AL-BIRUNI NEWSLETTER

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The making of an astrolabe

Astrolabes are still being made in the Middle East, but the demand is mostly by tourists looking for a charming souvenir or a bargain for a possible resale. The market, of course, has adjusted itself accordingly. I estimate that there are about ten metal engravers in Persia, mostly in Isfahan and in Tehran, who still make astrolabes. However none of these knows the proper constructions for the instrument and how it should be used. They are operators from which the feedback loop of guidance by an astronomer has been cut away. They have degenerated in copying from one another and make devices that to their taste look like astrolabes. The items offered for sale are of poor finish and are completely disfigured in their functional appearance. They sell very well however, small ones for about $ 30.- larger ones for more.

Some years ago an engraver in Isfahan by the name of Agha Kamal Ashrafzadeh made for me an accurate copy of the beautiful large astrolabe of Shah Abbas II, which is now in the museum in Oxford. This copy, made after a set of photographs, took several months to complete. Ashrafzadeh took pride in making the astrolabe as accurate as possible and became interested in its history. Together with a friend he studied the book on elementary astronomy by Al-Biruni, the only book of this astronomer which he wrote in Persian.

After I had received the Abbas astrolabe I started sending them information on the subject and early this year I visited Isfahan to give further instruction on the theory. Following this Kamal started to make a new astrolabe for me. This was done because I wanted an astrolabe for personal use and because I wanted to go through the experience to have one made according to exact specifications. The engraving on this astrolabe is Kufic, but the positions of the stars and the calendar dial on the back are for epoch 1950. The engraving has some minor shortcomings which could have been avoided if I had been in Isfahan all the time. A photograph of the front and back of the astrolabe is enclosed with this newsletter.

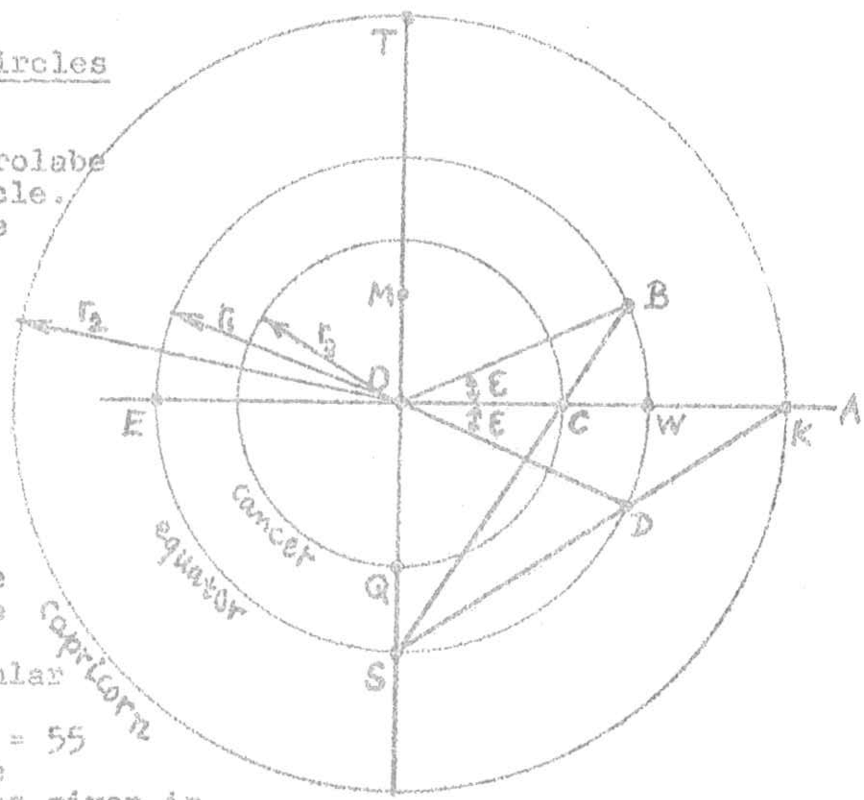
Kamal may now be the only engraver in the world, who is still engaged in the making of true astrolabes. The following pages are the information I sent to him step by step during our correspondence.

Metal work is an important industry in Isfahan. Engraving is still done as it was described by Al-Biruni, except perhaps that now hammer and chisel are used rather than a chisel that is pushed by hand. For engraving an astrolabe it is pressed on a patch of heated tar on a piece of wood that is kept firm on the knees by a belt. That what is to be engraved is first written in pencil on the sand-papered brass surface and, while hammering, the chisel is guided along the writing.

From my experience I would say that the making of an accurate astrolabe requires close cooperation between an astronomer and an intelligent engraver for a period of several months. A good astrolabe therefore is necessarily costly. The simplest way of making an astrolabe is by giving a sample to the engraver and ask him to make a copy. By keeping an eye on its progress one could then guide him and make small alternations. It is probably for this reason that many of the existing antique astrolabes are not quite as old as their possessors like to believe.

Frans Bruin

The equator circle and the circles of Cancer and Capricorn



All constructions of the astrolabe are based on the equator circle. Therefore the radius R of the equator circle is the most important measure for the astrolabe. In the following all calculations have been carried out for a radius R of 45.0 mm

If an astrolabe has an equator circle with radius different from this, as usually will be the case, all its other measures become proportionally different. The angles and degrees, however, remain the same in their angular measure.

For example, if the radius R = 55 mm, then all measures will be 55/45 = 11/9 times as large as given in these sheets.

On all tympans of an astrolabe one may see three concentric circles, namely the one of Cancer, the one of the Equinoxes (the equator) and the one of Capricorn. The tympans are always somewhat larger in radius then the latter, so that the star Antares will still fit on the spider.

To construct the circles one first draws a pair of perpendicular lines and then draws the equator around their point of intersection O.
Now draw lines OB and OD under angles of $\varepsilon = 23^{\circ}27'$ with OA. (This angle usually is taken as $23\frac{1}{2}$ degrees. It is the obliquity of the ecliptic.)
These lines will cut the equator circle in B and D.
Draw SB and SD. These intersect OA in points C and K.
OC is the radius of the circle of Cancer
OK is the radius of the circle of Capricorn.

The length of these radii can also be found through calculation:

$$r_1 = OB = R$$
$$r_2 = OK = R \cot (90-\varepsilon)/2 = 1.524\ R$$
$$r_3 = OC = R \tan (90-\varepsilon)/2 = 0.656\ R \qquad R = 45.0 \text{ mm}$$

The ecliptic circle

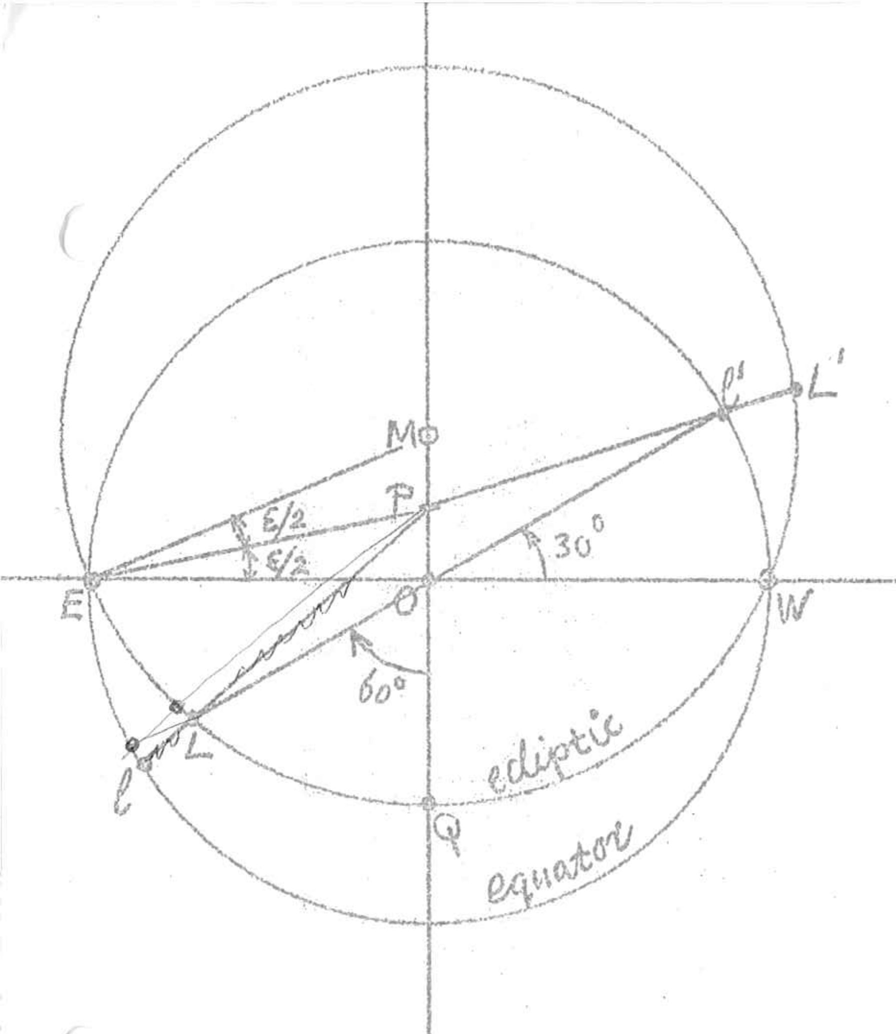
The ecliptic circle should pass exactly through points E, Q and W. The radius of this circle is

$$r_4 = (r_2+r_3)/2 = 1.090\ R.$$

The center of this circle M is at a distance from O

$$OM = r_4-r_3 = R \tan \varepsilon = 0.434\ R$$

If all circles are properly constructed the ecliptic circle should be tangent to the circles of Cancer and Capricorn in the points Q and T. The ecliptic circle is the <u>outer</u> edge of the zodiacal ring on the spider.



The degrees on the ecliptic circle

The center M of the ecliptic circle is found by marking off an angle of $\varepsilon = 22\frac{1}{2}$ degrees in point E. In our case, where OW = 45 mm, we have OM = 19.5 mm.
The ecliptic circle is drawn through points E and W with M as center.

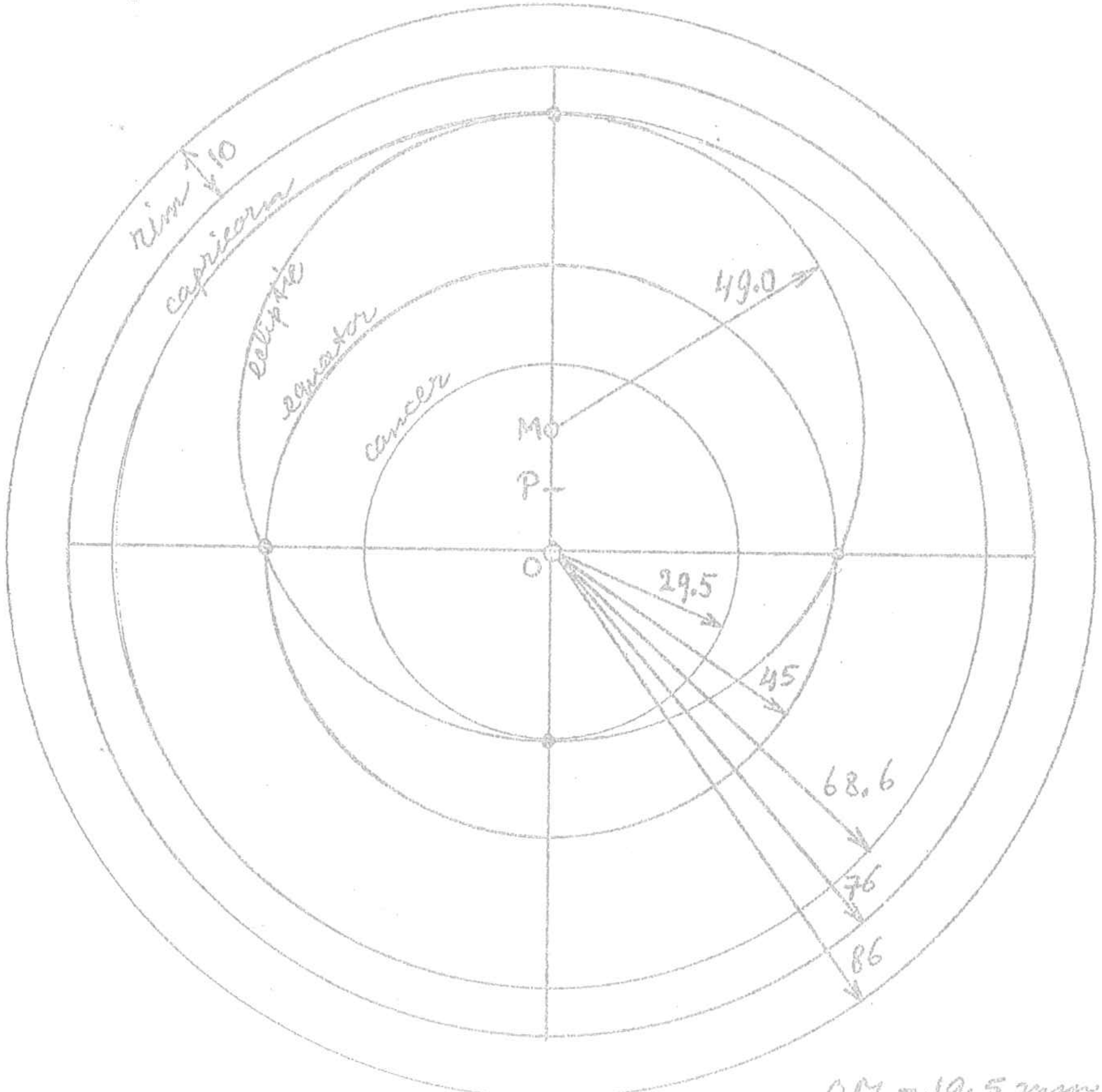
The ecliptic is divided in 12 sections of 30 degrees, a total of 360°. In our case every section (zodiacal sign) is divided in 5 divisions, so that every division comprises 6 degrees. These divisions can easily be constructed with mathematical exactness. For this one needs the pole P of the ecliptic, which is found by bisecting angle ~~MOE~~ EO. (OP = 9.4 mm).

Example of the construction of one division

Suppose now that one wants the position of a division e.g. 60 degrees from point Q on the ecliptic. This is the endpoint of the sign of Aries and the head of the sign of Taurus. The construction is as follows:
Draw a line under 60° with OQ. It will intersect the equator circle in point l. Draw Pl, which cuts the ecliptic circle in point L. Point L marks the desired division.
In this way all divisions on the ecliptic may be constructed. As a second example is shown the end of Libra and the beginning of Scorpio. This is the point L'.

Although this construction is very simple, it should be remarked that a mistake is easily made. Be sure to start from O and to mark first on the equator circle. The old manuscripts are full of mistakes when discussing the division of the ecliptic, and it is even doubtful if the correct construction was known at all by the Arabs and Persians.

dimensions in mm.



OM = 19.5 mm
pole ecliptic = OP = 9.4 mm

list of stars

		name	R.A.	R_*
1	3	Diphda	10.3°	62.2
2	6	Menkar	44.9	42.0
3	9	Aldebaran	68.3	33.6
4	10	Rigel	78.0	52.0
5	11	Capella	78.2	18.2
6	15	Betelgeuze	88.1	39.5
7	16	Sirius	100.7	60.4
8	18	Procyon	114.2	41.0
9	21	Regulus	151.4	36.3
10	27	Ginah	183.3	61.1
11	30	Spica	200.6	54.5
12	32	Arcturus	213.3	31.8
13	35	Alphecca	233.1	27.6
14	37	Antares	246.6	72.4
15	39	Rasalhague	263.1	36.0
16	41	Vega	278.8	21.5
17	42	Nunki	283.0	72.5
18	44	Altair	297.1	38.6
19	45	Deneb	309.9	18.6
20	50	Markab	345.6	34.6

$R_* = 45 \tan \frac{90-\delta}{2}$ mm

$R = 45$ mm

R.A. = right ascension in degrees

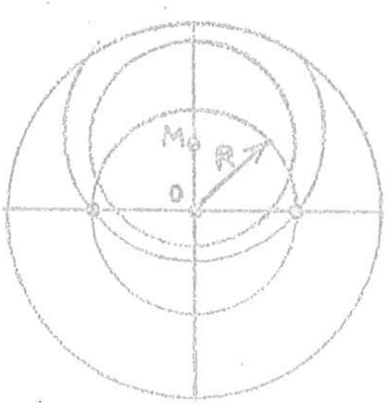
δ	$45 \tan \frac{90-\delta}{2}$ mm
90	0
85	2.0
80	3.9
75	5.9
70	7.9
65	10.0
60	12.0
55	14.2
50	16.4
45	18.6
40	20.9
35	23.4
30	26.0
25	28.7
20	31.5
15	34.5
10	37.8
5	41.3
0	45.0
−5	49.1
−10	53.6
−15	58.6
−20	64.2
−25	70.6
−30	77.9

declination scale

δ = declination

Table for OM $R = 45.0$ mm

A \ φ	30	32	34	36	38	40	42	44
0	77.9	72.0	66.7	61.9	58.5	53.6	50.0	46.6
6	64.5	60.1	56.2	52.6	49.2	46.1	43.2	40.5
12	55.0	51.7	48.6	45.8	43.0	40.5	38.1	35.9
18	48.2	45.5	42.9	40.6	38.3	36.2	34.2	32.2
24	43.0	40.7	38.6	36.6	34.7	32.8	31.1	29.4
30	39.0	37.0	35.2	33.5	31.8	30.2	28.6	27.1
36	35.8	34.1	32.5	31.0	29.5	28.0	26.6	25.2
42	33.3	31.8	30.3	29.0	27.6	26.3	25.0	23.7
48	31.3	30.0	28.6	27.4	26.1	24.9	23.7	22.5
54	29.8	28.5	27.2	26.1	24.9	23.7	22.6	21.5
60	28.7	27.3	26.1	25.0	23.9	22.8	21.8	20.7
66	27.6	26.4	25.3	24.3	23.2	22.1	21.1	20.1
72	26.9	25.7	24.7	23.7	22.7	21.6	20.6	19.7
78	26.4	25.3	24.2	23.2	22.2	21.3	20.3	19.3
84	26.1	25.0	24.0	23.0	22.0	21.0	20.1	19.2
90	26.0	24.9	23.9	22.9	21.9	21.0	20.0	19.1



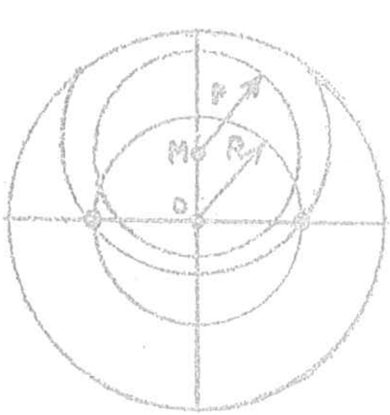
$$OM = \frac{1}{2} R \left[\cot \frac{\varphi + A}{2} - \tan \frac{\varphi - A}{2} \right]$$

φ = latitude

A = altitude

Table for r   R = 45.0 mm

A \ φ	30°	32°	34°	36°	38°	40°	42°	44°
0°	90.0	84.9	80.4	76.6	73.1	70.0	67.2	64.8
6°	74.0	70.5	67.4	64.6	62.1	59.9	57.8	56.0
12°	62.2	59.6	57.4	55.7	53.5	51.7	50.2	48.8
18°	52.9	51.0	49.3	47.7	46.3	44.9	43.7	42.6
24°	45.3	43.9	42.5	41.3	40.3	39.2	38.2	37.3
30°	39.0	37.8	36.8	35.8	35.1	34.1	33.3	32.6
36°	33.5	32.5	31.7	31.0	30.3	29.6	29.0	28.4
42°	28.6	27.9	27.2	26.6	26.1	25.5	25.0	24.5
48°	24.2	23.6	23.1	22.6	22.2	21.7	21.3	20.9
54°	20.2	19.7	19.3	18.9	18.6	18.2	17.9	17.6
60°	16.5	16.1	15.8	15.5	15.2	14.9	14.7	14.4
66°	12.9	12.7	12.4	12.1	12.0	11.8	11.6	11.4
72°	9.6	9.4	9.2	9.0	8.9	8.7	8.6	8.4
78°	6.3	6.2	6.1	6.0	5.9	5.8	5.7	5.6
84°	3.1	3.1	3.0	3.0	2.9	2.9	2.8	2.8
90°	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



$$r = \frac{1}{2} R \left[\cot \frac{\varphi + A}{2} + \tan \frac{\varphi - A}{2} \right]$$

φ = latitude

A = altitude

Construction of the vertical circles

First, from the Table for OM find the zenith. This is point Z at $A = 90^\circ$. For $\varphi = 30^\circ$ we find OM = 26.0 mm. This is OZ.

Next draw a complete circle through points Z, E and W. The radius and center of this circle can be found by construction or by calculation:

$$ZN = \tfrac{1}{2}\left[\frac{OE^2}{OZ} + OZ\right]$$

$$ON = \tfrac{1}{2}\left[\frac{OE^2}{OZ} - OZ\right]$$

Again, for $\varphi = 30^\circ$, we find ZN = 51.8 mm and ON = 25.8 mm
This circle with center N, through points E and W is called the <u>first</u> vertical circle.
In order to construct the other vertical circles, draw a horizontal line H --- H through N. The centers of all remaining vertical circles will lie on this line.
We wish to draw the vertical circles for 15°, 30°, 45°, 60°, 75°, and 90°.
As an example I have chosen the one for 30°. This goes as follows:
Draw a line from Z under 30° with ZN. It will cut H--- H in point N_{30}. This is the center of the vertical circle.
Draw, with N_{30} as center, a circle through Z. This is the desired circle.
The other circles are done in the same way. I have not drawn these so as to make no confusion in the construction.
In astronomy the counting of the vertical circles is somewhat different from what is used in the construction. The conventional numbering is given in the smaller sketch.