it out of account.

Fortunately the next year was in all respects more favourable for my enterprise. During my furlough in the summer of 1910 I again had the pleasure to work for three weeks at the observatory under the guidance of Prof. VAN DE SANDE BAKHUYZEN, and this time the heavens often gave an opportunity for observations. After my stay at Leyden I was moreover able to practise quite by myself for a few weeks in Gelderland with the instrument I had taken with me.

Under good prospects I therefore returned to Jidda towards autumn, and when early in November the greatest heat and also the busiest time at the consulate were over, I could begin regular observations and also Mr. SALIM could practise systematically under my supervision. Soon we were able to execute determinations of time and of latitude alternately on succeeding days. But now we met with another mischance. The chronometer employed for the observations began to accelerate very much and very irregularly and at last it stopped altogether (December 2). Since no observations could be made with any of my pocket-chronometers, the only thing left to do was to stop our observations until another box-chronometer could be forwarded from Leyden.

Owing to this ill luck and on account of the irregular connexion between Holland and Jidda, a delay was caused of more than six weeks. Not till the end of January 1911 could we resume the observations and with a view to the advanced time, it seemed best that they should further be done by Mr. SALIM alone.

Thanks to his ability and zeal the series of observations undertaken could be brought to a satisfactory result between January 25 and March 23 1911. During this time three journeys were made to Mecca. Before the first journey and after the 1st, 2nd and 3rd the corrections of the chronometers were determined at Jidda on 23 nights and during the journeys 14 determinations of time were accomplished at Mecca. Besides, the latitude of Mecca was determined on 10 nights and that of Jidda on 13 nights, while for the last mentioned place already 7 determinations of latitude had been accomplished by the two of us in Nov.—Dec. 1910.

Finally, a journey from Mecca to Jidda made on foot by Mr. SALIM with the determination of distances and directions enabled him to make a map of the road between the two places.

As much as possible we calculated our observations ourselves, also to continually control our instruments, but of course the accurate calculation and the systematic derivation and discussion of the results could not take place until after my return to Holland.. These have been done at the observatory at Leyden under the supervision of Prof. VAN DE SANDE BAKHUYZEN, who also investigated the best methods of combining the observations. The extensive calculations have been for far the greater part executed by Mr. H. W. HAMERSMA, late chief mate of the Royal Dutch Navy.

In this way results have been obtained for the geographical position of Mecca which certainly exceed in accuracy all that has been known up to this time and therefore I take the liberty to offer a paper on this subject to the Royal Academy of Sciences.

II. *Instruments. Stations of observation.*

The instrument with which our observations were made was the universal-instrument Pistor and Martins N°. 905, belonging to the Technical University at Delft and kindly lent to me by Prof. HEUVELINK. The same instrument had formerly been employed by Mr. S. P. L'HONORÉ NABER of the Royal Dutch Navy for his observations for the demarcation between the republic of Liberia and French Congo.

The telescope of the instrument is at the end of the horizontal axis, while for the observation of small zenith-distances a reflecting prism can be brought before the ocular. The circles are read with verniers, the diameter of the vertical circle is 130 mm. and that of the objective is 28 mm. The value of a division of the level attached to the alidade-circle is about 8″. During my first stay at Leyden the spider-lines were broken. They were replaced by two horizontal threads only, at about 6′ distance from each other.

For a moment we had thought of employing instead the small universal instrument of the Leyden observatory, which has the same dimensions but is read with micrometer-microscopes. The consideration, however, that it is advisable in the damp and warm climate of Jidda to make as little use as possible of spider-threads especially of movable ones, made us give up this idea.

In the choice of the chronometers to be used, particular attention had to be paid to the peculiar circumstances attending the transport from Jidda to Mecca, which is done by camels, so that shocks cannot be altogether avoided. Moreover the road is far from safe; nearly every year a caravan is attacked and robbed by Beduins and it is therefore desirable not to take any conspicuous boxes. To carry these on foot would be altogether impossible. Discussing this point with Prof. VAN DE SANDE BAKHUYZEN and Mr. C. F. J. COSYN, Chief of the bureau of instruments of the Royal Navy, the latter drew our attention to the pocket-chronometers of Leroy, the so-called chronomètres-

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torpilleurs. These had been used by Mr. NABER in the above mentioned observations and had proved very satisfactory (see his communication in *Marineblad*, vol. **24**), while also at Mr. COSYN's bureau they had been found to go very regularly.

Through the kind permission of the Admiralty six of these watches have been lent to me, while the Home Office took the risks of their carriage to and in the Hedjaz. I here express my respectful thanks to their Excellencies the ministers.

In order to carry these six watches Mr. NABER had had a wooden box made with six pigeonholes, which was again to be packed into a leather bag to be carried knapsack-wise. This box and this bag we were allowed to employ, and transporting the watches in this way we could be pretty sure that they were free from disturbance.

The observations, however, could not be made directly on their very low ticks (5 per second) and therefore I had from the Leyden observatory the loan of a box chronometer by Cummins. As I have said before, however, this chronometer got out of order in Nov. 1910, and then Prof. BAKHUYZEN sent me another chronometer, by Dent, so that the greater part of our observations has been made with this one.

Finally my equipment contained an aneroid-barometer marked: Holosteric 7225 with an attached thermometer, a separate thermometer for the external temperature and a magnetic boussole. The correction of the barometer was determined at Leyden, through a comparison with the normal barometer of the observatory and was found to be $-1^{mm}.5$ in Dec. 1909 and $-2^{mm}.8$ in Aug. 1911. No dependence on the reading of the barometer was appreciable and so I corrected all my readings with -2^{mm}. As corrections of the attached thermometer and of the other one I found respectively $+1^{\circ}.0$ and $-0^{\circ}.5$, which corrections have always been added.

In the beginning there was some difficulty in getting the universal instrument well stationed at Jidda. The observations could not be made in the open because that would have been very conspicuous and we should certainly have been molested by the population, while no doubt difficulties would have arisen with the Turkish authorities. A fairly large enclosure next to the consulate, which I had been thinking of, proved to be impracticable, since the outlook to the west was too far intercepted by the consulate.

So there was nothing else for it but to find a place on the roof of the consulate. This seemed to be easy, since here, as everywhere else, there was a flat roof offering sufficient room. Such a roof, however, rests on fairly thin beams over which matting is spread covered with a layer of cement, so that it trembles when walked upon. Yet I succeeded in constructing a fairly stable mounting; near one of the corners of the roof on two walls that crossed each other and were raised a few centimeters over the roof, two heavy beams were laid and cemented down and on the top of these two thin beams were nailed on which the tripod of the instrument could be placed.

For further illustration see the picture on plate I. This shows that the tripod was made heavier by a big block of stone and we took care not to touch the supporting beams, although we had to adopt rather uncomfortable poses for some of the positions of the telescope. We soon got used to this, however, and the end was attained. We could now walk round the instrument, even stamping our feet, without causing the bubble of the level to move in the least. Afterwards Mr. SALIM arranged his station as Mecca in exactly the same way on the roof of a house rented by me.

The only thing sometimes preventing pleasant and quiet working was the noise in our neighbourhood. Regularly every evening at about 8 o'clock there was a musical performance by the Turkish military band at Jidda, and even more troublesome was the noise often occurring in the evenings in my neighbour's house and occasioned by an ice-machine making almost two turns per second. All we could do was to wait till quiet should return, although sometimes stars were lost in this way.

We had also made a point of determining, if possible every night, the zenithpoint of the instrument on a signal at some distance. This was done in order to continually control the mutual stability of the parts of the instrument, and also to facilitate the computation of the observations and to trace immediately eventual errors, e.g. in the reading of full degrees or in the employed star. At Jidda we used as signal a lantern with a circular hole placed on the roof of the sufficiently far off French consulate. At Mecca the observer used a black spot on the wall of a post situated on the Jebel Abu Kobeis a hill quite close to the town.

3. *Value of the parts of the level. Zenithpoint of the instrument.*

The divisions of the alidade-level are numbered in such a way that if the reading of the bubble is too low, the reading of the verniers must be increased. The value of a division was measured a couple of times by displacing the alidade, the instrument being clamped.

In Oct. 1909 11 determinations in 9 days gave 1 d. = 7″.85 ± 0″.20
in Oct. 1910—March 1911 15 determinations
in 12 days . . . . 1 d. = 8″.91 ± 0″.19
while all the determinations together would yield 1 d. = 8″.46 ± 0″.17

Will it be better to use for our observations the value 8″.91 or 8″.46? Since 8″.7 had been actually used for the calculations, there did not seem to be any reason to change. The influence of an error in the value of a division on our final results is but small. A change in the adopted value by 0″.5 would alter the results for the latitude of Mecca and of Jidda with less than 0″.2.

The zenithpoint was with a few exceptions determined every evening and each time for both the horizontal threads. In the following table have been collected the means of the two results together with their differences, i.e. the mutual distance of the threads. (See the table on p. 535).

For each period there have been added the means of the daily results; in forming these means we have left out of account Nov. 18 and 24, the results of which days are divergent.

From this table it appears that in each period the zenithpoints, determined on different evenings, mostly agree satisfactorily, but that after every journey the reading for the zenith has become a little higher. After the last journey back from Mecca it has considerably increased, with about 4′.5, probably owing to a displacement of the level-tube with regard to the alidade. A few oscillations seem to appear in the thread-interval, while two very diverging results occur in Nov. 1910.

4. *Determination of the geographical latitude of Jidda and of Mecca.*

Coming to the observations proper I will now first communicate the latitude determinations executed at Jidda and at Mecca and the results derived from these. For their reduction we must naturally know the corrections of the chronometer used, just as knowledge of the latitude is required for the reduction of the time determinations. I will, however leave the tables containing the chronometer-corrections till the next paragraph.

With a few exceptions each latitude determination consists in the observation of a northern and of a southern star, each in the two positions of the instrument. Every time two pointings were made, one on each of the two threads; the level was always read before and after the reading of the verniers.

ZENITHPOINT DETERMINED ON THE SIGNAL.

	Mean zenithpoint	Thread-interval
Observations 1910		
Scheltema		
Nov. 18	90° 12′ 20″0	5′ 13″7
„ 23	8.1	56.9
„ 25	7.2	51.3
„ 28	16.7	56.4
„ 30	15.8	53.9
Mean	**90° 12′ 11″9**	**5′ 54″6**
Salim		
Nov. 24	90° 11′ 52″2	5′ 18″1
„ 26	69.9	41.2
„ 29	54.1	39.6
Mean	**90° 12′ 2″0**	**5′ 40″4**
Observations 1911		
1st period Jidda		
Jan. 23	90° 11′ 53″7	5′ 44″4
„ 25	60.2	54.6
„ 26	47.3	50.0
„ 28	58.0	49.7
„ 30	57.8	48.1
„ 31	55.8	39.4
Febr. 1	52.0	50.9
„ 3	60.2	53.8
„ 6	57.1	48.6
„ 7	54.2	34.4
„ 8	48.5	46.8
„ 12	56.8	51.0
Mean	**90° 11′ 55″1**	**5′ 47″6**
2nd period Mecca		
Febr. 15	90° 12′ 10″2	5′ 52″5
„ 16	17.0	61.4
Mean	**90° 12′ 13″6**	**5′ 57″0**
3rd period Jidda		
Febr. 18	90° 12′ 17″4	5′ 56″1
„ 20	18.8	49.3
„ 22	4.9	44.8
Mean	**90° 12′ 13″7**	**5′ 50″1**
4th period Mecca		
Febr. 24	90° 12′ 16″4	6′ 5″0
„ 25	16.2	4.1
„ 26	16.7	13.6
„ 27	18.6	12.9
Mean	**90° 12′ 17″0**	**6′ 8″9**
5th period Jidda		
March 2	90° 12′ 21″4	5′ 40″3
„ 3	25.1	51.0
„ 7	28.2	51.8
„ 8	24.7	46.1
Mean	**90° 12′ 24″8**	**5′ 47″3**
6th period Mecca		
March 11	90° 12′ 24″8	6′ 9″2
„ 12	31.9	11.3
„ 14	23.5	8.2
„ 15	32.7	7.8
„ 16	38.3	5.0
„ 17	35.6	6.2
Mean	**90° 12′ 31″2**	**6′ 7″9**
7th period Jidda		
March 19	90° 16′ 53″4	5′ 49″1
„ 20	67.0	52.5
„ 21	49.6	70.0
„ 23	55.6	64.8
Mean	**90° 16′ 56″4**	**5′ 59″1**

In reducing the observations that value of the zenithpoint was used, which had been determined on the day itself. In the very rare cases that the signal had not been observed the zenithpoint has been derived from the determinations of preceding and subsequent days.

We have always tried to choose the two stars for one evening in such a way that their absolute zenith-distances would not be too great and almost equal, in order to practically eliminate from the result of each evening the flexure of the instrument and the systematic division-errors of the circle. We have been fairly successful in this and find:

		z	$z_N - z_S$	Mean ($z_N - z_S$)
Jidda	1st series	37° to 56°	— 3° to + 4°	— 1°.5
,,	2nd ,,	10 ,, 40	— 4 ,, + 2	— 0 .4
Mecca		23 ,, 44	— 7 ,, + 2	— 2 .0

while one evening only the zenithdistance has exceeded 45°.

Both the chronometers employed in the observations (as well as the Leroy-watches) had been regulated after mean solar time, and so their readings, after having been corrected, had still to be reduced to sidereal time. In all our calculations account was taken of course of the variation of sidereal time at mean noon with the longitude.

The pointings were mostly arranged fairly symmetrically with regard to the meridian. The reduction to the meridian was computed with the aid of ALBRECHT's tables; the term dependent on $\sin^4 \frac{1}{2} t$ has always been taken into account if it exceeded 0″.05. The star-places were taken from the Nautical Almanac, and BESSEL's refraction was used.

Below I shall first give as an example the detailed observations of one night, viz. February 25, 1911, at Mecca.

The given temperatures and barometer-readings are corrected ones. The level-readings given are each time the mean of the readings before and after those of the verniers, which nearly always agreed fairly well *inter se*. They represent the deviations of the position of the bubble from the middle of the graduation, whereby the sign is taken positive when the reading of the bubble was too low and the reading of the verniers had to be increased.

In the table the 1st and 2nd column contain the star and the position of the instrument; the 3rd column contains first the chronometer time of the pointing, then the hour angle derived from it; the 4th gives the readings of the two verniers, the 5th the employed zenithpoint. The remaining columns need no further explanation. Finally we have given the results for the latitude, such as follow from the observations of this night.

Determination of latitude.

Mecca, 1911 February 25.

North star α Aurigae Z 24°29′.
South star ζ Orionis 23 25.

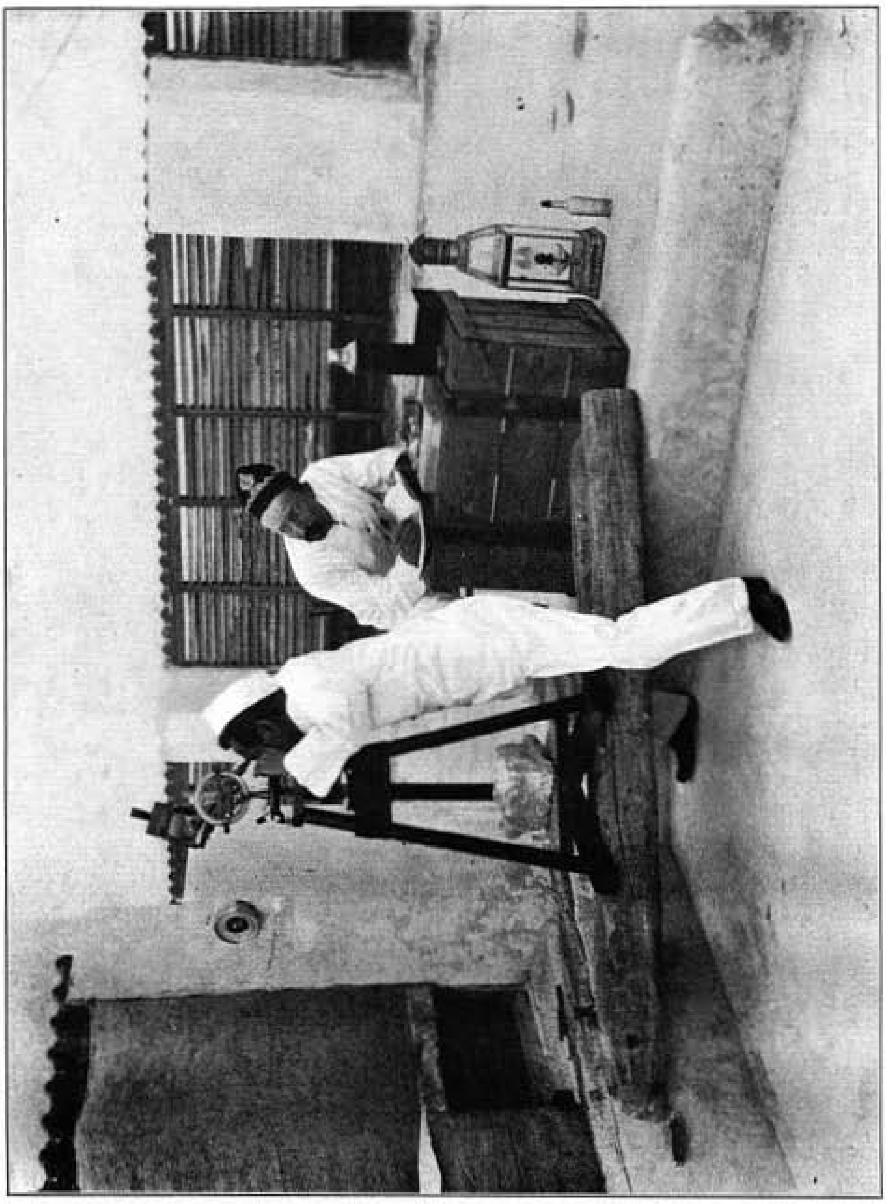
		T. ext.	T. Bar.	Barom.	Level
α Aurigae	T. L.	28.3	28.9	735.1	+ 1p45
					+ 1.45
	T. R.	27.8	28.3	735.3	— 2.35
					— 2.6
ζ Orionis	T. R.	27.8	28.3	735·3	+ 1.3
					+ 0.95
	T. L.	27.5	28.1	735.5	— 1.8
					— 1.6

Star	Instr.	Chron. Time / Hour angle	Verniers	Zenithpoint	Refr.	Red. on merid.	Latitude
N.	T. L.	18 36 5 (m s)	65°38′ 20″	90° 9′ 14″2	24″1	—1′ 36″7	21°25′21″1
		— 5 37.0	245 38 30				
		22 14.0	65 45 30	15 18.3	24.0	— 12.0	4.9
		—1 58.9	245 45 45				
	T. R.	30 24.0	114 46 20	15 18.3	24.1	—1 58.2	27.9
		+ 6 12.6	294 46 40				
		34 33.0	114 43 50	9 14.2	24.1	—5 29.4	27.2
		+10 22.3	294 44 10				
S.	T. R.	44 23.5	113 41 35	90 15 18.3	22.9	—2 40.8	21 25 3.4
		—5 55.1	293 42 5				
		48 11.0	113 33 20	9 14.2	22.9	— 20.6	9.4
		— 2 7.0	293 33 50				
	T. L.	56 16.5	66 42 25	9 14.2	22.9	—2 45.2	10.4
		+ 5 59.9	246 42 45				
		0 20.5	66 43 0	15 18.3	23.0	—7 45.4	32.9
		+10 4.6	246 43 30				

Latitude North star 21°25′20″3
„ South star 14. 0
„ Mean 21°25′17″2

RESULTS OF THE DETERMINATIONS OF LATITUDE AT JIDDA.

		North Star			South Star			$\frac{\text{North}+\text{South}}{2}$
		T. L.	T. R.	Mean	T. L.	T. R.	Mean	
				First Series				
1910		21°29′	21°29′	21°	21°29′	21°29′	21°	21°
Nov. 18	Sch	16″1	32″9	29′24″5	8″3	12″7	29′10″5	29′17″5
» 23	»		17.8	18.8	22.6	7.0	14.8	16.8
» 24	Sa	21.6	— 1.0	10.3				8.6
» 25	Sch	29.8	— 2.0	13.9	7.6	20.2	13.9	13.9
» 26	Sa	15.1	33.3	24.2	19.8	— 5.9	7.0	15.6
» 29	»	27.1	3.0	15.0	8.4	30.0	19.2	17.1
» 30	Sch	5.4	7.2	6.3	21.7	17.3	19.5	12.9
Dec. 1	Sa	21.1	— 0.5	10.3	—1.1	27.6	13.2	11.8
				Second Series				
1911	Sa	21°29′	21°29′	21°	21°29′	21°29′	21°	21°
Jan. 25	»	15″8	29″8	29′22″8	30″0	3″6	29′16″8	29′19″8
» 26	»	33.6	—5.4	14.1				12.4
» 28	»	2.7	38.3	20.5				18.8
» 30	»	27.8	9.3	18.6	7.3	34.3	20.8	19.7
» 31	»	29.9	16.9	23.4	5.2	16.0	10.6	17.0
Febr. 1	»	31.6	12.6	22.1	5.0	18.6	11.8	17.0
» 3	»	25.7	12.1	18.9	20.1	33.4	26.8	22.8
» 6	»	21.7	22.6	22.2	15.3	13.4	14.4	18.3
» 7	»	20.0	29.6	24.8	24.2	4.6	14.4	19.6
» 8	»	35.5	20.3	27.9	5.3	20.8	13.0	20.4
» 20	»	30.8	22.0	26.4	35.2	12.4	23.8	25.1
» 21	»	11.6		10.6	— 1.1	14.9	6.9	8.8
March 23	»	16.8	22.7	19.8	26.4	7.0	16.7	18.2



Secondly there follow the results from all latitude determinations first from those at Jidda, subsequently from those at Mecca. In these tables have been collected the results from "Telescope left" and "Telescope right" for the north star and for the south star; the values given are the mean results of the pointings on the two threads.

On Dec. 1 and Febr. 21 no zenithpoint had been determined. For Dec. 1 we have used 9′9″.4 and 14′43″.5 and for Febr. 21 the mean of the results of Febr. 20 and 22. For Nov. 23 too a mean has been employed of that date itself and of Nov. 25, 28 and 30. On Nov. 23 and on Febr. 21 one star had not been observed in the two positions of the telescope.

For the few days on which the observations were not complete, we have in order to deduce mean results employed the systematic differences found hereafter. (See the table on p. 538).

RESULTS OF THE DETERMINATIONS OF LATITUDE AT MECCA.

		North Star			South Star			North+South / 2
		T. L.	T. R.	Mean	T. L.	T. R.	Mean	
1911		21°25′	21°25′	21°	21°25′	21°25′	21°	21°
Febr. 15	Sa	21″5	11″5	25′16″5	3″9	30″1	25′17″0	25′16″8
» 16	»	25.9	25.1	25.5	12.6	34.1	23.4	24.4
» 25	»	13.0	27.6	20.3	21.6	6.4	14.0	17.2
» 26	»				27.8	15.1	21.4	23.1
» 27	»	26.0	24.4	25.2	20.0	10.4	15.2	20.2
March 11	»	22.4	53.4	37.9	36.8	27.2	32.0	35.0
» 12	»				27.8	13.5	20.6	22.3
» 14	»	21.5	8 3	14.9	22.9	47.3	35.1	25.0
» 15	»	22.9	16.7	19.8	14.4	37.8	26.1	23.0
» 16	»	23.5	28.7	26.1	21.2	19.6	20.4	23.2

(To be continued).

Astronomy. — "*Determination of the geographical latitude and longitude of Mecca and Jidda executed in* 1910—11." By Mr. N. SCHELTEMA. Part II. (Communicated by Prof. E. F. VAN DE SANDE BAKHUYZEN).

(Communicated in the meeting of June 29, 1912).

4. *Determination of the geographical latitude of Jidda and Mecca.* (Continued).

About the results given in the two preceding tables it must still be noted that some of them in the first series at Jidda depend on one pointing only. These are: Nov. 23 North star T. R., Nov. 29 North star T. L. and T. R. and Nov. 26 and Dec. 1 South star T. L. and T. R.

In the first place we shall now see what may be deduced about the accuracy of our observations as regards chance errors, from a comparison of the individual results.

If the mean error of one pointing on a star be . . . . m
" " " of one pointing on the signal be . . . . . M
then we have

m. error of the zenithpoint for the mean of the two threads $\frac{1}{2}M$

(m. error)² of a zenithdistance derived from two pointings
on the star in one position of the telescope . . . $\frac{1}{2}m^2+\frac{1}{4}M^2$.

We may now consider the m. error of a latitude φ to be equal to that of the zenithdistance from which it has been deduced and thus we obtain:

$$(\text{m. e.})^2 \text{ of } \varphi \text{ from one posit.} = \text{I} = \frac{1}{2}m^2+\frac{1}{4}M^2$$

$$\text{,, of } \frac{1}{2}(\varphi_L-\varphi_R) = \text{II} = \frac{1}{4}m^2+\frac{1}{4}M^2$$

$$\text{,, of } \frac{1}{2}(\varphi_L+\varphi_R) = \text{III} = \frac{1}{4}m^2$$

$$\text{,, of } \frac{1}{2}(\varphi_N-\varphi_S) = \text{IV} = \frac{1}{8}m^2$$

$$\text{,, of } \frac{1}{2}(\varphi_N+\varphi_S) = \text{V} = \frac{1}{8}m^2$$

from which: $\text{II}+\text{III}=\text{I}$

$$\text{II}-\text{III}=\frac{1}{4}M^2.$$