ronology

II

Chapter III. The Planets.

Chapter IV. The Fixed Stars.

Chapter III. The Planets.

Μᾶλλον δὲ καὶ αὐτὸ τὸ ἁπλοῦν τῶν οὐρανίων οὐκ ἀπὸ τῶν παρ' ἡμῖν οὕτως ἔχειν δοκούντων προσήκει κρίνειν, ὁπότε μηδ' ἐφ' ἡμῶν τὸ αὐτὸ πᾶσιν ὁμοίως ἐστὶν ἁπλοῦν.*)

Ptolemy Almagest XIII, 2.

*) And, moreover, "simplicity" of celestial phenomena should not be judged according to our standards, because even among us "simple" does not always mean the same to everyone.

The use of solar and lunar eclipses for obtaining fixed points of ancient chronology can just be called <u>the</u> classical method of chronology. As we have seen in the preceding chapter this method reaches its limit with the eighth century B.C. because of lack of older records. Fortunately enough, however, in both Egypt and Babylonia have been preserved some records of a different type which open certain possibilities of pushing back absolute chronology about one millenium: these are observations of Venus during the First Babylonian Dynasty and recordings of the rise of Sirius during the XIIth Dynasty in Egypt. This and the next chapter will be devoted to the discussion of these data and other problems of methodically related character.

The main difficulty in dealing with planetary phenomena consists in the fact that for planetary movements the earth is no longer so convenient a center of reference as in the case of the moon. The movement of a planet appears from the earth the way an observer on the sun would see a moon rotating swiftly around the earth: sometimes in front of the earth and sometimes behind, thus sometime moving in the same direction as the earth, sometime becoming "retrograde".[341] This analogy in principle is, however, subject to essential modifications, first, because the planets are by no means close satelites to the sun as the moon is to the earth; secondly, the luminosity of the sun is so great that the planets become invisible as soon as they appear (when seen from the earth) to be near to the sun. The understanding of the planetary phenomena therefore requires the <u>combination</u> of heliocentric <u>and</u> geocentric considerations. The following paragraph is devoted to this problem.

341) Our moon rotates so slowly around the earth that an observer from the sun would only see accelerations and retardations but no retrograde parts.

§ 1. Astronomical concepts.

<u>38</u>. <u>Notations</u>.

In the following, the customary planetary symbols will be used:

☿	Mercury	♂	Mars	♄	Saturn
♀	Venus	♃	Jupiter		

The origin of these symbols is unknown, although it is very probable that they were created by the late-Egyptian-Hellenistic astrologers.

The above-given arrangement follows the distance from the sun. Because the earth would be placed between Venus and Mars, ~~these two planets~~ Mercury and Venus are called interior or inner planets, while Mars, Jupiter and Saturn are exterior or outer planets. For most of our discussions it will be sufficient to consider all the orbits of these planets as circular with the sun as center and belonging to the same plane. This common plane is of course the plane of the ecliptic because the movement of the sun with respect to the earth defines the same plane as the movement of the earth with respect to the sun.

So far as the description of the orbits of the sun and moon is concerned, as seen from the earth, the use of the center of the earth as the center of reference is very convenient; for the description of the planetary movement, however, the heliocentric system is much more convenient. Correspondiggly, heliocentric coordinates must be introduced. The plane of reference is again the ecliptic, in which heliocentric longitudes are measured with the direction from the sun to the vernal point (which is to be considered as a known point on the fixed-star sky). Analogously, heliocentric latitudes are measured by the angles subtended at the sun, whose plane is at right angle to the ecliptic and which are counted from the ecliptic as plane of latitude zero.

As Kepler found from investigation of the orbit of Mars, the planets move in elliptic orbits (fig.36) with the sun at one of the two foci. The velocity of a planet reaches a maximum in the perihelium P of its orbit and a minimum in the aphelium A. The excentricity of an orbit therefore measures not only the deviation from a circular form but is also an expression of the irregularity of the movement during each revolution. The size of an elliptic orbit is determined by giving the semi-major axis a (usually measured by the semi-major axis of the earth's orbit as the unit) and by the excentricity e which indicates the fraction of a by which the focus is distant from the center. The accompanying table gives the values for a in round numbers in order to indicate the order of magnitude.[342] The excentricities, however, are given much more accurately

342) Moreover, the three greater planets discovered in modern times: Uranus 20, Neptun 30, Pluto 40. - It might be mentioned that the distance of the moon, measured in this unit, is only 0.0026. The distance of the nearest fixed star is 270000.

because the deviations from the circular form are so small. Only Mercury has a high degree of ellipticity, while the orbit of Venus is almost circular. The movement of Venus is therefore distinguished by great regularity in contrast both to Mercury and Mars.

	semi major axis a	excentricity e
☿	$\frac{1}{2}$	0.205
♀	$\frac{3}{4}$	0.007
earth	a = 1	0.016
♂	$1\frac{1}{2}$	0.093
♃	5	0.048
♄	10	0.056

39. The synodic movement.

We now proceed to the description of the configurations as defined by earth, sun and planets during their movement. We disregard in this discussion the problem of the actual visibility from the earth of the positions in question, just as we did in the case of the new moons where the syzygies themselves cannot be observed (except in the case of an eclipse). We shall, however, return in a following section to the question of visibility of a planet during its movement around the sun.

The analogon of the synodic month or of the lunation is the "synodic period" of the planetary movement. If an outer planet stands in a straight line with sun and earth (fig.37), this is called "conjunction" if the sun stands between earth and planet; "opposition", however, means that the planet is seen opposite to the sun. An inner planet, on the contrary, never comes into opposition to the sun but has two kinds of conjunctions: an exterior conjunction when standing beyond the sun, an interior conjunction when standing between sun and earth. The angular deviation of a planet from the sun as seen from the earth is called its "elongation". The elongation of an inner planet is obviously limited (fig.37); the maximal elongation of Venus is about 46°; the maximal elongation reached by Mercury in the course of one revolution depends on the direction of the great axis of its orbit with respect to the earth. Accordingly, the maximal elongation of Mercury varies between about 18° and 28°.

The length of the synodic period is clearly the result of the combined movement of planet and earth, as the length of the synodic month depends both on solar and lunar movement. In order to describe this combined interaction, we must decide with respect to which system we measure all movements. We assume therefore that we are able to locate points on the fixed-star sky and call "siderial period" the time which elapses between two succesive moments when a planet is projected on the same fixed star as seen from the sun.

Let us now suppose that the sidereal period of a planet is very great, i.e., that its movement around the sun is very slow. It then follows immediately (cf. fig.38, a) that the synodic period will be only a little longer than one year, the time required for the earth to complete one revolution and the additional little angle of the movement of the planet in the meantime. If, however, the sidereal period of the planet deviates only a little from the sidereal period of the earth (i.e. the year), a long time will elapse between two succesive conjunctions (fig. 38, b). Finally, we consider an inner planet moving very swiftly around the sun (fig. 38, c).

Only a fraction of the year will pass before a new conjunction is reached. 343)

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343) This can easily be formulated in exact terms. Let p denote the sidereal, q the synodic period of a planet, both measured in years (i.e., sidereal period of the earth = 1). Then

$$q = \frac{p}{p-1} \qquad (p > 1)$$

holds for an outer planet and

$$q = \frac{p}{1-p} \qquad (p < 1)$$

for an inner planet (and conversely

$$p = \frac{q}{q-1} \qquad \text{exterior planet}$$

$$p = \frac{q}{q+1} \qquad \text{interior planet}) .$$

These general considerations can be seen confirmed by the adjoining list of sidereal and synodic periods. The sidereal revolution of Mercury only requires three months; and one month later conjunction is again reached. Saturn, on the contrary, requires almost 30 years to return to the same fixed star; and the sun therefore again comes to conjunction with Saturn only slightly later than with a fixed star. Jupiter with a sidereal period of 12 years has a synodical period of 13 months in consequence of its movement by one zodiacal sign each year. Mars and Venus, however, rarely come in conjunction with the sun because the duration of their revolution around the sun is fairly close to the duration of one year.

	sid. per. (trop.years)	sid. per. days	synod.per. (days)
☿	0.24	88	116
♀	0.62	225	584
♂	1.88	687	780
♃	11.86	4332	399
♄	29.46	10760	378

For ancient times, only the synodic periods are of importance because no sidereal periods were known before the adoption of a heliocentric system.

40. Apparent velocities.

The reason for the complexity of the planetary movement lies in the fact that in the final analysis we need the planetary positons as viewed from the earth. We have two equivalent ways of expression at our disposal: we either consider earth and planets as rotating around the sun; the problem then consists in the description of a movement as seen from a moving body. Or we speak about the sun as rotating around the earth, and of the planets as rotating around the rotating sun - which again requires the composition of two different movements. Such considerations of combined movements are greatly facilitated by consistently using the consept "vector" in speaking about velocities.

Let us suppose that a point P moves along a sufficiently smooth plane curve such that this path might be considered at any moment as a part of a circular orbit with center S (fig.39). The momentaneous direction of the moving point at P is given by the tangent at P , i.e., the momentaneous movement progresses in a direction at right angle to PS . The amount of this momentaneous velocity can be expressed as a certain distance covered per time unit. Any such number can be represented graphically as a certain length by choosing a unit of length as the equivalent of a unit of velocity. We now combine these two characteristic elements of the movement, direction and quantity, into one picture. The direction is given by the tangent to the curve, and its amount shall be indicated by the length of an arrow starting at P and pointing in the direction of the momentaneous movement. Such a directed line segment of given length is called a "vector".

Let the movement of a point now be observed from another point E which lies in the plane of the orbit. If the point moves strictly in a direction pointing towards E , no change at all in the position of the point can be seen from E . If, however, the point moves at right angle to the line joining E and the point, the full amount of the movement will then be observed from E . Hence, for an observer in E there is no distinction possible between the movement of P as represented by the vector $\underline{T}$ (fig.39) and by the vector $\underline{N}$, where $\underline{N}$ is the projection of $\underline{T}$ into the direction at right angle to EP. The real movement of P can therefore be produced by combining a movement as represented by $\underline{N}$ with a movement represented by the vector $\underline{R}$, directed towards E . $\underline{N}$ and $\underline{R}$ are called "components" of $\underline{T}$ in the given directions normal to, and coinciding with, EP .

Conversely, if a point P is subject to two simultaneous movements, one represented by a vector $\underline{A}$, the second by the vector $\underline{B}$, the velocity of the resulting is given then by the vector $\underline{C}$, which is the diagonal in the parallelogram of sides $\underline{A}$ and $\underline{B}$ (fig.40).

We are now ready to discuss one of the most conspicuous facts in the apparent movement of a planet, its "retrogation". We begin our considerations witha limiting case which represents an idealization of circumstances as presented by a very slowly moving outer planet like Saturn. This idealization consists in the assumption that the planet has no sidereal movement at all with respect to the sun, i.e., that such a "planet" Π^{∞} (fig.41) does not rotate around the sun but stands at a fixed distance from the sun. Seen from an observer on the sun, Π^{∞} does not move at all, i.e., the straight line $S\Pi^{\infty}$ always points towards the same fixed star. If we now consider the movement of this couple $S\Pi^{\infty}$ with respect to the earth E then S moves on a circle around E and consequently Π^{∞} on a congruent circle ($S_1 \Pi_1^\infty = S_2 \Pi_2^\infty$ and $S_2 \Pi_2^\infty$ parallel to $S_1 \Pi_1^\infty$). An observer in E therefore gets the impression that the planet Π^∞ oscillates between two limits Σ_1 and Σ_2. The direction of its movement coincides with the part $\Sigma_2 \Pi_1 \Sigma_1$ with the movement of the sun (called "direct" movemmnt) but is retrograde on the remaining part from Σ_1 to Σ_2.[344] The apparent velocity

344) The synodic period q of this "planet" is obviously equal to one rotation of S around E i.e. = 1 . This is in agreement with the formulae given on p.### note ### according to which $q = \frac{p}{p-1}$. We obtain our ideal outer planet by increasing the length p of its sidereal period beyond any given value and this brings the quotient $q = p/(p-1)$ as close to 1 as we wish.

is very slow near Σ_1 and Σ_2, where the planet changes its direction. Σ_1 and Σ_2 are therefore called "stationary points".

Actually no such planet Π^∞ exists, but the movement of a real outer planet Π can be considered as the result of the combination of a movement such as we have just considered with a slow rotation of Π around S. Because this latter movement proceeds with a much lower velocity than the movemnt of the sun around the earth, the main feature remains the fact that the direct parts of the apparent movement are interrupted by an arc of retrograde movement limited by two stationary points. These stationary points cannot be determined so simply as in the case of Π^∞ (fig.41). But they are characterized by the same quality, namely, that the vector of the ~~xxxxxxxx~~ momentaneous velocity points towards E. This velocity vector is composed of two compenents (fig.42): the velocity $\underline{E}$ tangential to the sun's orbit around E which affects S and Π by the same amount; and secondly, the vector $\underline{S}$ of the sidereal movement of Π around S , tangential to the planet's orbit around S , but of smaller absolute value. The planet appears to be stationary if the direction of the resultant $\underline{R}$ of $\underline{E}$ and $\underline{S}$

passes through the point E . It follows from figs. 41 and 42 that the stationary points belong to the semi-circle which contains the point of opposition of ♃ and that the oppositions lie in the middle between the two stationary points, assuming, as usual, constant velocity of S around E and of ♃ around S .

The same kind of considerations applies for an inner planet P (fig.43). The only difference lies in the fact that now the movement of P around S is faster than the movement of S around E . These two movements are added at the moment of exterior conjunction, but counteract each other at inferior conjunction. Because of the superiority of S over E , this results in a retrograde movement of P in the neighborhood of the inferior conjunction. Fig.44 shows the combined velocity in a stationary point. It is obvious that these stationary points do not coincide with the points of maximal elongation (fig.45), because at these points only the direction of S passes through E while the component E of the sun's movement around E still remains visible from E . The arc of retrograde movement is therefore shorter than the arc between the points of maximal elongation; this arc is subdivided into two equal parts by the point of inferior conjunction.

The previous considerations are based on the assumption of coincidence of the plane of the planetary orbit with the ecliptic. This simplification is perfectly justified for many historical problems, e.g., the dating of horoscopes. For the appearance of the retrograde part of the planets' orbits, however, the existence of small deviations from the plane of the ecliptic is very essential. Just as the plane of the moon's orbit is inclined towards the ecliptic, so also the planes of the planetary orbits do not exactly coincide with the ecliptic. The values of these angles between the orbital plane and the ecliptic are approximately as follows:

☿	7°	♂	2°
♀	$3\frac{1}{2}^{\circ}$	♃	1
		♄	$2\frac{1}{2}$

With the sole exception of Mercury, all planetary orbits are thus less inclined than the moon's orbit. There is, however, a very essential difference between moon and planets. The nodal line of the moon's orbit always passes through the center of the earth (cf. fig.27 p.###); the nodal line of a planetary orbit, however, passes through the center of the sun. The lines of vision from the earth to the moon therefore always lie in the plane of the moon's orbit and the latitude of the moon can never appear greater than the angle between lunar orbit and ecliptic, i.e., 5°. The same holds for an observer on the sun who will never see, e.g., Venus, more than $3\frac{1}{2}^{\circ}$ above or below the ecliptic. Seen from the earth, however, Venus can appear much higher above or below the ecliptic. Suppose, Venus is near to its maximal deviation from the ecliptic and, moreover, near to the earth, i.e., near to inferior conjunction (fig.46). In this situation Venus is only about $\frac{1}{4}$ of the semidiameter of the earth's orbit distant from the earth[345)]

345) Cf. p.###.

and therefore appears much higher above the ecliptic from the earth than from the sun. But from the assumed fact that Venus is near inferior conjunction, it follows that its geocentric movement appears to be retrograde. Analogously, it follows from the nearness of Mars that this outer planet is near opposition and therefore also retrograde. In other words, the deviation of the planetary orbits from the ecliptic is especially clearly visible from the earth near the retrograde part of the apparent movement.

The consequence of these facts is that the retrograde movement is not seen as a simple oscillation between two limits on a straight line but as some kind of loop which varies considerably in size and shape owing to the special situation of the conjunction or opposition with respect to the nodal lines. Examples are shown in fig. 47. The magnitude of these loops varies greatly with the different planets. Jupiter and Saturn reach only about 5° of retrograde movement in the ecliptic and this takes 4 to 5 months. The retrograde movement of Mars, however, happens with about fourfold speed (about 12° in about 2 ½ months). Venus covers about 15° retrograde during 40 days and Mercury about 20° in 3 weeks. The retrograde movement of the interior planets is, however, much less impressive than the loops of an exterior planet (like Mars) because an inner planet at inferior conjunction disappears in the rays of the sun. This means that only the beginning and end of the retrograde orbit of Venus and Mercury are visible and never the complete loop.

41. Visibility.

The last mentioned fact, the invisibility of a planet near its conjunction with the sun calls for a more detailed discussion. It is obvious that this problem is very analogous to the problem of invisibility of the moon near its conjunction with the sun, the only difference being that more configurations must now be considered.

We start by assuming an exterior planet in conjunction with the sun, i.e., at the moment when both sun and planet have the same geocentric longitude. In the following days, the longitudes of both bodies as seen from the earth increase but the sun's longitude increases faster than the longitude of the planet. The planet therefore obtains an increasingly western elongation from the sun. After some days this western elongation is great enough to make the planet visible already in the dusk of the eastern horizon while the sun is still below the horizon (cf. fig. 48). This first appearance of an outer planet after conjunction is called its "heliacal rising". The following days the elongation becomes still greater; the planet consequently rises considerably earlier than the sun, and therefore becomes visible for an increasingly longer part of the night. Near opposition the planet rises when the sun sets and is therefore fully visible all night; at the same time its brilliance is maximal, just as in the case of the full moon. From now on, the opposite process sets in. The planet stands higher and higher above the horizon when the sun sets in the west. Shortly before reaching conjunction again, the planet will be so near to the sun that it will set only a few minutes after the sun, just enough still to be seen in the falling darkness. This last visibility on the western horizon is called "acronychical setting" (cf. fig. 49). From now on until after conjunction, i.e., until heliacal rising, the planet remains invisible.[346] This concludes the synodic cycle of the planet.

346) Jupiter remains from 25 to 35 days invisible at Babylon, Saturn 30 to 45 days. For the modest accuracy of the Babylonian observations of Jupiter see Vogt (H) [2] p. 39, cf also below p. [illegible].

Combining these results with the previous ones regarding the geocentric movement, we obtain the following sequence of phenomena seen during one synodic revolution of an outer planet:

invisible	conjunction	direct
	heliacal rising in the east	
	stationary	retrograde
	opposition, highest brilliance	
	stationary	
invisible	acronychical setting in the west	direct
	conjunction	

Each part of this cycle moves slowly through all parts of the ecliptic.

The only new element in the case of an inner planet consists in its limited elongation. We begin again with the exterior conjunction where the planet is invisible. Now the planet separates itself more rapidly from the line of the syzygy than the sun, i.e., the planet gains an eastern elongation from the sun. If we therefore consider the western horizon, there will be an evening when the eastern elongation of the planet is for the first time sufficiently great to make the planet visible shortly after sun-set. This is the western rising of the planet as evening star (cf. fig. 50a). In the following days, the eastern elongation of the planet increases more and more, and results in longer visibilities of the planet after sun-set. This holds, however, only until the moment when the planet reaches maximum elongation (fig. 50 b); from then on, the interval between sunset and the setting of the planet becomes shorter and shorter until the planet is visible for the last time above the western horizon shortly after sunset (western setting; fig. 50 c). This cincludes the planet's career as evening star. There now follows a short period of invisibility near inferior conjunction until the planet again reaches so much elongation from the sun to rise heliacally in the east as "morning star" (fig. 51 a). The further history as morniñg star is analogous to the appearances as evening star (fig. 51 b and c) and is concluded by the eastern setting before exterior conjunction.

We accordingly obtain the following complete succession of phenomena during one synodic period of an inner planet:

invisible	exterior conjunction	direct
	western rising	
evening star	maximal elongation	
	stationary	
	western setting	
invisible	inferior conjunction	retrograd
	eastern rising	
morning star	stationary	
	maximal elongation	
	eastern setting	
invisible	exterior conjunction	direct

Because the invisibility of a planet is mainly determined by its elongation from the sun, it is obvious (cf. fig.52) that the period of invisibility around inferior conjunction is much shorter than around exterior conjunction. Venus, e.g., is invisible about 60 or 70 days at exterior conjunction but only a few days at inferoir conjunction.[347)]

347) Cf. below p.###.

If the inferior conjunction occurs near the nodal line of Mercury or Venus, a phenomenon takes places which corresponds to a solar eclipse, i.e., the disc of the planet is projected on the solar disc, at least as seen from certain regions of the earth. Such a transit of Venus or Mercury, however, cannot be observed by the naked eye; it was not before the 17th century that such transits were seen through telescops.[348)] They are, moreover, much more rare than solar eclipses.[349)] Venus and Mercury transits are therefore of no importance for historical chronology.

348) Cysat and others observed the first Mercury transit in 1631 XII 6; Horrox the first Venus transit in 1639 XII 4. Cf. Wolf, Hdb.II p.162 ff.

349) About 13 transits of Mercury occur during one century; the Venus transits have a period of 243 years, and are spaced within this period at intervals of 8 years, 121 ½ years, 8 years and 105 ½ years.

For the sake of simplicity, the preceding description of typical phenomena of the synodic revolution of a planet disregarded all secondary influences which cause more or less visible variations of the general scheme. For chronological problems in which only the positions of the planets with respect to the ecliptic play a rôle (as, e.g., in the dating of horoscops), more details about the planetary movement are scarcely needed. As soon, however, as the question of visibility is involved, e.g., when dates for appearance or disappaerance are given, such idealizations as, e.g., the identification of the plane of the planetary orbit and the plane of the ecliptic, are no longer justified. We shall need more details about the visibility of Venus, which we now proceed to explain.

According to our simple schematic considerations, the conjunction would subdivide the intervals of invisibility into exactly equal parts. This conclusion no longer holds if we also take the influence of the latitude into consideration. Venus becomes invisible if its angular distance from the sun as seen from the earth is less than about 10°. In other words, Venus is invisible as long as it is inside a cone of axis ES (cf. fig.53), corner E and angle of 20° subtended at E . If the conjunction occurs near the nodal line, Venus has to cross this cone at its maximal width. If, however, the conjunction coincides with the moment when Venus reaches maximal heliocentric latitude, only a smaller sector of this cone has to be passed by the planet. This becomes especially significant at the inferior conjunction. Venus at about 3° of heliocentric latitude is at inferior conjunction so near the earth that its geocentric latitude amounts to about $8\frac{2}{3}{}^{\circ}$ (cf. fig. 46 p.###). In this case, Venus again emerges almost immediately from the cone of invisibility; i.e., the time from the last setting as evening star to the first rising as morning star can be reduced to two days only.

This shows that the duration of invisibility at inferior conjunction depends very much on the latitude of Venus at this moment.[350] The position of the nodal line can be considered as practically invariable in the ecliptic.[351] We can therefore also say that the length of the period of

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350) At exterior conjunction, however, a heliocentric latitude of 3 degrees appears only as $1\frac{1}{2}^{\circ}$ geocentric latitude.

351) The nodal line moves only about 1° per century. (The longitude of the node is given by $\theta = 75^{\circ}46'46''.73 + 3239''.46\ T + 1''.476\ T^2$ where T is measured in Julian centuries (= 36525 days) and $T = 0$ corresponds to 1900 A.D. Jan. 0 Greenwich mean noon.)

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invisibility of Venus at inferior conjunction depends upon the longitude of the sun, i.e., upon the season in which the conjunction occurs.

The variable length of the path of Venus across the cone of invisibility is not the only cause which makes the appearance and disappearance of the planet depending upon the seasons. As in the case of the moon,[352]

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352) Cf. above p.###.

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the changing inclination of the ecliptic with respect to the horizon also shows its influence. Moreover, appearances and disappearances are not symmetrical phenomena; in the case of disappearance, the planet has been visible all the previous days and the place of the horizon where the star should be seen (if still visible) is known. In the case of reappearance after days or even weeks of invisibility, the faint first gleam is difficult to find if the place on the horizon is not exactly known. All these superposed effects create a rather irregular relationship between the date of the conjunction and the dates of appearance and disappearance. How irregular the resulting time intervals are is shown by fig.54. The abscissa gives the longitude of the sun (and of Venus) at the moment of conjunction, i.e., the season of the year. The ordinate indicates how many days before conjunction the planet disappears (E.S. and W.S.) and how many days after conjunction it again becomes vivible (E.R. and W.R.). This shows clearly that the moment of conjunction does not, in general, divide the period of invisibility into equal parts. The total length of invisibility is represented on fig.55.

The irregularity in the visibility of Mercury is still greater owing to the obvious reason of the great inclination of the orbit of Mercury.[353] The difficulty of observing Mercury makes this planet of very

353) Cf. above p.###.

little use for chronological problems and we therefore do not need to go into details. The outer planets, on the contrary, show much more regularity, with the exception of Mars, where the influence of the inclination of the orbit is equally clearly expressed as in the case of Venus (cf. fig.46 and 56). While Mars remains invisible for a period between three and almost seven months, Jupiter's invisibility varies only around one month; Saturn is invisible about 10 days longer because of its lesser brightness (fig.56).

The brightness of the planets is, of course, subject to change during their synodic period. The general type of this variation is indicated in fig.57; the value 3 of the ordinate means brightness of a star of third magnitude, 2 of second, 1 of first magnitude, and this principle is continued to stellar magnitudes 0, -1, etc. The exterior planets reach their maximum brightness at opposition, especially pronounced in the case of Mars. Mercury appears brightest near exterior conjunction (i.e., after W.R. and before E.S.), while Venus reaches her highest brilliance near inferior conjunction (i.e., before W.S. and after E.R.). The nearness of the planet to the earth compensates the fact that Venus is only of crescent shape near inferior conjunction.[354]

354) It might be remarked that the phases of Venus are not visible with the naked eye and that all statements of a Babylonian discovery of this fact are totally unfounded.

§ 2. The Venus Tablets of Ammizaduga.

42. The texts and their history.

a. The development of the problem.

The texts around which all attempts are concentrated to establish a fixed point of Babylonian chronology in the second millenium B.C. have a history of their own which now, more than 70 years after their discovery, might have come to a certain end. The following short report will show in chronological order the main steps in the development of the problem.[355]

355) Further details are given in Langdon -F.-S. p.28-44.

1870. In the third volume of the first great publication of tablets from the British Museum, the "Cuneiform Inscriptions of Western Asia" by H.C.Rawlinson, G.Smith published among others the tablet K 160, described as "a tablet on the movements of the planet Venus, and their influences".[356]

356) III R pl.63.

1874. A.H.Sayce, in a long paper on "The Astronony and Astrology of the Babylonians", gave a translation of this text,[357] today, of

357) Sayce [1] p.316-339. The astronomical discussion followed five years later in Bosanquet - Sayce [1].

course, antiquated but correct in the main outlines. It became fully clear that a list of dates for disappearance and reappearance of Venus were given and omens drawn from the time of invisibility or the date of reappearance.

During the following 30 years, different fragments of the same text became known, all belonging to the Ashurbanipal library, like K 160. It was an important step forward when in

1906 G. Schiaparelli recognized[358] that all these texts con-

358) Schiaparelli [1] and Scritti I,1 p.3-27.

stitute three "documents" (now called L, M and N) in different arrangement. The si uation is illustrated by fig.58. The smaller fragments K 2331 etc. constitute a tablet which contains two different texts, L and M. K 160 begins and ends with L but this text is interrupted by a third document, N, which is inserted in the latter half of L. This shows that the texts at our disposal had been subjected to an ancient editorial activity and force us to face the problem of restoring, if possible, the original form. We shall return to this problem soon. Schiaparelli made an attempt to date these texts astronomically and came to the result that they belong to a period either around 800 B.C. or 650 B.C. We know now that this is about 1000 years too late; the cause of Schiaparelli's error lay in his assumption of the historical background of the texts as belonging to the first millenium B.C.

1912, Kugler announced[359] the discovery that a sentence in K 160, translated by Sayce[360] as "for a year service continues; gold is exchanged(?)", actually is a "year formula"[361] from the reign of Ammizaduga

359) Kugler SSB II p.255 ff.

360) Sayce [1] p.317,8.

361) Cf. above p.###.

a king of the first Babylonian dynasty, and should be read as "year of the golden throne". This year formula was already known as the name of the eighth year of Ammizaduga. Hence Schiaparelli had based his calculations on false assumptions and astronomical elements valid in the second millenium B.C. had to be used instead. Kugler consequently investigated the relation of the recorded dates to the movement of Venus around 2000 B.C. and came to the result that the first year of Ammizaduga corresponded to -1976. We shall refer to this result as "chronology I".

The following year brought a lively discussion of Kugler's result and the methods he used to solve the problem. We shall see that a selection among the recorded dates is necessary in order to compare the texts with modern calculation, and therefore other solutions could be proposed ("chronologies II to V"). During these years a few additional fragments of duplicates were discovered. This whole material was collected

1928 in the book of Langdon, Fotheringham and Schoch "The Venus tablets of Ammizaduga". The essential progress made here consists in the astronomical part, which is due to Schoch's efforts. He computed tables with special reference to conditions in Babylonia, thus laying the foundations for any systematic computation of Venus and lunar phenomena in Mesopotamia. This made possible a comparison of all proposed chronologies and led the authors to the result that "chronology II", proposed already in 1923 by Fotheringham,[362] gave the best agreements between texts and calculation.

362) Announced by Langdon in OECT 2, preface.

1929 the present author showed[363] in a review of the above -

363) Neugebauer (O.) [6] (cf. also [4]).

mentioned book that none of the arguments by which Langdon, Fotheringham and Schoch attempted to distinguish between the different possibilities was conclusive. The conclusion reached was that only historical evidence could bring a decision. Such new outside evidence indeed came eight years later when an archive from the city of Mari on the middle Euphrates was excavated. The correspondence of the local rulers showed clearly that Hammurabi was a contemporary of the Assyrian king Shamshi-Adad I.[364)]

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364) Thureau-Dangin [3].

1938 and 1940 Albright[365)], Ungnad[366)] and Sidney Smith[367)] independently

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365) Albright [1] and [2].
366) Ungnad [1] and [2].
367) Smith (S.) Alalakh [Alalakh is a site on the bend of the Orontes which gave Sidney Smith the essential archeological support for his chronology].

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came to the result that the synchronism thus established between Babylonian and Assyrian history required substantial lowering of the chronology of the first Babylonian dynasty. According to Albright, Ammizaduga should be dated about -1650; practically the same was Ungnad's result. Sidney Smith and his collaborator J.W.S.Sewell proposed a precise date, again using the Venus tablets, namely -1645 as his first year, a result independently also obtained by Ungnad[367a)] ("chronology VI").

Since Kugler's discovery of the year formula of Ammizaduga 8, the date of the first Babylonian dynasty has been reduced by more than 300 years. In order to understand how astronomical records can allow so great a variability in dating we will have to discuss in detail the character of the documents involved. In referring to the various proposed chronologies, we shall use the following list

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7a) More precisely we should write: Ammizaduga 1 ≈ −1645/44 if we assume that the first regnal year coincides with the calendar year.

No.	proposed or accepted by	Ammiz. 1
I	Kugler 1912[359]	−1976[374]
II	Fotheringham 1923;[362] Langdon-F.-S. 1928[368]	−1920
III	Schoch 1925;[369] Thureau-Dangin 1927[370]	−1856
IV	Weidner 1915[371]	−1808
V	Kugler 1924;[372] Ed.Meyer 1925[373]	−1800
VI	Smith-Sewell 1940[367] Ungnad 1940[366]	−1645

368) Langdon-F.-S.

369) Schoch [2].

370) Thureau-Dangin [4].

371) Weidner [4].

372) Kugler SSB II p.569.

373) Meyer (Ed.) GAN p.3 ff.

374) The notation adopted here and in the following is Amm. 1 = −1976/5.

The relative chronology of the first Babylonian dynasty is so well established that the dating of the reign of Ammizaduga is sufficient to date the whole period. If we suppose that Ammizaduga 1 corresponds to the year $-n$ then we obtain:

$$\text{Ammizaduga } 1 = -n \qquad \text{Ammizaduga } 21 = -(n-20)$$

$$\text{Hammurabi } 1 = -(n+146) \qquad \text{Hammurabi } 43 = -(n+104) \qquad (45)$$

$$\text{First Babyl. Dynasty from } -(n+248) \text{ to } -(n-37)$$

Determining any year of the reign of Ammizaduga and the dating of the first Babylonian dynasty are therefore equivalent problems.

b. Character and origin of the "documents".

The part most easily disposed of is the "document N". It contains twelve groups of omens connected with the reappearance of Venus, all built according to the same scheme. As an example, the first group may be given:

If Venus appears on I(b) 2 in the east, distress will be in the land.
Until IX(b) 6 she will be in the east and disappear on IX(b) 7.
She will be absent in the sky for 3 months.
She will rise on XII(b) 7[375] in the west, king will declare hostility against king.

375) Sic according to the text; the scheme requires the 8th day. The replacement of 8 by 7 is easily explained as a copyist's error.

What is given here are the dates of ER, ES and WR, including one period of invisibility of three months at exterior conjunction. The following group is not the natural continuation but begins with a new date for WR which is one month and one day later than the ERm which was the starting point of the preceding group. The structure of this scheme is shown by the following list[376] (omitting the omens)

rising	setting	invisible	rising
I 2 E	IX 7 E	3 m	XII 7 W
II 3 W	X 8 W	7 d	X 15 E
III 4 E	XI 9 E	3 m	II 9 W
IV 5 W	XII 10 W	7 d	XII 17 E
....	....	.....	....
XI 12 E	VII 17 E	3 m	X 17 W
XII 13 W	VIII 18 W	7 d	VIII 25 E

376) E = east, W = west, m = month, d = day.

The purely schematic character of this list is evident. Its value lies in two facts: first, it shows us the type of method by which Venus phenomena were predicted at an early period. These methods are certainly so crude that they would never have sufficed to restore earlier observations. The assumption, improbable in itself, that the dates given in the documents L and M are calculated dates, is ruled out completely. These dates cannot be based on any thing but observations. The second fact is the possibility of determining the value for the synodic period which was assumed by the author of this scheme. From each pair of consecutive lines in the list given above, it follows that the following time intervals have been used:

Venus as morning star:	8 m + 5 d
invisible at exterior conj.:	3 m
Venus as evening star:	8 m + 5 d
invisible at inferior conj.:	7 d

which makes a total of 19 months and 17 days. Assuming months of 30 days' length,[377] this gives 587 days as the synodic period, i.e., 3 days to much This error is certainly not very great, but shows again that we are dealing here with a comparatively early and primitive stage of development.

377) Cf. above p.▮▮▮.

At the end of N appears a colophon which says that the text is a "copy from Babylon".[378] The same remark is alsomfound on a duplicate of K 2321, excavated at Kish, which contains the documents L and M [379]

378) Langdon-F.-S. p.13. This passage has been omitted by Langdon in his copy of the text given on p.23 but is shown on the photograph of K 160 on the title-page of Virolleaud ACh.I.

379) Langdon-F.-S. p.19.

(cf. fig.58). This Kish tablet was written, according to the colophon, during the reign of Sargon, i.e. about 700 B.C. This is the oldest extant copy of these texts, the others being neo-Babylonian copies. That these records of Venus were preserved and copied for 1 ½ millenia is due to their having been incorporated in the large series of astrological texts called "enuma Anu Enlil". We shall again meet this relationship to astrology in the documents L and M .

The document L contains Venus observations and omens, connected with the eastern or western rising. As an example we quote the following passage,[380] typical for the whole document:

380) Langdon - F. - S. p.8.

If Venus disappeared on VI(b) 26 in the west,
remained invisible for 11 days, and
was seen again on VII(b) 7 in the east, the heart of the land will be happy.

If Venus disappeared on I(b) 9 in the east,
remained invisible for 5 months and 16 days,
was seen again on VI(b) 25 in the west, the heart of the land will be happy.

Unlike document N, here disappearance and reappearance of Venus are recorded in their natural order year after year. The irregularity of the intervals, the mention of intercalated months and the general agreement with the astronomically expected facts make it certain that real observations are here recorded. The explicit date of the eighth year of Ammizaduga corresponds to the year by year arrangement. From historical sources it is known that Ammizaduga ruled for 21 years; here again we find agreement with L , where 21 years are recorded - with the sole exception of the 18th year. At the point where this year should be expected, document N is inserted, making it still more evident that the document N originally did not belong where we now find it.

The document M is only a rearranged form of the document L. While L gives all phenomena in their natural order, M enumerates the same dates and omens, arranged, however, according to their month of appearance. The two passages quoted above from document L would therefore be placed in M under the first and sixth month, respectively, regardless of the years. The interest of document M therefore lies only in its value as a check for the dates given in L. From the fact that the dates from year 18 are also missing in M,[381] it follows that M was abstracted from L at a time when L had already been disrupted by the insertion of N.

381) Cf. Langdon - F. - S. p.19 note 2.

That the original document L belongs to the reign of Ammizaduga is further confirmed by the fact that intercalated months VI_2 are mentioned in the 11th and 19th year and that we know from contracts of this period that these years were actually leap years. This does not imply, however, that the preserved form of L is the original form. On the contrary, clear signs which indicate later editorial activity are visible. For example, some dates are astronomically impossible, e.g., in the 9th year WS = III(b) 11, ER = XII(b) 15 which would make Venus at inferior conjunction invisible 9 months and 4 days, which is absurd. Therefore, at least one date must be wrong, and it is easy to see that the first date is only a copyist's error caused by a preceding WS = III(b) 2. The extant text of L, However, does not recognize the error but promptly gives 9 months and 4 days as the duration of invisibility. This and analogous cases show that the duration of invisibility was calculated afterwards and not from the actual records.

Also the omens hardly belong to the period of the period of the observation. Reading the omens in their arrangement as given in L , one will recognize that they make groups of good and bad predictions separated by a neutral remark like the year formula of the 8th year. This seems to indicate that actual observations were later combined with historical records, i.e., lists of year formulae, in order to discover the influence of the date of the rising of Venus on the future. The final form of these texts as we now have them could therefore stem from very considerably later times than the observations recorded during Ammizaduga's reign.

43. The attempts to date the Venus observations.

It is not surprising that texts like the tablets discussed here contain a number of errors due to copying and rearrangement. We have already mentioned the omission of year 18. Several other errors are easily corrected because of such transparent causes as dittography. Some errors are less simple to correct and the proposed corrections are still open for discussion There exists, however, another difficulty which affects document L as a whole, namely, the fact that the system of dates recorded id in itself contradictory. Herein lies the essential problem for all attempts to use these dates for chronological purposes.

In order to explain this statement, we must describe a simple relationship between Venus phenomena and lunar months: the synodic period p of Venus amounts to[382)]

382) We give here a more accurate value than the 584 days mentioned on p.###.

$$p = 583.92 \text{ days}$$

and the lunar month to

$$m = 29.53 \text{ days.}$$

Hence

$$(46) \qquad 99\text{ m} - 5\text{ p} = 2923.5 - 2919.6 = 4 \text{ days} \quad .$$

On the other hand, 8 Julian years are equal to 2922 days. We can therefore express (46) as follows: After 8 years, the date of y Venus phenomenon in a lunar calendar falls 4 days earlier than the previous occurence. For example, suppose the last visibility of Venus took place in the west on XI(b) 15 of the year 1; then one can expect that Venus will again be visible for the last time as evening star on the 11th of a month in year 9 and on the 7th of year 17; the names of the months depend, of course, on the intercalations. But supposing the rule of intercalation to be known, the dates are then known for all groups of eight years' interval if the dates of the beginning are known. Before applying this rule to our texts, we must remark, however, that the relation (46) does not take into account the small change in the longitude of the sun caused by the difference of 1 ½ days between 99 months and 8 years. The actual date differences can therefore deviate by ±1 day from 4 days, such that accurate calculation shows small deviations from our simple rule (46).

We are now able to explain in what sense the dates given in the document L are a inconsistent system. We consider, for example, the WS's during the 21 years of Ammizaduga arranged in groups of 8 years. [The first number gives the year, the numbers in ( ) will be explained shortly.]

1 XI 15	3 VI 23 (29)	5 II 2 (I 29)	6 VIII 2
9 [XII] 11 (12)	11 VI 26 (25)	13 II 5 (I 25)	14 VII 1
17 XII 11 (8)	19 VI_2 1 (20)	21 I (22)	

Let us consider the first group: WS in 1 XI 15 and 9 XII 11 shows exactly the expected difference of 4 in the dates, but it is impossible that

9 XII 11 and 17 XII 11 are both correct dates. In the second group, the first pair is impossible (increase from 23 to 26 instead of decrease by 4) but the second may be right, etc. Obviously, corrections of recorded numbers are necessary in order to eliminate such contradictions; but the main difficulty consists in deciding which numbers can be considered more trustworthy than the others ? The resulting chronologies finally depend on the difference of this selection.

How difficult such a selection is can best be shown by assuming "chronology II", i.e., assuming that Ammizaduga 1 = -1920. Calculating the Venus phenomena under this assumption, one obtains among the 13 recorded WS's three exact coincidences, namely, 1 XI 15 , 6 VIII 28 and 16 IV 5 . All other numbers should be corrected as indicated in the above list in ( ). Moreover, four of the remaining dates should be later than given in the text, six earlier. That the text gives a date too early for the disappearance of Venus can always be explained by bad weather or bad observation. The six cases, however, where Venus was seen for more days than according to calculation constitute a strict contradiction which cannot be overcome except by arbitrary corrections of the text. Exactly the same difficulty appears in dealing with the dates of the three other phenomena recorded (WR, ES, ER) and for all proposed chrohologies. And the common reason is, as we have seen, that the dates of the text do not fulfill the necessary rule of the relation between synodic period and lunation but fluctuate around <u>every</u> possible system of dates. It must be repeated, on the other hand, that the deviations are only small in most of the cases and that there can be no serious doubt that the original basis of the document L was actual observations.

Langdon - Fotheringham and Schoch gave a complete comparison of all recorded dates with all the dates which would follow from all chronologies proposed at the time. From this comparison they concluded that chronology II is the best because it would yield the greatest number of cases where the deviation between text and calculation does not go beyond ± 1 day. One can come, however, to totally different results if one counts the number of cases where a chronology strictly contradicts dates given by the texts. Chronology IV then represents WS with the least number of contradiction, III is the best chronology for ER, II and IV are equally good (or bad) for ES, and I and VI for WR. The total number of strict contradictions are (among about 300 dates)

I	18	III	16	V	20
II	17	IV	20	VI	16 .

It is obviously a purely arbitrary procedure to derive any kind of preference for any proposed chronology from such numbers.

Although never admitted, this fact was obviously felt more or less clearly by all defenders of a definite chronology as derived from the Venus tablets. Different attempts have therefore been made to obtain additional information from these texts. One consists in considering the relation of the Venus phenomena with respect to the seasons in order to evaluate dates of contracts concerning the harvest; the second is based on a study of the consequences of a chronology with respect to the lunar calendar. We shall discuss both arguments in the stated order.

The easiest way to explain how a relation between the chronologies of the Venus tablets and the seasons can be established consists in considering a special group of dates contained in the text, e.g., the inferior conjunction of year 6 limited by the dates WS VIII(b) 28 and ER IX(b) 1. Let us suppose that these dates give correctly recorded numbers, which is at least perfectly possible. Then we can obtain the following information from this data. First, the inferior conjunction of Venus coincides nearly exactly with new moon. Secondly, because the conjunction falls at the end of the eighth month, the longitude of the sun must be about 240° or, say, 30 degrees more if Nisan of this year fell late because of a preceding intercalated XII_2. Third, Venus is supposed to be only 2 or 3 degrees invisible at this conjunction (the number depends on whether VIII(b) had 29 or 30 days ·) and a glance at fig. 54 tells us that so short a period of invisibility requires a longitude of the sun of about 270° but is incompatible with 240°. Hence, from the assumption of the correctness of this pair of numbers it follows that Nisan of Ammizaduga 6 was <u>late</u> in the spring season. The same holds in other cases, and in the same way each selection of dates considered to be correct, i.e., each chronology, leads to a certain position of the months with respect to the seasons. Chronology V, for example, requires all months to be more than 30 days earlier with respect to the Gregorian calendar (representing the seasons) than it should be according to Chronology II. The total oscillation between all chronologies amounts to 54 days.

This fact – that each chronology places the lunar calendar differently with respect to the seasons – has for a long time been the main source of discussion. Some tried to prove from contracts and similar documents that harvest dates or delivery of fruits (especially dates) could or could not agree with the season required by the respective chronology. It is evident that this kind of argument, which is open to all types of arbitrary assumption, cannot lead to really convincing proof. If, moreover, the calendar is regulated according to the actual agricultural situation – and this is, as we have seen, very probably the case[383] – then a late Nisan means simply that we must accept a late harvest, whether it seems to be likely or not. And, finally, Thureau-Dangin showed that the

383) See above p.###.

dates of contracts for future deliveries are couched in terms of a schematic calendar, by saying, e.g., that dates should be delivered in the month of Tishri, regardless of whether or not the actual harvest should fall in the lunar month Tishri or not.[384] This fact completely destroys the basis of

384) Thureau-Dangin [4] p.188 ff.,His examples not only belong to the First Dynasty of Babylon (p.188), but also to the Persian (p.190 f.) and neo-Babylonian periods (p.193).

all discussion of contract dates with respect to the seasons and XXXXXXXXXX XXXXXX definitively eliminates speculations from chronology about the weather 4000 years ago.

The situation up to this point in our discussion can be described as follows: each chronology accepts a certain group of recorded dates as correct and is forced to reject another group as incorrect without being a priori able to distinguish between these two classes (except in trivial cases): and each chronology has the equal right to adjust the weather correspondingly. It therefore meant real progress when Schoch introduced[385]

385) Used in Langdon -F.-S.

a new idea based on an astronomical principle, namely, the comparison of the computed length of the lunar months as required by a given chronology with the actual records.

We may suppose that the movement of the moon and the visibility conditions at Babylon known with sufficient accuracy[386] in order to de-

386) This latter part, the knowledge of the visibility conditions, is by no means simple to ascertain. Actually, no modern measurements from Babylon are available. Schoch was therefore forced to determine the elements in question in such a way that his calculation fitted as closely as possible Neo-Babylonian records (Langdon-F.-S. p.48).

termine exactly the date of each evening on which the new crescent was visible for the first time at Babylon. This means that we may assume that for each month during the period in question it is known whether it had 29 or 30 days. If we now, supposing a straight line to represent the time-axis, we mark all the new-moons on this axis at their right distance and write their lengths below the intervals, i.e., either the number 29 or 30 (cf. fig.59). In order to simplify matters, we now replace each interval of 30 by ● and call it "black" and each interval of 29 by ○ and call it "white". The assumption that we know the exact length of all months is then equivalent with saying that we assume the complete sequence of black and white points to be given. We call this sequence T .

We now make a second assumption: say we have original texts preserved (which is certainly incorrect and will therefore be later modified) which tell us for <u>each</u> month whether it had 29 or 30 days. We write these numbers down in their calandarical order and again replace 29 by ○ and 30 by ● . The new sequence of black and white points may be called H . Supposing that our calculations are correct and that the observations which produced H were undisturbed, the two sequences T and H should be identical. It would therefore be possible to place H below T in such a way that below each black point of T lies a black point of H , and below each white point of T a white point of H .

This necessary relationship between H and T can be used for dating the documents from which H comes if the sequence H is not too short. This latter condition is obviously very essential because if H consists, e.g., of only three elements, say black-white-black, this H could then be placed in many ways below T such that black-white-black of H falls below black-white-black of T . If, however, H extends over a longer period of consecutive years then the required correspondence with T might determine uniquely the place of T , i.e., the time, because of the irregularity of the distribution of black and white on a longer section.[387)]

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387) Actually, one should be sure that no periodicity in T exists; this exclusion would be very difficult.

Unfortunately, sufficient documents give a complete sequence H do not exist. The only documentary evidence as to the lengths of months is contracts which mention the 30th day of a month. What we can obtain from texts is therefore only a sub-sequence h of H containing only black points. The question arises whether h can be used for dating.

Let us suppose that T is calculated, say, from -2000 to -1500 and let h be given for 200 years. This means that we assume that we know from each contract dated on the 30th day of a certain month of a certain year when it should be placed with respect to any other contract of this type. This assumption can be accepted as correct for the First Dynasty of Babylon because we know the number of years which each king ruled and also which years were leap years. Hence h consists of a series of black points of given distances.

Let us now, as an example, assume that the month Nisan of the fifth year of Ammizaduga is attested as having been 30 days long. According to chronology I, the day Amiz. 5 I(b) 1 would correspond to -1972 IV(g) 27 , according to chronology II to -1916 IV(g) 9 , etc. In other words, each chronology assigns to the sequence h a definite place with respect to the time axis T , and it is obviously a necessary condition for a chronology to be correct that the corresponding position of h with respect to T is such that the points of h always lie below black points of T .

This is the basic idea introduced by Schoch to distinguish between the accuracy of the different chronologies. He computed T and compared for each of the proposed chronologies the number of agreements between h and T , where h was compiled from all available contracts of the First Dynasty of Babylon dated on the 30th of a month. He found the following number of agreements expressed in cases per hundred:

I	37 %	III	56	V	34
II	75	IV	62		

which seems to indicate a clear superiority of chronology II. This has evidently been the main reason for considering chronology II as <u>the</u> correct one.

This method of distinguishing between chronologies is, however, open to very serious objection. First of all, the correct chronology should result in 100 % agreement between h and the black points of T and not only in 75 % . But even 100 % agreement between h and T is only a necessary, but by no means a sufficient, condition for the correct placing of h . This can easily be shown by an artificial example. Let T in fig. 60 be the calculated sequence of black and white points and assume the the correct placing of a given sequence h would be h_1 ; than, of course, h_1 and T show 100 % agreement. Someone else, however, might have reasons to believe that h should be dated 2 months later (h_2) and a third person might even date h 5 months later (h_3). Fig.60 shows that also h_2 and h_3 result in 100 % agreement in spite of the irregularity of both T and h . Hence, even a considerably better degree of agreement than shown by chronology II (100 % instead of 75 %) would not be a sufficient proof for the correct chronology of a sub-sequence h.[388)]

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388) The inconclusiveness of this method has been pointed out in Neugebauer (O.) [6] col. 919 f.

The actual situation in the arguments used by Schoch is still worse. The number of contracts from the First Dynasty of Babylon which determine a month as having been 30 days long amounts to only 2 out of a hundred This means that in the scale of fig.60 (which contains 42 points), only one point of h would be recorded. It is self-evident that an agreementof a single black point among 50 proves nothing because in the average, every second place produces an agreement. Schoch's idea is therefore doomed to failure until sub-sequences h of a larger order of magnitude of density are available. Only if we had the dates of a very complete and extensive archive at our disposal would this method offer a chance for chronological results. It is therefore not surprising that chronology II could later be proved to be wrong in spite of the apparently good agreement with the calculated sequence of lunar months.

44. The "short" chronology. Summary.

The inconclusiveness of all the arguments proposed in favor of each of the chronologies I to V could not have been better underlined than by the fact that new historical evidence has made it necessary to lower the date of the First Dynasty of Babylon by about 2 ½ centuries. From archives excavated at Mari, a site on the middle Euphrates, it became clear[389] that

389) Thureau-Dangin [3].

Hammurabi must have been a contemporary of the Assyrian king Shamshi-Adad I.[390] By this fact the chronology of the First Babylonian Dynasty came

390) For a short report about the essential historical arguments cf. Neugebauer (O.) [7].

in direct contact with Assyrian chronology, which does not admit serious stretching. Hence, the First Babylonian Dynasty must be placed in the period from about 1900 tc 1600 and Ammizaduga consequently around 1650. In other words, chronologies I to V tried to identify the records of Venus phenomena with the Venus appearance of totally wrong periods, exactly in the same sense that Schiaparelli was mislead by false historical assumptions 30 years before. We are, therefore, facing for the third time the problem of determining the date of the Venus phenomena in a given century. An answer is proposed by Smith and Sewell in "chronology VI", which assumes Ammizaduga 1 = -1644. We will now explain how this new solution could have been proposed.

This problem is connected with the more general one of determining the periodicity of a group of Venus phenomena in their relationship to a lunar calendar. We have already seen that five synodic periods are almost the same as 99 lunations, or, more precisely (cf. p.### equation (46))

$$8 \text{ years} \approx 5\,p \equiv -4 \text{ days} \quad \text{modulo lunations} \quad .$$

Multiplying this relation by 7 we obtain

$$35\,p \equiv -28 \text{ days} \quad \text{mod. lun.}$$

and, because 28 days are almost a complete lunar month, we have approximately

$$(47) \qquad 35\,p \equiv 0 \quad \text{mod.lun.}$$

In other words, after 35 synodic periods, i.e., after about 56 years, the Venus phenomena again fall approximately on the same date in a lunar calendar (of course only so far as the day number is concerned, the month number depending upon the intercalations which had been inserted in the meantime). This explains the time differences between chronologies I ### to

V (cf. p.???):

I - II = 56   II - III = 64 = 56+8   III - IV = 48 = 56-8   IV - V = 8

i.e., 56 or 56 $\pm$ 8 . We now see that each chronology which gives a fairly good agreement with the recorded dates also agrees not too badly with a chronology 8 years earlier or later and a chronology 56 years earlier or later. The 8-years' differences could be excluded if the system of recorded dates were not in itself so inaccurate that emendations of dates by $\pm$ 4 days are at any rate necessary. The 56-years' differences, however, would require a still higher degree of reliability for the texts before we could decide between solutions 56 years apart. On the other hand, these periods are not exact enough to be repeated more than once or twice. The situation can therefore be represented by a scheme like fig.61: There must always be groups of solutions which agree equally well (or equally badly) with the recorded dates.

These periods of 8 and 56 years are not the only possible ones. Exactly as we found series of succesive improved periodic repetitions in the case of the movement of the moon, both in XX longitude and latitude, also the common periods of moon and Venus can be better and better approximated. Disregarding fractions, we thus obtain the following common periods of synodic periods p and lunations m :

$$(48a) \qquad \begin{aligned} 172\ p &= 100434 \\ 3401\ m &= 100434 \end{aligned}$$

to which we add

$$(48b) \qquad 275 \text{ trop.years} = 100441$$

This shows that after 275 years, not only are the dates in a lunar calendar unchanged but also the relation with respect to the seasons is only altered by the very small period of 7 days. Therefore also the visibility conditions which depend upon the seasons are preserved. Consequently, any system of chronology which agrees with the texts for a certain date will also agree with dates 275 years earlier or later. And, indeed, the time difference between chronologies II and VI amounts to 275 years.

Chronology VI is therefore simply the periodic repetition of chronology II. There is, however, no real reason for repeating only chronology II because, as we have seen, there is no real means to establish a clear superiority of this chronology over the whole group of chronologies obtainable by adding $\pm 56 \pm 8$ years. Moreover, we have seen that the main argument for chronology II was the alledged best agreement between the 30 days' months as given by contracts and the calculated 30-days' months. Let us suppose that this agreement actually existed (although the argument is not conclusive in reality) and let us ask whether such an agreement remains also unchanged by the addition of 275 years. To answer this question we need only remark that the visibility of the new moon depends not only on the seasons and lunations (which are unchanged) but also on the moon's latitude.[391] Hence we have simply to find a multiple of the length of the

391) Cf. above p.###.

nodical month $n = 27.212$ days which comes as closely as possible to the length of the 100434 days of our period (48a). This is given by

$$3691\ n = 100440 \text{ days}$$

i.e., 6 days more than the Venus period. During 6 days, however, the moon's latitude changes very considerably, e.g., almost completely from the node to extremal latitude because 6 days are almost 1/4th of the nodical month. The sequence T of numbers 29 and 30 will therefore be totaly different for the periods of chronology II and VI. Therefore, if one believes that the agreement of chronology II with the lunations speaks in favor of chronology II, then one must at the same time consider it as unfavorable for chronology VI. If one, however, considers the lunations as absolutely undecisive (and this is the conclusion to which we came above), then again no reason exists for preferring chronology II above all other chronologies with a difference of ±56±8 years.

We can now summarize our results. The Venus tablets alone are certainly not sufficient to establish the absolute chronology of the First Babylonian Dynasty. If, however, the century of Hammurabi or Ammizaduga can be determined by other considerations, the Venus tablets can then be used to pick out special dates which are the only possible dates and whose distance amounts to 56 years (perhaps ±8 years). The present situation is therefore as follows. The Venus tablets alone are compatible with the following dates[392)]

392) In order to avoid mistakes, it is explicitly stated that the astronomical dating is restricted to the reign of Ammizaduga and that the other dates are obtaines by adding the usually accepted figures for the duration of the First Dynasty of Babylon and the reign of Hammurabi (cf. formula (45) on p.[illegible]).

Ammizaduga 1	-1701	-1645	-1589	-1533
Hammurabi	-1847	-1791	-1735	-1679
	-1843	-1749	-1693	-1637
First Bab.Dyn.	-1949	-1893	-1837	-1781
	-1664	-1608	-1552	-1496

and perhaps dates which are greater or smaller by 8 years. Dates between these years, however, are astronomically excluded. Which group is historically correct cannot be decided on astronomical grounds but only by historical means. The two middle columns apparently contain the solutions which are historically most likely.

§ 3. Horoscopes.

45. Character of the texts.

Horoscopes are ceratinly not classified as a very respectable type of ancient literature; they definitely belong to the underpriviledged class of "sub-literary" texts.[393] Here is not the place to discuss the rôle of astrology in the frame of ancient thought and science, although I must confess that I have difficulties in distinguishing between the spiritual level and background of astrological writers and the works of church fathers or ancient philosophical doctrines which contain many more basic errors and logical inconsistencies than the hypothesis of the direct influence of celestial phenomena on the life on earth. For purely chronological problems, however, the value of horoscopes cannot be denied. A horoscope establishes a relationship between planetary constellations and a certain date, frequently expressed in regnal years or years of a certain era, thus yielding us information of high great significance for chronology. It is therefore necessary to discuss here briefly the character of these documents and the methods of evaluating them astronomically.

The chronological value of horoscopes is somewhat reduced by the fact that the constellations recorded are in all probability not observed constellations but the result af calculations, whose accuracy is, of course, subject to discussion. This is not only evident from the general consideration that horoscopes were frequently computed many years later for grown-up

393) Powell RHP p.34 ff.

people but can also be directly seen from the fact that invisible constellations are mentioned, e.g., planetary positions during daytime or conjunctions with the sun. Additional difficulties occur from the use of unknown points of departure for measuring longitudes (e.g., of precession combined with the assumption of the vernal point inside the sign aries[394]) or the use of different calendars, as, e.g., Egyptian or Alexandrian counting of months.[395]

394) Cf. above p.▮▮▮.

395) Cf. above p.▮▮▮.

No rules can be given to overcome such difficulties in all cases. The only solution is the careful discussion of all possibilities in each individual case based on experience with the already known material.

It is usually considered "well known" that the idea of casting horoscopes originated in Babylonia. Actually, the problem is by no means so simple. All the older Babylonian omens referring to celestial phenomena have an impersonal character of the same type as we have seen in the Venus tablets: some astronomical facts are considered as revealing certain information as to the future of the country or its king but we never find anything like a horoscope in periods before the fourth century B.C. And even during Seleucid times, the total number of horoscopes preserved in cuneiform literature is only three, the oldest text being a horoscope both for conception and birth dated in -257 III 17 and XII 20.[396] This

396) This and another horoscope are discussed by Kugler SSB II p.558-562. The third horoscope is published in Thompson (R.C.) [1] p.34 (AB 251) and pl.2.

can, of course, be purely accidental, but we have several hundreds of purely astronomical texts from the same ▮▮▮ period which show no trace of horoscopic interest and are simply devoted to the systematic calculation of celestial phenomena (lunar calendar, eclipses and planetary phenomena).

In the first century B.C., the interest in astrology becomes very evident in Syria; monuments and coins reveal this clearly.[397] It is, however, not before the first years of our era that Greek horoscopes are preserved, and all these were found in Egypt with the only exception of a few horoscopes written on walls of houses in Dura-Europos,[398] the famous outpost of Hellenism on the upper Euphrates. The total number of these horoscopes in the Greek language amounts to 54, almost uniformly distributed over the first five centuries A.D. In addition to these, we have 8 horoscopes written in Egyptian, all of which are from the first century A.D., two on the ceiling of a tomb,[399] one on a coffin lid and 5 Demotic ostraca.[400] The Greek horoscopes are all written on papyrus, except for the few wall-grafitti and one ostracon.[401] Not a single horoscope in Latin is preserved. When we consider these facts and think how many horoscopes must have been cast in Egypt and Rome, we get a good impression of what a vanishingly small fraction has actually been preserved.

397) E.g., the famous tomb-relief of Antiochus I of Commagene (frequently discussed and reproduced e.g. Cumont [1] p.148). A lion is there represented, surrounded by stars indicating that Antiochus was born when Jupiter, Mars and Mercury were in Leo (-96).

398) Dura Rep. II p.161 ff. and pl.51, Rep. IV p.105 ff and p.115 ff., Rep. VI p.246 f.

399) Petrie, Athribis p.12 f., p.23 f. and plates 36-38.

400) Neugebauer (O.) [8].

401) Wilcken, Ostraca II p.422 No.1602.

In spite of their comparatively small number, the horoscopes furnish us much valuable chronological information. The natural tendency to use eras in astronomical calculations has preserved for us, e.g., early examples of the use of the era Diocletianus.[402] Problems of local eras were clarified by horoscopes ar Dura;[403] they were also valuable archaeologically because of the dating of the houses on the walls of which these horoscopes were written.[404] Questions of Roman chronology in the difficult later

402) E.g. P.Soc.Ital.VII p.53 No.765 dated era Diocletianus 31.

403) Dura Rep. IV p.108 ff.

404) Dura Rep. VII p.164.

period have been solved by the same source of information.[405] The same holds

405) E.g. P.Ox. XII p.231 f.

for problems of the use of the different forms of calendar employed in Demotic documents. One can therefore say that the study of horoscopes has amply repayed the modest amount of work invested.

The general pattern of the known horoscopes exhibits little variation. The most common type gives the date of the birth (year, month and day, frequently also the hour) and indicates simply the zodiacal signs in which the sun and the five planets were at the given time. The position of the moon is frequently more accurately indicated; the higher exactitude in this case is necessary because of the moon's rapid movement (between 11° and 15° per day). Some horoscopes, however, give the positions of all bodies with very high accuracy, even to fractions of degrees[406] - obviously the re-

406) This seems to be especially the case in the earlier group of horoscopes, e.g., P.Lond. No.93,110,130 (= Kenyon GP I p.126-129).

sult of calculation. These more elaborate horoscopes also contain introductory remarks and astrological comments to the different signs, but the explicit result as to the final conclusion is never given. The astrologers apparently avoided the formulation of their conclusions in writing; moreover, if the constellations are known, all conclusions could be gathered from the astrological handbooks and treatises which have come down to us in great number and variety.[407] It is difficult to understand why some papyri contain collections of several horoscopes with no apparent interrelation, even duplicates with small variants.[408] Here a more detailed study is obviously necessary

407) Cf. e.g. Vettius Valens or the texts collected in the CCAG.

408) E.g. P.Soc.Ital. I p.48 ff.

which, among other things, should attempt to discover the astronomical methods and rules according to which the constellations were calculated. This latter point might be of considerable chronological interest because in order to determine more precisely the reliability of horoscopic data, we must know the accuracy of the ancient tables which were used.

46. Approximate calculation of planetary positions.

It has already been mentioned that horoscopes usually contain only planetary positions of very restricted accuracy. It is therefore meaningless to investigate horoscopic dates by calculating with high accuracy. For such purposes, it is fully sufficient to guarantee the calculated position with an accuracy of about 1° in longitude and to disregard latitudes completely. The same kind of approximative determination of planetary positions will also be useful for checking ancient observations in most cases because the accuracy of ancient instruments or tables will hardly have reached a higher degree.

With these simplifications, the calculation of planetary longitudes for a given date become a very easy affair. Tables have been computed by

P.V.Neugebauer[409] which, by a few additions, make it possible to find planetary positions with an accuracy of $\pm 1^{\circ}$ [410] for the period between -2500

409) Neugebauer (P.V.) GT.

410) The longitude of the sun (which must be known before the longitude of the planet can be determined) is given with an accuracy of 0.2°.

and +1999. These tables are reproduced in the appendix of the present book in a slightly modified form, in the sense that -1000 and +499 are adopted as time limits.

Before giving the simple rules according to which planetary positions should be calculated from these tables, I wish to explain their basic principle, although these calculations can be carried out mechanically without the slightest understanding. Let us suppose that we know exactly the shape of the orbits of the earth and the relevant planet around the sun (fig.62). Let us further assume that also the "age" a of the palnet is known, i.e., the number of days elapsed since the last preceding (superior) conjunction, together with the place of this conjunction. Then obviously the place Π of the planet is determined; but by the given date for which we wish to calculate the geocentric longitude of the planet, the place E of the earth is also determined. Therefore the angle α = SEΠ is given; but α is nothing but the elongation of the planet from the sun or $\alpha = \lambda - \odot$, where λ denotes the longitude of the planet, $\odot$ the longitude of the sun. We need therefore only add α to the longitude of the sun in order to obtain the longitude of the planet.

How this idea works out in detail can best be explained by calculating an example. Suppose we wish to check the positions of the planets as indicated in a horoscope dated -141 III 1.[411]

411) This is the third Babylonian horoscope mentioned above.

☉	♓	♂	♑
☾	beginning of ♊	♀	♑
♄	♌	☿	← [not indicated]
♃	♎	☾	beginning of ♊

It is convenient to arrange all calculation according to a clear scheme in order to avoid errors and to save time and labor. Such a scheme is given on p.***, which we are to consider as being gradually filled as the calculation progresses.

The first step consists in determining the position of the sun. Calculate by using plate ***:

interpolate between -200 III 1 337.8 and -100 III 1 338.5 } -141 $\odot_1 = 338.2$

split -141 into -200 + 59 and find for 59

$$\odot_2 = -0.3$$

Then the longitude of the sun is

$$\odot = \odot_1 + \odot_2 = 338^0$$

and hence[412)] its distance from the earth

$$R = 512 .$$

Both R and ☉ must be entered at their places in the scheme for all planets

412) It is sufficient to use $\odot \approx 340$ and year 0 instead of $\odot = 338$ and year -141 because decimal fractions can be disregarded in R.

The next step consists in calculating the age a of the planet (we use Mercury as an example) and, at the same time, the distance m from the preceding perihelium P (cf.62). Calculate by using plate III:

−200	$a_1 = 64.4^d$	$m_1 = 17.9^d$
59	$a_2 = 111.7$	$m_2 = 84.5$
III 1	$a_3 = 60.0$	$m_3 = 60.0$
added	236.1	162.4
reduce mod.period	− 115.9 [413]	− 88.0
	$a' = 120.2$	$m = 74.4$

---

413) Here only p instead of 2p is substracted because this would lead to negative values of a in the following step.

The value a' is obtained by assuming uniform movement. Therefore, a correction must be added which depends on the deviation of the orbit from the circular form, i.e., on the value of m . At the same time, the value r of the planets heliocentric distance can be noted down. We obtain from pl.### and "## :

$m = 74.4$: $a_4 = -7.0$ $r = 62$

0 III 1: $a_5 = -0.6$

hence $a = a' + a_4 + a_5 = 112.6$

and $R - r = 450$.

Knowing the age a and the heliocentric distances R and r [414] pl. ###

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414) Actually neither R nor r are the heliocentric distances indicated by these letters in fig.62 but the logarithms of these magnitudes (minus a constant number). Therefore R − r represents not the difference between the heliocentric distances but their ~~proportion~~ ratio − which is the only magnitude needed to determine the shape of the triangle ESΠ.

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gives by interpolation

$$\lambda - \odot = 357.4$$

and because of $\odot = 337.5$

$$\lambda = 695 \equiv 335 \text{ mod. } 360$$

i.e. in the zodiac ♓ 5 . Mercury was therefore only 3° before exterior conjunction.

The calculation of the longitudes of the other planets follows exactly the same scheme with the only exception of Jupiter and Saturn where the preliminary value a' contains an additional small correction a_o listed on pl.***. This shows that all planetary positions listed in the horoscope agree with our calculations.

The determination of the position of the moon follows the same method if we are satisfied with an accuracy permitting (in unfortunate cases) an error of as high as $\pm 2^\circ$. This accuracy is certainly sufficient for horoscopes where no precise moment is given because the moon anyhow moves about 0.5° per hour; moreover, ancient lunar calculation scarcely reached a higher accuracy. For horoscopic calculations, therefore, tables like pl.*** ff. are fully sufficient.[415) The scheme of the calculation is as follows:

415) These tables are composed from Neugebauer (P.V.) TAChr.II with slight modifications. For higher accuracy, however, the original tables must be used (TAChr.II p.68 ff. and p.XXIV ff.).

-200	$a_1 = 96.0^\circ$	$m_1 = 250^\circ$
59	$a_2 = 258.2$	$m_2 = 18$
III 1	$a_3 = 70.6$	$m_3 = 64$
5^h (Babyl.)	$a_4 = -5.4$	$m_4 = -6$
	$a_o = 1.4$	$m_o = 5$
sum	420.8	$m = 331$
reduce mod.360°	-360	
	$a_1 = 60.8$	

	☿		♀		♂		♃		♄		☾		
	a	m	a	m	a	m	a	m	a	m	a	m	
−200	64.4	17.9	363.2	25	414.9	285	88.3	262	150.4	25	96.0	250	−200
59	111.7	84.5	527.9	202	490.7	252	9.2	422	375.8	0	258.2	18	59
III 1	60.0	60.0	60.0	60	60.0	60	60.0	6	60.0	1	70.6	64	III 1
a_0	—	—	—	—	—	—	−0.4	—	0.8	—	−5.4	−6	5^h
	236.1	162.4	951.1	287	965.6	597	157.1	690	587.0	26	0	0	Babylon
mod. p	−115.9	−88.0	−583.9	−225	−779.9	0	0	−433	−378.1	0	1.4	5	a_0
a′	120.2	74.4	367.2	62	185.7	597	157.1	257	208.9	26	420.8	331	
a_4	−7.0		1.4		17.8		3.0		−7.9		−360		mod. 360°
a_5	−0.6		−3.2		4.3		2.2		2.1		60.8		
a	112.6		365.4		207.8		162.3		203.1		−3.2		a_5
											57.6		λ
R	512		512		512		512		512				
r	62		372		670		1244		1492				
|R − r|	450		140		158		732		980				
λ − ☉	357.		314		301		221		166				
☉	338	= ♓ 8	338		338		338		338				
	695.		652		639		559		504				
mod. 360°	−360		−360		−360		−360		−360				
λ	335	= ♓ 5	292	= ♑ 22	279	= ♑ 9	199	= ♎ 19	144	= ♌ 24	58	= ♉ 28	λ

Now comes the correction which is necessary because of the excentricity of the orbit. With $m = 331^{\circ}$ as distance from perigee, it follows from pl.### that $a_5 = -3.2$ and therefore

$$\lambda = a' + a_5 = 57.6^{\circ} \approx ♉ 28 .$$

According to the text, we should get the beginning of ♊, but this discrepancy disappears when we assume the position of ♈ 8° for the vernal-point, which is the usual position within a large group of Babylonian astronomical documents;[416] $\lambda = 58$ then corresponds to ♊ 6. Hence all positions are correct as given in the horoscope.

416) Cf. above p.###.

47. Dating of horoscopes.

Much more important than the checking of the positions given in a horoscope of known date is, of course, the problem of determining the date of a horoscope by means of the given positions. As a rule, the attempt to solve such a problem must start with the most significant elements, namely, the positions of Saturn and Jupiter. Since the sideréal period of Saturn as about 30 years, of Jupiter about 12 years,[417] it is clear that these two planets repeat their relative position woth respect to each other and with respect to the zodiac only after a period of about 60 years. The sun, on the contrary, passes through all the zodiacal signs each year and practically the same holds for the two inner planets Mercury and Venus. If, therefore, the positions of Saturn and Jupiter are not given (or not preserved) in a horoscope, there will be many possibilities to place the remaining bodies satisfactorily; if, however, positions of Jupiter and Saturn are given, they will

417) Cf. above p.###.

immediately eliminate all dates between solutions which are 60 years apart. By historical or philological considerations, only one or two centuries are usually admissible and hence the number of [redacted] possible years is actually very small if the two outer planets are placed correctly. Once the year is known, the month can be guessed from the sun's position. Calculation of the position of Venus or Mercury with this approximate date easily shows how many days approximately should be added or substracted in order to place also these planets correctly. The moon. finally, gives the exact date because of its rapid movement.

The first step in this general program consists therefore in developing a simple method to find the right year for Saturn and Jupiter. We do this in the following way. We construct on graph paper a rectangle, 60 units long and 12 units high, representing 60 yeyrs and the 12 zodiacal signs, respectively. Then on two sheets of transparent paper we draw on the same scale a diagram of the mean movement of Saturn and of Jupiter, i.e., straight lines which cross the strip of 12 units width in 11.85 and 29.45 units of lengths,[418] corresponding to the sidereal period of Saturn and Jupiter (fig.63). Finally we use the table (given below on p.200) containing the positions of Saturn and Jupiter in the zodiac[419] with 60 years interval; we

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418) This accuracy can easily be reached on paper with millimeter squaring, if 1 cm = 1 year and 1 zodiacal sign.

419) The zodiacal signs are here, of course, only abbreviations for longitudes measured from the truw vernal point. The historical boundaries of the signs must be investigated in each case.

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consider the left hand side of our rectangle e.g. as the zodiac at -600 and place the Saturn-diagram so that it intersects this line at ♑ 3, the Jupiter -diagram at ♑ 17, then we have the movements of these two planets graphically represented for the 60 years from -600 to -540.[420] If we are given the positions of

420) As a check of the accuracy one can use the fact that the lines of the diagrams should cross the righthand end of the rectangle at ♑ 16 and ♒ 7 as required for -540.

I 1	♄	♃	♂
-840	♏ 17	♏ 1	♒ 29
-780	♏ 29	♏ 19	♑ 24
-720	♐ 11	♐ 9	♑ 0
-660	♐ 22	♐ 27	♐ 5
-600	♑ 3	♑ 17	♏ 10
-540	♑ 16	♒ 7	♎ 14
-480	♑ 28	♒ 28	♍ 18
-420	♒ 12	♓ 20	♋ 18
-360	♒ 24	♈ 13	♉ 3
-300	♓ 8	♉ 6	♓ 25
-240	♓ 23	♊ 2	♒ 28
-180	♈ 8	♊ 28	♒ 1
-120	♈ 25	♋ 27	♑ 7
- 60	♉ 11	♌ 17	♐ 13
0	♉ 27	♍ 9	♏ 18
60	♊ 16	♎ 2	♎ 23
120	♋ 2	♎ 21	♍ 18
180	♋ 20	♏ 11	♋ 26
240	♌ 7	♏ 29	♉ 17
300	♌ 22	♐ 18	♈ 4
360	♍ 8	♑ 7	♓ 5

these two planets in a horoscope, we can now immediately see whether or not there exists a year in this interval where both graphs cross in the same year the required signs (e.g., ♏ and ♓ in fig.63). By repeating this process for every 60 years, we can without calculation find all possibilities where there is any chance that the two outer planets are in the sign indicated by the horoscope.

Here again, the best way to illustrate this method consists in working out a concrete problem. We want to determine the date of a papyrus fragment published in "Papyrus Fouad I" as No.6. The first lines, which, according to the usual scheme, contained the name of the client and the date of his birth, are destroyed. Only the name of the month and the hour is preserved: Pharmouthi [////] 3^h at night. Pharmouthi is the eighth Egyptian month, but it remains to be determined whether it is to be understood in the Egyptian or in the Alexandrian calendar.[421] The remaining part is completely preserved and

421) Cf. above p. ???.

gives the following constellation

Saturn is horoscopos in Virgin

Sun and Jupiter in Fishes

Mars in Aries

Venus in Aquarius

Moon in Leo

Mercury in Fishes .

Palaeographical arguments place the text in the late first or early second century A.D., most likely the latter.[422] We shall see that this date is

422) P.Fouad I p.13.

fully confirmed by our results, which are, of course, obtained without taking advantage of this palaeographical information. The application of the above -described graphical method shows first of all that for centuries before 120 A.D. Jupiter did not enter the Fishes while Saturn was in the Virgin. The first possibility occurs around the beginning of the year 125 A.D. (cf. fig.64), the next is 183/4 and then several later possibilities with about 60 years' difference. Although the actual movement of Mars is only very approximately represented by the average movement, the graph is sufficient to eliminate these later possibilities, thus leaving only the first mentioned case for closer investigation.[423]

423) In order to avoid all possible errors, the position of Mars has also been calculated for 184 III 11 , showing that Mars was then in Libra, i.e., roughly opposite to its required position.

The next bit of information is given by the position of the sun in Fishes and of the moon in Leo, i.e., one sign before full-moon. Ginzel II contains tables of New-moon dates during our period showing that new-moons[424]

424) Ginzel does not contain tables of full-moons for this period.

were 125 II 21 and III 22 , to which we must add about 12 days in order to obtain the proper relative position of sun and moon. Calculation of the longitude of the sun for 125 III 5 gives ♓ 14; dates one month later or earlier are now ruled out because the sun would be far from the Fishes. Calculating the longitude of the moon for 125 III 5 , one obtains ♌ 18 in agreement with the text – but one day earlier or later would also be possible. Finally, Venus is found in Fishes 16, Mercury in Aquarius 29 – positions which are reversed in the horoscope. This can hardly be due to anything else but the inaccuracy of the ancient calculation or an error.[425] The

425) Aquarius 29 could, of course, actually be already in Fishes but Fishes 16 remains contradictory to the given position of Venus.

Julian date III 5 corresponds to the eighth month only if we use the Egyptian and not the Alexandrian calendar. Our final result is therefore +125 VIII(e) 16±1 = III(j) 5±1 as the date of birth; the palaeographical arguments, mentioned above, seem to indicate that the horoscope was actually written not much later.

This example shows the typical procedure which leads to a result with very little calculation. It might be added that in cases where regnal years are involved, it is wise to consider not only the given regnal year but also the preceding and following number because of possible differences in local eras of an imperfectly known epoch. The hour of birth, which is frequently given, is usually valueless for the dating (cf. our example) because it would at any rate only affect the position of the moon which had to be given very accurately in order to determine the hour. For the ancient astrologer the hour was of course the most important element because it determined the rising sign, the "horoscopos".

§ 4. The week and related problems.

48. The planetary week.

Although the week will only rarely occur in connection with problems of absolute chronology, at least a short discussion of this concept is needed because it plays a great rôle in late antiquity and medieval times. In principle, we could have dealt with this subject in the first chapter but "week", in the sense that we use it here, means the "planetary" week and therefore bears a direct relationship to the problems of the present chapter.

The planetary character of the week is obvious from the names of the days, although in English and other Germanic languages only after partial retranslating into Roman week-names:

	Saturday	♄	
	Sunday	☉	
	Monday	☾	
(49)	Tuesday	♂	Ital. Martedi
	Wednesday	☿	Mercoledi
	Thursday	♃	Giovedi
	Friday	♀	Venerdi

That Sun and Moon are here considered as "planets" may be accepted for the moment, although we shall have to return to this point. Much more distressing at first hand is the principle of arrangement which seemingly has no relation to the astronomical order which would be

(50) ♄ ♃ ♂ ☉ ♀ ☿ ☾

if we arrange the planets according to their distance from the earth. There is, however, a direct bridge from (50) to (49) which consists in the following astrological construction. Let us assume that each <u>hour</u> of the day is ruled (or dominantly influenced) by a planet, and let us start with the first hour of Saturday ruled by ♄ . Now we proceed from hour to hour by following (50), and, beginning after the 7-th hour (ruled by the moon), again with Saturn and so on. Because $24 \equiv 3$ mod.7, the result of going through 24 hours must be that the first hour of the next day is ruled by the planet which in (50) is three places farther advanced than the day before (cf. fig. 65). The order of the subsequent first hours thus obtained is precisely the order (49). The names of the weekdays are therefore the names of the rulers of their first hours beginning with Saturn on Saturday.

It is highly probable that this explanation, already given in antiquity,[426] represents the real history of the coordination between planets and week-days. It presupposes the combination of two different elements: the existence of a cycle of seven days and its astrological interpretation. A short discussion of both components is therefore necessary.

General agreement seems to be reached in assuming that the cycle of seven days is based on the Jewish Sabbath, celebrated at least since the eighth century B.C.[427] Much divergency of opinion, however, exists about

426) Dio Cassius (3rd cent.A.D.) XXXVII 18. The text is given in Colson, Week, p.123 f. and translated on p.43 f. The same principle is applied by Vettius Valens (I,10 ed.Kroll p.26), an astrological author writing about 150 A.D.

427) Colson, Week, p.11.

the origin of this Jewish institution. The most favored theory seems to be that the Sabbath originated from a full moon festival falling on the 14th of the Babylonian lunar calendar. It seems to me, however, that this theory fails to explain the most characteristic and most essential peculiarity of the Jewish Sabbath, namely, its regular repetition after 7 days. No lunar festival can ever have a period of 28 days which would show a difference of 3 days with respect to the lunar calendar after only two months, and nobody using a lunar calendar could have come to the assumption that the lunar phases are 7 days apart. As to the alledged relation to Babylonia, it is true that there are texts which lay emphasis on the seventh day of the month both for festivals or for hemerological purposes. But here again the regularity of repetitions is lacking because in the same context, e.g., also the 19th day is mentioned;[428]

428) Cf., e.g., Landsberger KK p.108, p.119 f.

nor must we forget that these days are dates in a lunar calendar and therefore never repeated after four 7-day weeks but only after 29 or 30 days. The only conclusion I am able to come to is therefore that the explanation of the Jewish Sabbath can only be expected from Jewish religious sources independent of Babylonian or other lunar calendars. There is certainly no trace of anything like the Jewish week in Babylonia.

Much the same is the situation so far as the astrological part of the week days is concerned. There can be no doubt that the astrological interpretation of the Jewish cycle of 7 days is a very late affair, probably not earlier than the first century B.C. The details of this process, however, and the history of its spread all over the ancient world still lie in much darkness.[429] The first step very probably consisted in explaining the

429) It might be of interest for the problem both of time and place of origin of the planetary week to mention the following parallel facts.

In apocalyptic writings attributed to Hystaspes, the doctrine is given that each planet (of seven !) rules one millenium of the existing world. These writings can be dated within narrow limits because from it follows the contents that thex are later than the conquest of Syria by Pompey (-63) and, on the other hand, we know that they were prohibited by Augustus under penalty of death. This shows the origin and rapid spread of these ideas during the first cent.B.C. from Syria over the Roman empire. Cf. Bidez-Cumont MH I p.217 ff.

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strange habit of the Jews in abstaining from work on a certain day by assuming that this day stood under the influence of Saturn,[430] the most malevolent of the planets. The initial step towards the planetary week hence seems to be the explanation of the Sabbath as Saturn's-day, and therefore taboo.

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430) Tacitus, Hist. V,4. Cf. also Colson, Week, p.16 f.

The next step is usually assumed to be a natural consequence of the first, namely, coordinating the remaining six days with the remaining six planets. This explanation, however, meets with very serious difficulties. The first, as we have seen,[431] is the arrangement of the planets based on their

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431) Above p.###.

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rulership over the hours, not over the days. Secondly, the original number of the "planets" is five and not seven. This is evident from Babylon, Egypt and Greek as well. There is only very little evidence from Babylonian sources that sun and moon were conceived as constituting a heptad together with the five planets.[432] Sun and moon play such an important rôle in Egyptian re-

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432) Cf. Boll [1]. Only one text from Ashurbanipal's library calls moon, sun and the planets "the seven planets" (CT 26, 45, 21) but there is no trace of this use in the astronomical texts.

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ligion of all periods that it is out of the question to place these two bodie on the same level with the obscure planets; the Greek astronomers[433] almost

433) E.g., Ptolemy passim in the Almagest (less outspoken in the Tetrabiblos).

consistently speak about the "five stars" when referring to the "planets", a word which refers to irregular wandering and therefore certainly does not originally include the sun and moon. On the contrary, it seems to me that the equivalence of sun, moon and planets in their rulership over the seven days of the week contributed essentially to the concept of the "seven planets". I think one must frankly admit that the exact circumstances which led to the construction of the planetary week are unknown. Only the general background can be described with fair certainty: the increasing interest in astrology and magical arts combined with the spread of Judaism must have lead to an astrological - number - mystical interpretation of the Jewish sabbath. The idea of a domination of each of the 24 hours might have been an Egyptian contribution because in Egypt there already existed the concept of 12 deities ruling over the hours of the day and 12 others over the hours of the night.[434]

434) Cf. above p. 59.

Equally unknown in detail is the history of the obviously rapid spread of this new institution. Here again we see only the outlines of the process. The main point is the fact that the planetary week must have been established as a pagan institution, as is evident from the appearance of pagan deities in the names of the days of the week in northern Europe[435] (e.g.,

435) Cf. Colson, Week, § 7. This is also shown by the use of the planetary week by pagan Vettius Valens, quoted above p. note 426.

Thursday, Friday). It is only a secondary development that the Jewish Sabbath was replaced in importance by the day of the sun and that this day became the ay of the Lord ("domenica"). The official acknowledgement of the holiness of unday is as late as the fourth century, when Constantine in 321 decreed that ll work should cease on the "venerabili die solis".[436)]

436) Cod. Just. III, 12, 2 (ed. Krueger p.127).

49. The calculation of week days.

The "Julian days" [437)] are constructed in such a way that it i

437) Cf. above p.###.

is especially simple to determine the week day of any given date because Julian day 0 is a Monday. One therefore only need reduce the Julian day number modulo 7 in order to know the week day, calling the remainder 0 Monday, 1 Tuesday, 2 Wednesday etc.[438)]

438) The "Domincal Letters" consist in nothing but replacing the remainders 0, 1, ..., 7 by letters A, B, ..., G and complicating the calculation by additional rules (cf., e.g., Ginzel III p.125 ff.).

Example: Determine the week day of -29 I(a) 1 . We find in Schram p.109:

year:	$-117 + 88$	Thoth 0	Julian day:	1710706
	hence	Thoth 1	$n =$	1710707 .

Now

$$n \equiv 5 \mod 7$$

and we therefore have the result that the first of Thoth, Alexandrian calendar, of -29 was a Saturday. The equivalent in the Julian calendar is VIII(j) 30 , as follows from Schram p.33 or p.107.

Our result

$$-29 \quad I(a) \quad 1 = -29 \quad VIII(j) \quad 30 \quad \text{Saturday}$$

has an interesting relation to a passage in Vettius Valens.[439] This author gives a rule how to compute the week day in the Augustan era and explains his rule by determining the week-day of Hadrian 4 VI(a) 13. He says that Hadrian 4 = Augustus 148.[440] Because $365 \equiv 1$ mod.7, each ordinary year corresponds to 1 day more in the week. To 148 days we must add 36 because 148 Julian years contain 36 leap years.[441] Finally, VI(a) 13

439) Vettius Valens I,10 ed. Kroll p.26.

440) Hence Augustus 1 $\approx$ -29/28.

441) The 148th year was not yet completed, hence 36 and not 37 leap years! Leap years are all years of the Augustan era which are $\equiv 0$ (mod. 4). (of our era) The leap days fall in the years -29, -25, ..., -1, +3, etc., i.e., years $\equiv -1$ (mod.4) (cf. Wilcken, Ostraca I p.789).

corresponds to the $5 \cdot 30 + 13 = 163$rd day of the year. Hence we have a total of $148 + 36 + 163 = 347$ days, which is $\equiv 4$ mod. 7. Now we are told that the first day of the Augustan era was a Sunday and therefore the 347th and the 4th day will be Wednesday. This is the answer to the problem given by Vettius Valens.

We are here only interested in the statement that the Augustan era began with a Sunday - which would correspond, according to our above calculation, to -29 VIII(j) 31. There exists, indeed, some controversy as to whether VIII 31 or VIII 30 was considered as the epoch of the Augustan era, and the statement of Vettius Valens seems to give the decision in favor of VIII 31.[442] Here, however, it is disregarded that Vettius

442) This is the point of view of Colson, Week, p.52. Cf., moreover, Ginzel I p.224 ff.

Valens defines the week day according to the planet ruling the first hour of the night - obviously a remnant from the Jewish evening epoch, which is of course also the epoch for the Sabbath. What Vettius Valens does is therefore simply that he begins the counting of the week days in the evening (cf. fig.66), at sunset, and therefore calls the first of the Alexandrian Thoth of the first year of Augustus a Sunday because the week-day which begins on the I(a) 1 is indeed a Sunday. Adopting, however, the present notation of epochs, we should say that

(51) Augustus 1 I(a) 1 = -29 VIII(j) 30 Saturday .

Because this epoch actually was accepted later[443)] than its formal date, the actual coincidence between the new "Alexandrian" (fixed) first of Thoth and the old "Egyptian" (wandering) first of Thoth happenned only four years later. Therefore we have

(52) Augustus 5 I(a) 1 = Augustus 5 I(e) 1 = -25 VIII(j) 30 Thursday .

Starting from (51) or (52), week days can easily be computed by using the rule given by Vettius Valens for the Alexandrian calendar and by omitting leap days for the Egyptian calendar.

443) Cf. Wilckens, Ostraca I p.789 and note 3 there.

§ 5. Planetary constellations.

50. Common conjunctions and occultations.

In the medieval and hellenistic world, fully convinced of the significance of astrological concepts, every unusual constellation of the planets attracted special attention. If records of such constellations escaped destruction, they may contain information of high chronological value. It is therefore necessary to discuss here briefly a few cases of this type.

The most extreme constellation one can think of would be the coincidence of all planets at the same place of the zodiac or at least in the same sign. Such a coincidence actually took place in 1186 A.D. when at IX 16 the five planets, sun and moon had an almost complete common conjunction in Libra: all seven celestial bodies stood in the interval from ♎ 0 to ♎ 15.[444] The idea that such a constellation indicated beginning and end of the world can be followed down to Platonic dialogues.[445] The doctrine that the world will go up in flames when all planets meet is usually assumed to be Babylonian. The only proof, however, seems to be a passage from Berossos,[446] quoted by Seneca,[447] according to which the future conflagration of the world will

444) It is no wonder that this constellation created much excitement. Cf. Horn-d'Arturo [1] p.194-202. (The conclusions of this article with respect to the history of the zodiacal and planetary symbols can be proved to be wrong because of earlier occurence; cf. Neugebauer (O.) [8] p.##).

445) The literature can be found, e.g., in Boll-Bezold-Gundel SS p.91 ff. and p.200 ff.

446) Cf. about him above p.###.

447) Beginning of our era. Seneca, Nat. Quaest. III 29,1 + Schnabel, Ber. p.266 f.

happen when all planets meet in the sign of Cancer (the summer solstice being the time of greatest heat) corresponding to the past general deluge, caused by the common conjunction in the sign of Capricornus (i.e. winter - solstice It seems to me, however, by no means excluded that this doctrine is a product of Hellenistic speculation, since there are no corresponding theories known from cuneiform sources. Planetary periods are, of course, mentioned in Babylonian texts but they are well-founded empirical periods (simple combinations of sidereal periods) with the only exception of an alledged period of Venus of 6400 years where no astronomical background is visible.[448)]

448) Kugler SSB I p.48-50.

In the rich material of the astronomical reports of the seventh century B.C. from Assyrian archives, numerous observations of common conjunctions are preserved. One of these reports,[449)] written by Balasi, describes

449) Thompson, Rep. No.88, discussed by Schaumberger - Schott[

Mars approaching Saturn but returning after having reached a distance of only 4 fingers (= 20'). Because Mars was just then describing a loop, the dangerous omen "if Mars goes around Saturn" (both planets are very unlucky !) was almost realized. These circumstances are unique enough to permit exact dating. The result, -668 III(j) 14/15 , determines the time of Balasi and can be used to date other observations reported by him.[450)]

450) Schaumberger - Schott [1].

The observation of an occultation of Mars by the moon is report by Aristotle.[451] Its date was established by Kepler[452] as -356 V 4[453] "after very long investigations".[454] Such mutual occultation yield very

451) Aristotle, De coelo 292 a, 9. It must, however, be remarked that an ancient scholion quotes Alexander of Aphrodisias (the famous commentator of Aristotle, ca. 200 A.D.) as saying that not Mars but Mercury was occulted; cf. Arist. opera IV (Scholia ed. Brandis) p.497 b 13 f. -- Aristotle alas observed occultations of stars in Gemini by Jupiter, but details necessary for dating are lacking (Meteorol.I 343 b 30 f.).

452) Kepler, Werke 3 p.408 f. (transl. by Caspar in Kepler, Neue Astron. p.383) and again Werke 2 p.265.

453) Kepler erroneously writes in both places April instead of May (the sun's position is given correctly as ♉ 10), as remarked by Schoch PT p.XX where also the modern calculation is given.

454) General statements about the possibility of mutual occultations of planets are given by Theon Smyrnaeus (2nd.cent.A.D.), ed. Hiller p.192 f., ed. Martin p.310 ff., transl. Dupuis p.313.

accurate chronological elements.for analogous reasons which make total solar eclipses so valuable. Much less accuracy can be attributed to ancient reports of planetary positions with respect to fixed stars because instrumental errors are involved.[455] This does not hold, of course, in cases of direct occultations like the occultation of Spica by the moon observed in Rome by Menelaos (98 A.D. I 11 6^h15).[456]

455) A series of such observations for Mercury, Mars and Jupiter between -271 and -240 are quoted in the Almagest and discussed by Böckh (Sonnenkreise p.286 ff.) in connection with the era Dionysios. The Mars observation is also used by Kepler (Werke 3 p.409 = Neue Astron. p.383) because the irregularity of Mars'orbit was the main object of his investigation in the course of his attempt to determine the laws of planetary movements.

456) Almagest VII,3 (ed. Heiberg I,2 p.30 f.) The modern discussion is given in Neugebauer (P.V.) AChr.I p.88 f.

The method of determining the date of such occultations ~~ix~~, of course, does not differ essentially from methods used in dating horoscopes, at least so far as reaching a first rough approximation is concerned. In the final discussion, however, a higher accuracy is required which guaranties positions within 0.01°. At this point the tables discussed in the previous paragraph are no longer sufficient and tables as given in P.V.Neugebauer's TAChr. II must be used.[457)]

457) Cf. the discussion of these problems in Neugebauer (P.V.) AChr. I p.90 ff.

51. Secular acceleration.

In connection with solar eclipses, we discussed the problem of determining the "secular acceleration" of the moon's movement, or rather of the slow decrease in the rotational velocity of the earth.[458)] The relationship of this problem with solar eclipses lies only in the precision of elements furnished by so sensitive a phenomenon as a total solar eclipse. Under favorable circumstances, an equal accuracy can also be obtained from occultations. One of the most important observations was discovered by P.V.Neugebauer and E.F. Weidner in a cuneiform tablet[459)] which states that in the year Darius 5, night of III(b) 25 in the morning, Venus entered the southern horn of the moon.[460)] The corresponding Julian date is –418 VI 19 be-

458) Above p.###.

459) The text is not yet published in full (inventory Berlin: VAT 4924).

460) Neugebauer (P.V.) [1] and [2].

for- sunrise. The situation is best illustrated by fig.67. The sun must still be below the eastern horizon in order to make Venus visible. The elongation of the moon from the sun will be smaller the greater the assumed secular acceleration of the moon. Suppose that fig.67 represents the configuration at the moment of occultation as calculated according to the elements of Schoch. If we now assume that the acceleration is slightly smaller, the moon would be at the same moment at a greater distance from the sun and from Venus, or, in other words, the moon would reach Venus at a later time than according to the previous calculation. The sun, however, would already be above the horizon if the occultation is too much delayed and it would thus be impossible to see the horn of the moon's crescent reach Venus. This specific constellation at the eastern horizon is therefore fitted to give a limit for the secular acceleration which must be reached in order to account for the observed facts. Calculation shows that this condition is fulfilled by Schoch's elements but not by the elements used in the lunar tables of Brown,[461] based on a slightly smaller amount of acceleration.[462] Moreover, the displacement of the moo

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461) Neugebauer (P.V.) [2].

462) Brown assumes $6.05''$ per century, Schoch $9.62''$ ~~XXXXXXXX XXXXXXXXXXXXXXX~~ for the elongation. This gives as time of the occultation 5^h according to Brown, 4^h according to Schoch. Sunrise at 4^h45 excludes Brown's elements.

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in longitude has the consequence that the subsequent positions are also displaced and that therefore no occultation at all occurs under otherwise unchanged conditions. Change in the geographical position of the observer, however, can compensate this effect; thus the smaller acceleration requires as the place of observation localities outside Mesopotamia, while Schoch's elements fit excellently for Babylon. The moon approaches Venus until 0.05^o and because Venus is almost at highest brilliancy[463] she will be seen as coinciding with the horn of the moon, as indicated by the ancient report.

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463) Cf. above p.###.

This example shows that the careful investigation of the rich material of observations from Mesopotamia can be used for determining astronomical constants for which the material of modern observations alone would not be sufficient.[464]

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464) It might be mentioned that another cuneiform tablet (Sp.I, 205 quoted in Kugler MP p.319) is also in best agreement with Schoch's elements and only with these elements. The text says that the moon was at SE 58 VIII(b) 6 beginning of the night 2 cubits (= 4^{o}) behind δ Capricorni. The equivalent date is -253 X(j) 30 . Because we are dealing here with sunset, we obtain now an upper limit for the secular acceleration. The combination of both texts results in the interval from 7.5" to 10" per century.

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§ 6. Bibliography of chapter III.

52. Astronomical.

By far the best tables for the calculation of planetary phenomena are those in the second volume of P.V. Neugebauer TAChr. (1914) which guarantee an accuracy sufficient for all historical problems. For approximate calculation, sufficient in most cases, the "Genäherte Tafeln" of the same author are very convenient;[465] risings and settings of planets should be calculated according to P.V.Neugebauer's TAU and not according to the tables given by Schoch in his "Oxford tables",[466] except for Venus, because their accuracy is not sufficient to avoid large errors in certain cases.

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465) These tables are reproduced in slightly modified form at the end of the book.
466) Printed in Lar[illegible]on-F-S.

A book which has no direct relation whatsoever with chronological problems but which might be useful for a reader who wants to obtain more information about the purely astronomical theory of the planetary movements is Airy, Gravitation; here a very successful attempt is made to explain the basic ideas of celestial dynamics by elementary means.

53. Historical.

The literature concerning the determination of Babylonian chronology by means of the Venus observations has already been quoted in § 2 of this chapter. For the chronology of the previous periods Jacobsen, The Sumerian King List is now fundamental, although his absolute numbers must be reduced by about 250 years according to the new "short chronology" for the Hammurabi age.

Extensive material for the chronology of the latest periods of Mesopotamian and Hellenistic history is scattered throughout the books of Kugler SSB and "Ergänzungshefte" and "Von Moses bis Paulus", the latter containing especially much for Seleucid and Ptolemaic history.

No attempt will be made here to list the vast literature on Hellenistic astrology. Suffice it to mention here the article "Zodiacus" in Daremberg - Saglio[467] and Cumont's "L'Egypte des astrologues" for the general

467) Cumont [1].

background. Even problems of so special character as the origin of the week have given birth to a large literature. By far the best discussion of the existing sources and the results obtained is given in Colson, The Week (1926) A summary of the older literature is given in the article "Hebdomas" of the

RE by Boll.[468] For the calculation of the week-days in Coptic and Ethiopic documents, see Chaîne ChrEE p.97 ff.[469]

468) Boll [2].

469) Curiously enough, Wednesday is here considered to be the first day.

For a survey of the general history of the astronomical theory of the planetary movement, the book of Dreyer, "History of the planetary systems", can be consulted, to be supplemented by Kugler SSB I for the Babylonian theory.

Chapter IV. Fixed Stars.

ὅν τε κύν' Ὠρίωνος ἐπίκλησιν καλέουσι·
λαμπρότατος μὲν ὅ γ' ἐστί, κακὸν δέ τε
σῆμα τέτυκται
καί τε φέρει πολλὸν πυρετὸν δειλοῖσι
βροτοῖσιν·

Iliad XXII 29 ff.*)

*) The star to which they give the epithet Orion's Dog. Although the brightest, he is an evil sign, and he brings much fever upon miserable mortals.

§ 1. Astronomical concepts.

54. Stellar coordinates.

We have already mentioned two systems of spherical coordinates which are used to determine the place of an object on the celestial sphere as seen from the earth: the ecliptical system of geocentric longitude (λ) and latitude (β) and the equatorial system of right ascension (α) and declination (δ); in both systems, the vernal point (cf. fig.68) is the point of departure in counting. The angles λ, β and δ are counted in degrees (λ from 0 to 360, β and δ from 0 to ± 90), whereas rectascensions are usually expressed in hours from 0 to 24. Obviously, one hour corresponds to an angle of 15 degrees, or one degree to 4 minutes. The great circles through the pole of the equator (like NS in fig. 68) are called hour circles.

Today stellar coordinates are usually given in rectascension and declination, while ancient and medieval astronomers preferred ecliptic coordinates. It is therefore necessary to know how to transform coordinates of a star given in one system into the coordinates of the other.[470] In the following tables are mentioned which are prepared for the practical use of historians.

470) The basic formulae can be derived from fig.68 by applying the formulae of spherical trigonometry to the triangle SNP.

Transformation of α , δ into λ , β . In almost all cases an accuracy of 0.2° is more than sufficient; the tables in Neugebauer (P.V.) TAChr.III can be used for this.[471] A list of bright stars near the ecliptic

471) Plates 24 to 26 and corresponding rules of procedure on p.XXXI ff. For higher accuracy (0.01°) see Neugebauer (P.V.) AChr.I § 20.

is given in Schoch PT p.13(M), which shows directly the ecliptic coordinates. This small list will in many practical cases be very useful because only the stars near the ecliptic will appear in texts concerning the movement of the moon or the planets. High accuracy will be required only in connection with problems of actual occultations, while all other cases will at any event be affected by the inaccuracy of ancient measurements.

Transformation of λ , β into α , δ . For the reason just mentioned, only restricted values of β can be expected to be of importance in investigating ancient sources. Tables for latitudes not exceeding $\pm 10^{\circ}$ are given by Schoch (PT p.11; accuracy 0.1°) and for higher accuracy by P.V.

Neugebauer (TAChr.II; β not exceeding $\pm 9^\circ$).[472]

472) Tables 92-117 and p.XVII f. For transformations valid for all values of β (accuracy 0.03°) see Neugebauer (P.V.) AChr.I § 20.

The names of the most important fixed stars are given in P.V. Neugebauer TAChr.I p.83 f. in alphabetical order; the corresponding coordinates can be found in Tables I and III. The first table also contains the values for the proper motion of these stars per century. These changes are, however, so minute that one can consider the relative configurations of the fixed stars as unchanged during historical periods.[473] The influence of precession,[474] on the contrary, is of course very visible in the coordinates of the fixed stars and one must therefore not overlook the dates given in the different tables.

473) There are only about 50 fixed stars whose displacement amounts to about 1° during 4000 years.

474) Cf. above p.###.

55. Further characterisation of fixed stars.

Following ancient custum, stars are usually not only characterised by their spherical coordinates but are also referred to certain "constellations". The ancient method is based on the knowledge of certain delineations and contours of pictures such that expressions like "on the left knee" or "south of the shoulder" etc. give some meaning. This kind of description can easily be converted into modern notation in a case like Ptolemy's star catalogue where longitudes and latitudes are listed in addition to the names. For Egyptian constellations, however, such additional information is missing, and only a very small number of stars of the Egyptian constellations can therefore be identifies within narrow limits.[475)]

475) See below p.###.

The modern notation goes back to Joh.Bayer's "Uranometria",[476)] in which he listed about 1600 stars and introduced the Greek letters α, β, ..., etc. for the individual stars inside the single configuration (e.g. "Sirius" = α canis majoris). The limits of the constellations, however, are still more or less arbitrary lines which leave the exact limits between the constellations undetermined. Only since 1928 have precise definitions been established[477)] by dividing the celestial sphere into fields limited exclusively by arcs of ~~meridians~~ hour circles and of circles of constant declination, corresponding to the position of the celestial pole of 1875.0.

476) Augsburg 1603.

477) Cf. Transactions of the international astronomical union vol. 4 (Cambridge 1933) p.19, and Delporte AC.

Also the concept of "stellar magnitudes" is of ancient origin. While Hipparchus seems to have had no other distinction than "clear", "small" and "obscure", Ptolemy in his catalogue gave six different classes, numbered from 1 to 6.[478)] These six classes survived in the six magnitudes of stars

478) Occasionally subdivided by the remark "larger" or "smaller" (cf. Ptolemy, Almagest, transl. Manitius vol.II p.400). Also five nebulae are mentioned.

visible without the use of instruments until replaced by classification by modern astrophysical methods. The color of fixed stars and planets has been observed by Babylonian and Greek astronomers and is the basis for many astrological applications[478a)].

The only Nova known to us from antiquity was observed by Hipparchus according to a brief remark by Pliny.[479)]

478a) cf. Boll [4]

479) NH II 95 (ed. Jan-Mayhoff p.159, 10 ff.). This Nova is

usually considered to be the Nova Scorpii of -133, following Herschel, Astr. p.563 (= 4th ed. p.474) based on Biot [1] p.61, who used Chinese reports which I am not able to check.

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56. Heliacal rising.

On several previous occasions we have had the opportunity of remarking that the so-called "natural" concepts, introduced naively and supposed to be simple, are actually of a very complex nature and cause great difficulties until they are replaced by more rational definitions. A very typical case of this kind is the rôle of the horizon in ancient astronomy. To the primitive observer the point of the horizon where a star rises or sets appears to be a convenient means of characterisation. He is not aware that the use of the horizon introduces two groups of disadvantages: the dependency on the geographical coordinates and local circumstances of the place of observation and especially serious optical influences of the lowest layers of the atmosphere. These difficulties are clearly reflected in the chronological problems with which we are occupied here. Modern astronomy, of course, avoids observations near the horizon and is therefore not interested in collecting and tabulating systematically the empirical elements, variable from place to place, which would be necessary to calculate accurately the phenomena connected with the rising and setting of different stars at different seasons and under different climatic conditions. It is, moreover, by no means obvious that visibility conditions at sites like the ruins of Mesopotamian cities are the same today as in ancient times. It might, e.g., be possible that the advance of the desert into regions cultivated in ancient times has affected the visibility of stars observed perhaps from the top temple towers now reduced to the height of a few layers of bricks. Calculations involving such elements cannot be compared in accuracy and reliability with results obtained e.g., from reports on eclipses. On the other hand, the change in stellar phenomena caused by precession or the variability of the inclination of the ecliptic is so slow that only highly accurate observations could result in precise chronological results. Dates obtained by historical and archaeological considerations will usually guarantee much narrower limits than so-called astronomically obtained results from observations of fixed stars. This general situation, however, by no means makes it unnecessary to discuss here some fundamental concepts of ancient stellar astronomy because only the knowledge of the acutal character of certain ancient astronomical documents makes it possible to avoid errors and to use these sources in an adaquate way.

The fixed stars can be classified, with respect to a given horizon, into three groups: the always visible stars which never cross the horizon, i.e., stars near the north pole (cf. fig.69), the stars which rise and set and the never visible stars around the south pole. The discovery that more stars become visible as one travelled in a southward direction was one of the main arguments for the sphericity of the earth.[480)]

480) Cf., e.g., Almagest I,4. As pointed out correctly by Ptolemy, this only proves the curvature in a north-south direction. The east - west curvature is concluded from the difference of local time in the observation of eclipses (cf. above p.[illegible]).

The visibility of a star, however, not only depends on its relation to the horizon but also on its distance from the sun as well. In order to explain the typical phenomena in a simple qualitative way, we consider a star on the ecliptic and disregard the inclination of the ecliptic, thus eliminating the influence of the variability of the angle between ecliptic and horizon.[481)] We start our considerations with the moment of total invisibi-

481) This is also the general scheme followed in Greek astronomical treatises like Antolycos (ca.300 B.C.), De ortibus et occasibus (ed. Hultsch p.49 ff.).

lity of the star, i.e., with the conjunction of the sun and the star. A few days later (about 15 days, roughly), the sun will be so far from the star that the star will be visible for the first time above the eastern horizon before sun rise. Exactly as in the case of the planets,[482] this moment is called

482) Cf. above p.***.

the "helical rising" of the star (cf. fig.70 a). From now on the star is visible during the night for an increasingly longer time until the moment when its rising coincides with night-fall ("acronychal rising"[483] cf. fig.70 b).

483) From Greek ἀκρόνυχος "at night-fall". This term seems to be, however, of modern origin. The whole terminology in this subject is very chaotic. I follow here the simple principle that "heliacal" refers to sun-rise, "acronychal" to sunset.

The further progress of the sun will make it impossible to see the star rise in the evening; in the morning, however, the star will be already below the western horizon before the sun rises. But here comes a moment when the setting of the star is for the first time visible before sun-rise ("heliacal setting"; fig. 70 c), and the star will be seen setting earlier and earlier before sun-rise during the following days because the distance between sun and star from now on diminishes. Finally a stage is reached (fig. 70 d) where the star is only so close behind the sun that it is visible only when setting at night-fall ("achronychal setting"). After that, a new period of invisibility (about one month) begins and lasts until the next heliacal rising.

The preceding considerations only give a rough idea of the actual facts. The complic'tions involved are of exactly the same nature as we have already discussed in connection with the visibility of the new lunar crescent and of the planets. The distance of the star from the ecliptic plays a rôle, as does the changing inclination of the ecliptic during the seasons; and the brightness of the star is, of course, also of importance. Different values of the depression of the sun below the horizon (called "arcus visionis") are therefore necessary for different stars and also for different phenomena, because it is evident that a smaller arcus visionis is necessary if sun and star are on opposite parts of the horizon than if they are near one another.

For historical purposes the heliacal risings constitute the most important phenomenon connected with the fixed stars. Tables for some of the brightest stars under conditions likely to be correct for Babylon are given in Schoch PT col.XIV,[484] for Athens in 430 B.C. and for Rome in 45 B.C. by Hofmann.[485] It follows from the preceding remarks that these tables cannot

484) Corrections are given in Neugebauer (P.V.) [3] p.16 f.

485) Hofmann [1] p.22-25, reprinted in Bell [5], 2427-2430,

be used for other places. Tables for the heliacal rising of Sirius for the horizon of Memphis are given in Neugebauer (P.V.) TAChr. col.377 ff. These tables are based on $\beta \approx 9^\circ$, a value obtained from modern observations.[486] Ancient observations, however, seem to show a higher value for β, namely 11°, i.e., a later date of the observation for the heliacal rising[487] - each

486) Cf. Bordhardt [3] p.13. Details are given in Borchardt - Neugebauer [1].

487) This has been shown by Vogt [2] p.37 ff. from an investigation of Ptolemy's "Phases" (opera II p.3-67).

degree of increase in β corresponds roughly to one day's delay in the date of heliacal rising. This is supported by the relativ high values for the arcus visionis obtained from Babylonian observations of Jupiter, resulting here too in a delay of one or two days.[488] It

488) Cf. Vogt (H.) [2] p.39.

seems therefore preferable in chronological calculations to use the more inaccurate values assumed by the ancients than the modern values, i.e., to admit about two days' uncertainty in results obtained from modern tables.

§.2. Stellar Calendars.

57. Babylonian stellar coordinates and stellar calendars.

The earliest known systematic use of spherical coordinates is to be found in Babylonian astronomical texts of the Seleucid period. During these last three centuries B.C. systematic ephemerids for the moon and the planets were computed.[489] Here ecliptic coordinates are used by giving longitudes expressed in degrees with respect to zodiacal signs, latitudes (in lunar ephemerids only[490]) in degrees north and south of the ecliptic. This system is

489) The oldest text of this kind known is a lunar tablet dated in -207, the most recent text of the same type from the year -45. Our source material shortly to be edited by the present writer as "Astronomical Cuneiform Texts" within these limits is so complete that it seems very improbable that such ephemerids were computed earlier than the middle of the third century B.C.

490) This is, of course, essential for the calculation of eclipses, whereas the geocentric latitude of the planets is of little interest and very difficult to compute (cf. above p.###).

undoubtedly the predecessor to the predominant use of ecliptic coordinates from Hellenistic times through the Middle Ages.

Before the Seleucid period, however, no spherical coordinates in the modern sense of the word, existed to our present knowledge. The astronomical texts of the period from the 8th century B.C. onwards describe the position of the moon or the planets by their distance from nearby bright stars or configurations (among which also the zodiacal configurations occur); these distances, however, are not measured on precisely defined great circles but described in terms like "in front of", "behind", "north", "east", ect. Kugler made up[491] a list of 33 such stars of reference, but a rigid rule to use exclusively these stars hardly existed.

491) Kugler SSB I p.29.

From a still earlier period (perhaps the end of the second millenium B.C.), we know of devices for locating stars which can be considered as a kind of equatorial system. We have already mentioned[492] the tablets of the series called "Mul-Apin" (i.e. "Plow-Star"[493]) of which we have two tablets in Neo-Babylonian copies.[494] The first tablet begins with the enumeration of 71 constellations[495] assigning them to one of three "roads" : the "road of Enlil" (around the northpole), the "road of Anu" (a belt of about 33° breadth with the equator as the line of symmetry)[496] and the "road of Ea" (south of the "road" of Anu)[497]. This list of stars is our most complete source of

492) Cf. above p.###.

493) Probably our "Triangulum".

494) Published in CT 33, 1-8, discussed in Bezold [1], Kugler SSB Erg. p.141 ff. and frequently elsewhere.

495) The first being Mul-Apin, which therefore names the whole series. Other star calendars are discussed in Kugler SSB I 228 ff. and Erg. p.168 ff.

496) Here the planets are also mentioned, except Jupiter, which is mentioned among the stars of Enlil (reason unknown).

497) This does not necessarily imply the assumption of a spherical universe. We know nothing about the Babylonian concept of the Kosmos (a fact not always evident from modern literature !).

information about the Babylonian constellations and constitutes the main basis for all modern attempts to identify the Babylonian stellar names and the limits of the configurations.

The next section of this text contains what we may call a "stellar calendar", because relations are set up between the rising and setting of fixed stars and calendaric dates. These calendaric dates, of course, can only be given in the schematic calendar[498] and not in the variable lunar calendar. The solstices and equinoxes are assumed to fall on the 15th of their respective months such that the summer solstice is dated IV(b) 15 and chracterized by the appearance of Sirius.[499]

498) See above p.###.

499) The additional remark "4 mana is one watch of the day, 2 mana is one watch of the night" has caused much difficulty in the literature because nowhere in Mesopotamia is the longest day twice as long as the shortest night. The solution of this problem lies in the fact that these weights (mana) are understood as the outflow of a waterclock which is greater at the beginning than at the end. The ratio of the weights is therefore not the same as the ratio of time (which is 3:2 at the solstices).

This stellar calendar now gives us a clear insight into the use of the schematic calendar side by side with the real lunar calendar. No definite relationship between these two calendars is established beforehand. But the information given by the schematic stellar calendar can always be used for the real calendar by observing a stellar phenomenon and identifying the date in the real calendar with the date which is coordinated to this phenomenon in the formal calendar. Let us, e.g., consider the case where the stellar calendar says that the Hyades appear on the II(b) 20, Orion on the III(b) 10. Observation may show that the Hyades appear on the II(b) 6 of the real calendar; one will then be able to expect the appearance of

Orion on the 26th. In other words, the combination of real and formal calendar will make possible predictions which could not have been made withi the lunar calendar alone. It is, moreover, clear that the essential rôle is here played by the fixed stars, not by the place of the sun in the ecliptic. It is easy to understand that the rising and setting of stars precede the definition of the time in the year by the sun because it is by no mean simple to determine exactly the place of the sun on the sky. This type of stellar calendar can therefore be considered as predecessor of the characterization of the seasons by the position of the sun in the zodiac.

58. The "Parapegmata".

Like other people. the Greeks also noted that the disappearance and reappearance of compiciuous constellations like the Pleiades, Orion, etc. were invariably related to certain parts of the year.[500] Thus the

500) Cf. e.g. Nilsson PTR chapter IV (p.109 ff.).

stars can be considered as a means of determining the seasons and hence pr dicting the weather. This primitive belief in the relationship between sta and seasons has been frequently interpreted as evidence for certain stella years, "Sirius year", "Pleiades year", etc., parallel with "solar" or "lunar years". This is, however, a much too precise interpretation of vague and primitive concepts, and all chronological calculations based on such ideas lack any real basis.[501]

501) Here can be mentiones also an alleged "Sirius-year" in Babylonia which Kugler SSB II p.513 thought he discovered combined with an 27 years' intercalation cycle of lunar months. The passage in question, ho ever, is very obscure, and does not mention the moon or the months at all. Neither the "Sirius-year" nor a 27-years' intercalatory rule are attested

elsewhere in cueneiform sources. The most plausible interpretation of this passage is the one given by Nilsson PTR p.264, assuming that the text refers only to "the fact that the new moon and Sirius come back after 27 years into the same mutual relationship".

The "Parapegmata" constitute a real "stellar calendar" in the same sense as described in the preceding section from "Mul-Apin". The literal meaning of "Parapegmata" is "to affix", "to fix something beside", etc., but not until real "parapegmata" were excavated at Miletus did it become clear how this expression could have acquired the meaning of "astronomical and meteorological calendar". One of these excavated inscriptions contains the following section:

30

o The sun in Aquarius

o The Lion begins to set in the evening,
and Lyra is setting

o o

o Cygnus begins its acronychal setting

o o o o o o o o o

o Andromeda begins to rise in the morning

o o

o Aquarius is half rising

etc.

Counting the number of holes, indicated here by o , one finds that their number is 30, as expressly indicated at the top of this section. This number is supposed to give the number of days during which the sun travels in

Aquarius, and each hole corresponds to one day. The complete parapegma is therefore a list of stellar phenomena coordinated to the days of the solar year. Exactly as in Mesopotamia, however, this stellar calendar has no definite relation to the current shifting lunar calendar. Such a relationship must be established from time to time by watching the moon for the civil calendar and by sticking pegs or small labels into the holes of the "parapegma" thereafter. Observing, e.g., Andromeda appearing again in the morning of the 10th of a lunar month, the number 10 would be stuck in the corresponding hole, 11 and 12 in the two following ones, and the rise of Aquarius would then fall on the 13th, etc. In other words, a parapegma is a public calendar erected for the coordination of the schematic and invariable stellar calendar with the fluctuating civil calendar.

Directly related to these monuments[502] intended for practical

502) One of the two Milesian parapegmata is dated by coordinating a day of the Athenian calendar with one of the Alexandrian. The result is -109/108.

use are written stellar calendars preserved from various periods of Greek literature, e.g., the calendar attached to Geminus' "Introduction to Astronomy" or Ptolemy's "Phases" (i.e. the phenomena of heliacal and acronychal rising and setting).[503] The calendars not only list the

503) Geminus EA and Ptolemaeus opera II, p.1-68.

stellar phenomena but they give additional information ("episemasiai", i.e. indications[504] about the weather to be expected at this time of the year.

504) This terminology is, however, not so simple as one would expect; cf. Rehm [3].

Ptolemy's calendar is in so far separated from the other texts of this kind in that he founded his stellar phenomena on independent observations, arranged according to different geographical latitudes, and by selecting exactly defined bright stars.[505] Another progressive aspect of his work

505) Cf. Vogt (H.) [2].

is the definite coordination of the stellar phases with the Alexandrian calendar, a natural step after the Greek lunar calendar was abandoned. At this stage of development the original purpose of the stellar calendars was already forgotten. The Geminus-calendar, however, is still based on the number of days which the sun was assumed to travel across the different constellations of the zodiac, analogously as in the example given above from one of the Milesian parapegma. The second Milesian parapegma, however, does not show any arrangement with respect to the zodiac and is therefore still more closely related to the schematic calendar in Mul-Apin.

The analogy between the Greek and the Babylonian calendars can be carried still further. We have mentioned the fact that the solstices and equinoxes in Mul-Apin are called the 15th of their respective months. This has its parallel in the wellknown fact that also Eudoxos (ca. 350 B.C.) is credited with having assumed the vernal point at the 15th degree of Aries.[506]

506) Hipparchus, in Aratus ed. Manitius p.48, 7 ff. p.56, 15 f p.128, 25 ff., p. 132, 10 ff.

This brings us a new source of difficulties in dealing with early Greek notices concerning zodiacal positions. It is perfectly possible that these positions too are only meant to be "schematic" (like the dates in the Mul - Apin) and subject to individual coordination with actual observation from time to time. This might explain why in the very case of Eudocos, there exist different versions in ancient literature concerning his assumption of the equinoxes and solstices.507)

507) Geminus EA p.224,1 winter solstice 4th day of Capricorn, p.228, 19 vernal equinox 6 th day of Aries. On the other hand, the 8th degree is given by Columella, De re rustica IX,14 (the passage in question is quoted by Böckh, Sonnenkreise, p.185 and in Lydus, De ost. p.303 § 12).

59. Greek stellar catalogues.

The last mentioned difficulty is closely related to the two problems of determining the exact boundaries of constellations and of identifying special stars. We know that Hipparchus composed a star catalogue, written about -127[508] and including about 900 stars.[509] This catalogue

508) This date is plausible according to a remark in the Almagest VII,2 (ed. Heiberg p.15, 11 ff.).

509) Boll [3].

is lost, but much information can be won from Hipparchus' commentaries on Aratus and Eudoxos. This work of Hipparchus contains elements for the setting and rising of 42 constellations at Rhodes[510] and a list of culminating stars for each of the 24 hours.[511] H.Vogt succeeded in restoring from the material the coordinates attributed by Hipparchus to 122 stars.[512]

510) Hipparchus in Aratus p.182-270.

511) Hipparchus in Aratus p.270-280.

512) Vogt [1]. It is worth mentioning that Hipparchus frequently uses coordinates which are neither ecliptical nor equatorial but a combination of both. He gives the longitude of the point of the ecliptic which passes the meridian simultaneously with the star. This procedure can perh

be explained as a consequence of constructions in a "planisphaerium" because here these very elements can be conveniently determined. Cf. also Ptolemy, Almagest VIII,5 (Heiberg p.194 ff.).

This restoration of at least an important part of Hipparchus' catalogue of fixed stars has important consequences with respect to problems which involve the boundaries of stellar configurations. It has become customary in modern literature to assume that Ptolemy's catalogue of the fixed stars[513] is directly derived from Hipparchus' list by adding 2°40' in

513) Almagest VII,5/VIII,1. A special edition of this part of the Almagest has been made by Peters-Knobel PCS, an improvement over Heiberg's edition.

longitude (the amount of precession assumed by Ptolemy). From Vogt's results it follows (1) that there is no reason to doubt Ptolemy's statement that his catalogue is based on his own observations[514] and (2) that one cannot simply restore Hipparchus' list from Ptolemy's.[515] If we add Ptolemy's further statement[516] that he "did not maintain strictly the notation of

514) Almagest VII,4 (heiberg p.35).

515) Vogt [1] col.22-26.

516) Almagest VII, 4 (Heiberg p.37).

our predecessors, just as they did not follow their predecessors" but that he frequently introduced new denominations as required for better characterisation and nicer contaour lines", we then realize on what uncertain groun we are standing in astrographic problems before Ptolemy.[517] In this con-

517) This holds especially for the configuration of the zodiac. According to Almagest VII,5, e.g., Taurus begins in ♈ and ends in ♊.

nection, a systematic comparative study of Babylonian and Greek constellations would be of great value.518)

518) This is clearly shown by the results of Boll, Sphaera, a work which will be basic for all studies in this direction.

60. Egyptian stellar calendars.

Although a great number of problems in relation to Babylonian and Greek constellations are still unsolved it can be said that we are at least well informed about the meaning of the majority of the main constellations. This fact is not only due to the existence of a rich and, in general, reliable text material but also to the relationship between Babylonian and Greek constellations, which is especially obvious in the case of the zodiac. We face an entirely different situation in the Egyptian stellar configurations. We must here disregard the Egyptian zodiacs because they were merely adopted from the Greeks; no zodiac has been found on Egyptian monuments before the Ptolemaic period. The native Egyptian concepts, the "Decans", are, however, not yet identified with any degree of accuracy except that we know on one hand the place of Sirius among the decans and on the other hand their relation to the zodiac in astrological writings of the latest phase of Egyptian history.519) The later division of the zodiac into 36 decans is without much value because it is only the result of the general tendency of amalgamation of Egyptian and Hellenistic concepts carried out with very little concern for the previous boundaries of the constellations;

519) See for this period the exhaustive work of Gundel, Dekane.

and the relation to Sirius is, of course, not sufficient for the determination of the limits of pictures covering a large belt in the sky.

The monuments at our disposal for the investigation of Egyptian star maps and stellar calendars are certain ceilings in tombs of the New Kingdom and inscriptions on coffin-lids from the Middle Kingdom. Unfortunately, most of these documents are not yet published in a satisfactory form and a comparative edition and study of this material is lacking. It is therefore not surprising that scarcely more is identified than the Egyptian names for the Great Dipper, Orion, and Sirius.[520] A tentative list of further identifications is given by Challey [1].[521]

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520) Even these identifications have been doubted. Borchardt AZ p.54 note 2 replaces the Great Dipper by Ursa minor (without explanation), Hess (cf. Reall.Vorg. vol.9 p.205 and vol.12 p.422) doubts Orion (without explanation), and even Sothis could represent more than the single star Canis majoris in the list of decans because the decans are intervals, not single stars. Corrspondingly, the name of the Sothis-Decan is śpd , i.e., "pointed", whereas the single star Sirius is called śpd.t with the feminine ending referring to the goddess Isis, related to Sirius (cf. Sethe, Zeitr. p.293 note 2; Borchardt [1] col.506 even gives a definite constellation for the Sothis decan but does not mention any proof for his selection, except the triangular shape). The Greek name, Σῶθις is the Greek transliteration of śpd or śpd.t while Σείριος "the scorching" is the corresponding translation. The original Greek constellation is the κύων "the dog" (cf. Gundel [1] col.995 ff.).

521) Cf. also Pogo [3] and [4].

The decans are closely related with time measurement. This is especially evident from the Middle-Kingdom coffins[522] which contain in

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522) Ten such coffins are known, all belonging to noblemen and their wives of the IXth to XIth Dynasties; 7 were found at Asiut, and one each at Thebes, Gebelein, and Assuan (cf. fig. 72).

their top-line (D in fig.71) the 36 decades contained in the 12 months, each decade covering 10 days. The main field is accordingly subdivided into 36 columns, each of which contains 12 lines. These 12-times-36 small fields contain the names of decanal constellations, each diagonal series of fields containing the same decan (cf. fig.71). Pogo proposed the following explanation of this scheme: consider the last line of the last column before N-S (fig.71) as indicating the heliacal rising of the 29th decan (Sirius) in the last decade of VI(e). Ten days later Sirius will be 10° above the horizon at sunrise and the next decan will be rising heliacally. These 10° correspond to 40 minutes in time; because the rise of Sirius falls near the summer solstice, these 40 minutes correspond to about one seasonal "hour". In other words, when decan No.30 (fig.71) rises heliacally, Sirius (No.29) is already one hour above the horizon. This is indicated in the scheme by writing decan 29 one line above No.30. Hence the first line represents sunset, the lines beside H correspond to midnight and the 12th line to sunrise. Our discussion here for two columns near summer solstice is now schematically extended to cover the other fields by going from decan to decan and by moving simultaneously from hour to hour, thus obtaining a scheme where each diagonal row contains the same decanal name. This procedure is, of course, a very rough extrapolation of the situation around equinox because the 40 minutes delay from one decan to the other corresponds to one seasonal hour only around the summer solstice whereas it is only about one half of such an hour six months later, i.e., at the first and last column of the scheme.

This theory of Pogo at least gives the outlines of the concepts underlying the Egyptian stellar calendars. There can be no doubt that these texts are based on a strongly idealized representation of the facts, and this makes it already evident that these coffin-texts cannot be used for chronological purposes as has been done on different occasions.[522a] Beyond

522a) This in spite of Pogo's clear statement of the chronological unreliability of these calendars (e.g., Pogo [6] p.23).

that, however, various problems remain unsolved even if one accepts Pogo's explanation in principle. It is, e.g., unexplained why only 34, not 36, different decans occur in such a calendar, Nos. 1 and 2 being repeated after 34 instead of after 36 decans. Moreover, beginning with the diagonal following No.2 (cf. fig.71), where we would expect the repetition of Nos.1, 2, etc., we do not find decans at all but a list of other constellations, usually called Meta-decans (M in fig.71), again arranged in a diagonal pattern but with no evident connection with the preceding decans.[523] All this shows that we are still far from a real understanding of the Egyptian stellar calendars.[524]

523) These Meta-decans occur twice more in the standard scheme of these coffins, once in the list L at the end, following the decans, and again in the horizontal inscription H which contains an astronomical variant to the well known "offering formula" of Egyptian funeral texts (cf., e.g., Gardiner Gr. p.170 ff.). Instead of invoking the king to grant the offerings to the deceased, the sun and the meta-decans are here invoked.

524) Pogo's assumption ([5] p.14) that there existed a "24-column type" in addition to the 36-column type is due to the carelessness of the old artists who did not have enough space left for all 36 scheme.

The coffin-texts find their continuation in the astronomical ceilings of royal tombs of the New Kingdom. Here again lists of decans can be found, although with a number of variations within themselves and compared with the coffin texts. The calendaric relation of these texts becomes less clear because there are still less direct relations between the civil calendar and the stellar phenomena indicated; in addition to it, new constellations are mentioned and it is very doubtful how to distribute them exactly among the standard number of 36 decans.[525] All attempts to use these inscriptions for chronological purpose are doomed to failure so long as our knowledge of the Egyptian constellations is not much better founded than it is today.

525) The best available information are given by the inscription in the cenotaph of Seti I at Abydos (Frankfort CSA) because we have a Demotic commentary to its texts, making at least the terminology intelligible (Lange - Neugebauer(O.) [1]).

§ 3. Sothis and Egyptian chronology.

61. Preliminary remarks.

The absolute chronology of Egypt is based on the following facts and conclusions which we shall analyze in greater detail below. At the moment it is convenient to list them without comment.

(a) The Egyptian year is $\frac{1}{4}$ day shorter than the Julian year; hence a given coincidence between Egyptian and Julian dates will be repeated only after 1460 Julian years = 1461 Egyptian years ("Sothis period").[526]

526) Cf. above p. 16 .

(b) The relationship between the Egyptian and Julian calendar was perfectly known in Greco-Roman times; usually the following point of coincidence is chosen:

(50) +139 VII(j) 20 = I(e) 1

because this day was assumed to be the date of the heliacal rising of Sirius.

(c) The heliacal rising of Sirius, seen from Memphis at an arcus visionis of 9.5°, fell on I(e) 1 in the years[527)]

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527) The years -2772 and -1316 are Julian leap years, a fact, which must be taken into account in checking the fact that all the Julian dates given in (51) correspond to the same Egyptian date. The following dates are taken from P.V. Neugebauer, Hilfstafeln z. techn. Chronol. AN 261 (1936/7) col. 377f.

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(51)	-4230	VII(j)	17
	-2772	VII(j)	17
	-1316	VII(j)	18
	+ 139	VII(j)	20 .

These coincidences are called ἀποκατάστασις ("restitution" or "return") by the Greeks.[528)] It might be remarked that older literature uses instead of (51) the following dates[529)]

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528) Clemens Alexandrinus uses the word "Sothis period" in the same sense (PG 8, col.872, transl. Overbeck 227,11). For another expression see Lepsius, Chron. p.171 note 1 and Censorinus XVIII,10 (ed. Hultsch p.38f.)

529) E.g., Meyer (Ed.) Aeg.Chron. p.28.

-4240	VII(j)	19
-2780	VII(j)	19
-1320	VII(j)	19
+ 140	VII(j)	19

which are based on the incorrect assumption that the heliacal rising of Sirius follows almost exactly the Julian year.

(d) From (51) it follows that the interval between two successive coincidences of I(e) 1 and the heliacal rise of Sirius is almost 1460 years. The shifting difference between Julian and Egyptian year is therefore almost the same as between the heliacal rise of Sirius and the Egyptian year. If we are given the date of the reappearance of Sirius in the Egyptian calendar, i.e., if we know that the heliacal rising fell n days after I(e) 1 (or m = 365 - n days before I(e) 1) then approximately 4n years will have elapsed since one of the coincidences given by (51) (or 4m years are still missing until the next coincidence). This latter conclusion is the basic for the absolute chronology of Egyptian history.

62. The oldest "Sothis-date" and the origin of the Egyptian year.

The name of the first season of the Egyptian calendar is "inundation" and it is clear that this name must have originally coincided with the inundation. On the other hand, every point of the Egyptian calendar rotated through all parts of the solar year during one Sothic period. Hence two conclusions must be drawn: (a) The beginning of the season of the inundation cannot have been controlled by any astronomical phenomenon because the lack of $\frac{1}{4}$ day each year would have been evident after a very short while. If, on the other hand, the season "inundation" was only connected with the inundation of the Nile, then the error of assuming a year of only 365 days could not be detected before the elapse of two or more centuries because the inundation is very irregular in its beginning as well as in its progression.[530] In other words, the Egyptian year can only be explained as a purely agricultural year,[531] never as an astronomically

530) Cf. the examples given in Neugebauer (O.) [9] p.185 and 191

531) That a simple averaging process from intervals between inundations leads to the length of 365 days for our years has been shown in Neugebauer (O.) [9].

founded year (like a "Sirius"-year determined by the heliacal rise of a fixed star or by the solstices, etc.). (b) Admitting a margin of two or three centuries, the introduction of the Egyptian year must coincide with the period when the inundation season fell on the actual inundation which happened around 4200 and the next time around 2800 B.C. A later coincidence (the next would be around 1300) is out of the question because the calendar was in existence before then. Of the two earlier dates all evidence points to a date around 2800, i.e., the beginning of the Old Kingdom.[532)] This fits very well with the proposed[533)] explanation of the 30-days' months as schematic months which originated within the framework of the governmental administration of the country, because we know that the Third Dynasty laid the ground for many institutions.

532) This has been shown by Scharff [1] and Winlock [1].

533) Above p.[illegible].

The preceding considerations are based on the fact that any astronomical control of the Egyptian calendar must be excluded because it would have shown in too short a while the incorredtness of the 365-days' year. After centuries of the use of this calendar, the season of "inundation" must have preceded the real inundation by so much that the calendaric date could no longer be considered the true index of the coming flood. The rising of Sothis, however, always fell close to the actual inundation, and thus became the only reliable "bringer of the Nile". It must, however, be emphasized that there never existed an independent "Sothis-year" beside the civil calendar.[534)] All chronological conclusions based on the assumption

534) Neither was there ever anything like a 360-days' "rudimentary" year as assumed by Sethe (Zeitr. p.302 ff.). The 12 schematic months never constituted an independent unit.

of a coincidence between a Sothis-year and the civil calendar are therefore not valid, and all talk about an Early-Dynastic calendar reform connected with a Memphite unification of the whole country should be abondoned.[535)]

535) See for this alleged "calendar-reform", e.g., Breasted AR I p.30 (No.45), Sethe, Urgesch. p.92 (No.110), Kees, Hdb. p.301 and 322.

The Egyptian calendar was never "reformed" but kept alive the independent elements: the lunar calendar, mainly used in the temple service, the schematic calendar for official purposes and thus the civil calendar, originated from an agricultural calendar with three seasons and finally Sothis as announcer of the coming inundation but with no other calendaric rôle.

63. The historical Sothis-dates.

The non-existence of a "Sothis-year" does not affect the chronological value of any document giving the date of the rise of Sothis in the civil calendar. Unfortunately, however, only five instances of such dates are known. Two of them belong to the Graeco-Roman time, and therefore give us no information we do not already have. The three remaining dates are found in

(1) Kahun papyri, time of Sesostris III (XIIth Dyn.)
(2) Papyrus Ebers, time of Amenhotep I (XVIIIth Dyn.)
(3) Incomplete inscription of Thuthmosis III in Elephantine (XVIIIth Dyn.)

We shall now discuss these three dates in their chronological order.[536)]

536) Borchardt MZ mentions other evidence, but this is of so doubtful a character that it is hardly worth mentioning.

a. The Kahun papyri.

In 1889 Petrie discovered the remains of a town founded by Sesostris II east of the same Pharaoh's brick pyramid at Kahun; here he found numerous papyri. More papyri, evidently from the same place, appeared 1899 in the hands of dealers, and a renewed search led to the discovery in 1899 of a new group of texts which included the fragments of 41 leaves of a temple diary. This diary contains entries from a "year 5" to a "year 9" and mentions under "year 9" statues of the "late" Sesostris II and the "eternally living" Sesostris III. The regnal years referred to are therefore years of Sesostris III.[537)]

537) Borchardt [2]. The temple diary is, however, not restricte to the reign of Sesostris III but also contains entries from the reign of his successor Amenemmes III; cf. Scharff [2] p.23.

This temple diary contains under the "year 7" a letter, dated on VII(e) 25, stating that Sothis will rise on VIII(e) 16, and a corresponding record of the revenues of the Sothis festival for year 7 VIII(e) 17.[538)] The "Sothis date" VIII(e) 16 of year 7 of Sesostris III thus obtained is the cornerstone of the absolute chronology of Egyptian history. Some additional remarks about this document are therefore necessary.

538) Borchardt [2] p.101 and p.99.

The first thing to be noted is that the Kahun papyri (including the temple diary) which came to Berlin in 1899 are not yet published, although their high importance was immediately recognized.[539)] This is the

539) Borchardt [2] is only a short preliminary report of the discovery. Möller HL 1 p.18 f. contains a few lines from the diary and, fortunately, also the passage about the rise of Sirius (from P.Berl. 10012 line 18-21). Scharff [2] is a study of the letters of the archive.

more regrettable because the basis for this date is the identity of script of the letter of the year 7 and the notices belonging to the years 5 and 9 of Sesostris III. Borchardt[540] asserted that the entries in the diary are written in the same hand, and this statement has been repeated since, though probably only on Borchardt's authority.[541] This statement has been recently contradicted by Farina,[542] who finds that the two small excerpts published by Möller[543] do not show the same hand and he therefore feels

540) Borchardt [2] p.101.

541) Only Scharff [2] p.22 seems to make a statement of his own; he emphasizes, however, that the investigation of the diary is not yet completed (p.24).

542) Farina PR p.63.

543) Möller HL 1 p.18, 19.

free to assume that the Sothis-date belongs to Amenemmes IV. Actually, an unbased investigation of the published fragments shows neither clear identity of the hands nor decisive differences; and Scharff's investigation of a large group of letters from this archive seems to show from the persons mentioned that the temple diary belongs only to the reign of Sesostris III and Amenemmes III, not IV. In short, the most plausible assumption still seems to be to consider the rise of Sothis on VIII(e) 16 as belonging to the seventh year of Sesostris III, but the fact remains that this statement is based on authority alone and not on facts open to everybody's judgement.

Another very essential point must be emphasized in connection with this letter. This is the fact that the rise of Sothis on the 16th of VIII(e) is already announced in the letter dated on the 25th of the preceding month, i.e., 21 days in advance. In other words, we have here a definite proof of a Sothis festival based not on actual observation but obviously only on calendaric dates. This undeniable fact renders futile all attemp to investigate Egyptian Sothis-dates with requirements of high accuracy,e.g with regard to geographical latitude or arcus visionis. Ed.Meyer has clearl emphasized this fact[544] but without result; actually he did not go far

544) Meyer (Ed.) Aeg. Chron. p.18.

enough in his criticism of an alleged precision in the observation of Sothi He assumed that the rise of Sothis was announced according to a definite calendaric rule, namely, the invariable addition of one day every fourth year to the date of the preceding Sothis festival.[545] But there is no proof available for such a strictly cyclic calculation. Meyer's argument that this rule is stated in the decree of Canopus (237 B.C.) does not hold because one cannot retroject rules given in Hellenistic times for two thousand years.[546] Moreover, this rule cannot work invariably bacause it sup-

545) Meyer called this the "Normaltag" assumed for the Sothis festival all over the country.

546) The wording in the decree of Canopus is actually by no means so clear a rule as one would gather from Meyer's remark. The text says only "if it happen that the rising of the star changes to another day in 4 years ...." (translation by Bevan HE p.210; Greek and Egyptian text: Urk. II p.138/139).

poses an exact length of the Sothis period of 1460 years, which is actuall not the case as is shown by the dates given above p.???. It is very possib that was no rule but that the Sothis festival was kept on the same date as long as it appeared to be in not too great disagreement with the facts. In other words, one can assume the same kind of empirical intercalation in th case of the Sothis dates as one knows, mutatis mutandis, from empirically regulated lunar calendars. [illegible] for dates of the rise of Sothis an accuracy of more than, say, two or three days after the calculated rising. For chronology, this means at least a variation of 10 years, most likely in the direction toward our own time because the calendaric rise of Sothis will hardly be earlier than the real first visibility.

We shall now determine the date which corresponds to a heliacal rise of Sothis on VIII(e) 16. Because this date belongs to the second half of the year, we determine the difference from the following I(e) 1. The VIII(e) 16th is the 7·30 + 16 = 226th day of the year, the I(e) 1 the 366th hence the difference is 140 days and the rise of Sothis on VIII(e) 16 happened approximately 140·4 = 560 years before the following coincidence on I(e) 1. The only coincidence in question is -1320 (cf. p.##) and therefore -1320 - 560 = -1880 is the approximate day of the heliacal rise of Sirius in the 7th year of Sesostris III. Accurate calculation would give -1874/187 for the 7th year and hence -1880/1877 for the first year. But as said above, this accuracy is of little interest, and we can hardly say more than that Sesostris III began his reign between the years -1880 and -1860.

There is, however, another document from the Kahun archive[547] which has been used to reach higher precision from lunar dates. We have already mentioned this text as the earliest direct witness of an Egyptian lunar calendar.[548] This document is a fragment of a list of temple servic dated in a "year 31" of an unknown ruler. The following dates for the beginnings of duty are given[549]

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547) Published only in preliminary form by Borchardt [2] p.92 :

548) Cf. above p. 87.

549) Dr. Erichsen kindly collated the original in Berlin for me

year 30	X(e)	26	year 31	I	20[550]	IV	19[551]	VII	17
	XI	25		II	20	V	18	VIII	17
	XII	25		III	19	VI	18	IX	16

550) According to Erichsen the reading 19 would be better but is excluded by the following date II 20 which allows only I 20 or I 21 as the preceding date.

551) Text has perhaps 17 (Erichsen) but this is excluded by the preceding and subsequent dates.

The intervals between these dates are alternating 29 and 30 days except the sequence 30, 30, 30 between XI 25 and II 20, in other words, following a scheme which reminds us very much of the scheme of Pap.Carlsberg 9, discussed in chapter II.[552] Now two questions must be raised: does this

552) The present scheme is not identical with the Carlsberg - scheme because according to the latter the insertion of a 30-days' months should not occur after XII 25 but the year before (after XII 5; cf.p. 89).

list of dates reflect actual observations or are they based on a schematic rule of the Carlsberg-type; and secondly, to which ruler do the regnal years "30" and "31" refer. I do see no means to eliminate the possibility of schematic calculation, i.e., to make the chronological use of these dates much more doubtful. Also the second question is very difficult to answer. Borchardt[553] and Meyer[554] assumed Sesostris III to be the king in question, but Wheeler[555] proposed Amenemmes II, the second predecessor of Sesostris III.

553) Borchardt [2] p.93 and MZ p.31 f.

554) Meyer (Ed.) Aeg.Chron. p.52.

555) Wheeler (G.) [1].

Borchardt assumed that the dates in question refer to new moons (or at least days close to new moons) and found good agreement between the text and new moon dates in the year -1851/-1850. This seems to support the year -1881/-1880 as the fist year of Sesostris III which would agree nicely with the Sothis date obtained before. This result, however, is misleading. Borchardt's dates lie about one day later than the dates given in the text; if we admit the same deviation in the other direction, the years -1848/-1847 would give equally good results for "year 30". Moreover, we have already noted the high quality of the cycle of 25 Egyptian years,[556] and

556) Cf. above p. 40 equation (34).

both solutions mentioned must therefore be repeated equally well after 25 years. In other words, the lunar dates admit the same order of magnitude of uncertainty as the Sothic dates.

This uncertainty is not XX all. Wheeler found good agreement between the lunar dates and calculation in the year -1909/-1908 which could be the 30th year of Amenemmes II. This is no miracle, because 58 years (the difference between Borchardt's and Wheeler's solutions) are only 3 days less than 716 lunations, and the dates of the texts furnish us no means to eliminate deviations of this order of magnitude. Here too, of course, a 25-years repetition could be applied. We find here a problem which cannot be solved unless we attribute to the elements given by our sources a higher degree of accuracy than we can prove or can even assume for these texts. The astronom cal dating of the XIIth Dynasty cannot be narrowed to more than about 25 years.

b). The Eighteenth Dynasty.

On the island of Elephantine opposite Aswān could be seen until some years ago a Nilometer and a quay, built in Roman times of reused blocks from buildings erected by different rulers of the New Kingdom. A group of such blocks comes from a "calendaric" inscription of Thuthmosis III, enumerating gifts and stipends for various festivals during the year. One of these blocks, now in the Louvre, contains an inscription which, if complete, would date the 18th dynasty just as the Kahun temple-diary dated the 12th dynasty. This inscription begins as follows:[557] "XI(e) 28, day of the feast of the rising of Sothis. Offered for this day on account of ..." What follows is a list of offerings of meat, bread, beer, etc., but the year of the king is missing, which probably was given in the destroyed passage. What remains is therefore only the information that a rising of Sothis took place in some year of the reign of Thuthmosis III at XI(e) 28. This date is 2 + 35 days before the I(e) 1, i.e., 4·37 = 148 years before the nearest coincidence in -1316. What we know is therefore that Thuthmosis III ruled in the years around -1464. Unfortunately, this king enjoyed a reign of at least 54 years so that the astronomical dating of one year out of his reign brings us no further than relative chronology is able to do.[558]

557) Text: Urk. IV, 827. Cf. also Porter-Moss V p.225.

558) It is therefore of little value to emphasize that also the astronomically determined date is not very accurate. The difference in latitude delays the rise of Sothis at Elephantine by 5 days compared with Memphi (which is the basis of our tables). Not knowing the latitude actually employed hence involves a margin of 20 years, to be added to the inaccuracy resulting from lack of accurate observation.

We are in an equally unfortunate situation in the case of the second Sothis - date of the XVIIIth Dynasty, the "Calendar of the Papyrus Ebers." This document is excellently preserved, but internal difficulties make it of very questionable use for exact chronology. The text in question consists of a short hieratic inscription on the reverse of the medical papyrus Ebers, the first two lines of which run as follows:[559] "Year 9 under

559) The photograph of this passage is given in Borchardt MZ opposite p.20. Hieroglyphic transcription: Urk. IV, 44 and Meyer (Ed.) Aeg. Chron. p.47.

King Amenhotep I. Feast of the New Year XI(e) day 9, rise of Sothis." So far we would have a very nice Sothic date leading to 4·(21 + 35) = 224 years before the coincidence of -1316, i.e., to -1540.[560] This would give about

560) For the dates following from more precise observations cf. Edgerton [1] p.193.

-1550 for the beginning of the reign of this king. Unfortunately, however, the text continues by giving a list of monthly festivals all of which are dated as "day 9 rise of Sothis" beginning with XII(e) day 9 and ending with X(e) day 9. Here not only is the remark "rise of Sothis" absolutely meaningless but also the invariable date "day 9" is very suspicious because of the disregard of the five epagomenal days between XII(e) 9 and I(e) 9.[561] It

561) Theories of Borchardt cannot be upheld because they are based on invalid palaeographical assumptions (cf. Edgerton [1] p.191) made by Brugsch and accepted by Sethe (Zeitr. p.314 note 3).

seems hardly possible to explain these things as anything but blunders made by the scribe; but this cannot increase our confidence in the first two lines It is, therefore, more or less a matter of private taste whether one considers this "calendar" a serious document or not. If one assumes[562] that the

562) Meyer (Ed.) Aeg. Chron. Nachtr. p. 8 f.

omission of the epagomenae is not due to carelesness but is the result of some schematic calendar, then I do not see why one should accept the two first days as exactly meant, the remaining only as schematic. Five days' uncertainty combined with the necessary decade of uncertainty of any Sothic date gives at least 30 years' margin. Here again the accuracy of the basic documents is much lower than would be required for precise astronomical results.

Before turning to the rôle of the Sothis dates in Hellenistic times we must still mention an interesting fact about the "Ebers calendar." As mentioned above, a certain festival is mentioned for each month of the year; the new year's festival on XI(e) 9, the day of the rise of Sothis, heads the list and has been the object of our preceding discussion. What follows thereafter are other festivals, always connected with the 9th day of the corresponding month. The names of these festivals are directly related with the names used in the latest period of Egyptian history, Thoth, Phaōphi, Athyr, etc.,[563] but unfortunately not in the usual correspondence Thoth ≈ I(e), Phaophi ≈ II(e), etc., but one place advanced: the Thoth-festivals stands in the month XII(e), the Phaophi-festival in I(e), etc.[564] It has been shown by Gardiner[565] that this forward movement of the names in question cannot

563) Cf. above p. 2.

564) The presentation given here is simplified in so far as at different places the name of the festival was not yet the same as in the latest period. The essential point remains: that all months' names are moved by one step forward, compared with the canonical arrangement.

565) Gardiner [1].

be explained as an error or as a peculiarity of the scribe of the papyrus Ebers but that various independent texts show the same translation of the names of the festivals. Gardiner therefore came to the conclusion that one must either assume "that the festivals .... were transferred, as a body, from their original place" adding "but the difficulty is to find a motive for such a proceeding" or "that a certain number of days were at a given moment intercalated in the civil calendar", and he remarked that this assumption would upset the whole system of Egyptian chronology. A way out of this dilemma was found by Sethe who showed[566] that various facts corrobate the assumption that the names of months are taken from the festivals to which they led and not from the festival which fell into the month itself.[567] At the present time, at least, no urgent reasons exist to doubt the undisturbed continuity of the Egyptian calendar.

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566) Sethe, Zeitr. p.35 f.

567) Sethe pointed out that such a notation, which seems strange to us, has its parallel in the Roman calendar (see above p.[illegible]).

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64. The Hellenistic theory of the Sothic period.

It cannot be emphasized too much that many of the most common statements concerning ancient science and their history to be found in modern books are strongly influenced by theories created in late antiquity or by Hellenistic scholars. Common to most of these theories, modern and Hellenistic as well, is the tendency to give definite evolutionary accounts of the origin of known institutions or facts whose actual history was no longer known. The Greeks cannot be blamed too much in this connection; they simply followed the natural tendency to answer questions before knowing the real complexity of the problem.

It was evident for the Greeks that "year" must mean "solar-year" and therefore should have the length of $365\frac{1}{4}$ days (or at least very closely so). They recognized that the Egyptian year was bound to rotate in 1460 years through all seasons of the solar year whose length, they thought, was represented by the interval between the heliacal risings of Sirius. Consequently, the coincidence between the New-Year's-day of the wandering year and of the Sothis-year became a matter of interest to the Greeks - all the more so because such a coincidence was near at hand (139 A.D.). That such a contrast did not exist for the Egyptians (because they had only one "year") did not occur to the Alexandrian scholars living under the impression of the continuous divergence between their own calendaric concepts and the Egyptian calendar. The natural result of these facts was the creation of concepts like „Apokatastasis" and "Sothic-period" and their interpretation as a period of great significance. To this tendency were added the growing interest in the astrological interpretation of life and the related interpretation of the Roman emperors as saviors of a solar or astral character. This new interest in the importance of astronomical phenomena and astronomical periods was clearly shown when a "Sothic-period" reached its end in 139 A.D. and a new "age" opened for mankind. Coins were stamped with the inscription ΑΙΩΝ (αἰών = period of existence, lifetime, epoch) accompanied by a representation of the Phoenix-bird, the symbol of resurrection.[568)]

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568) Such coins are preserved from the second to the sixth year of Antoninus Pius (139 to 143 A.D.). Examples are given in Borchardt, Ann. p ff fig.9. For the historical background see Vogt (J.) AM.

It can be hardly doubted that a great deal of the emphasis which modern historians have laid on the importance of the Sothic period is a consequence of the interest of this concept for the Alexandrian scholars of Greco-Roman times. It is, however, very questionable whether we may extend these concepts backwards into Egyptian history proper. I believe ... that two probelms frequently discussed in connection with Egyptian chronology, t socalled "date of Censorinus" and the "Era Menophris" are of no value for the Egyptian chronology at all.

a. Censorinus.

Censorinus[569] in 238 A.D. wrote a little book entitled "De die natali", dealing with various calendaric subjects. In this connection he also mentions the Sothic period[570] and reports[571] that the rise of Sothis fell on the I(e) 1 hundred years before his time on the 21st of July.[572] This

569) A Roman grammarian.

570) Censorinus XVIII, 10 ed. Hultsch p.39.

571) Censorinus XXI, 10 ed. Hultsch p.46.

572) "Idem dies fuerit ante diem XII Kal.Aug. quo tempore solet canicula in Aegypto facere exortum". This passage is also reproduced in Wheeler (G.) [1] p.196 f. and frequently elsewhere, e.g., Meyer (Ed.), Aeg.Chr. p. 23 f.

date has been replaced since Scaliger by 20th of July because 139 VII(j) 20 = I(e) 1 and not VII(j) 21. That Censorinus' equation is incorrect cannot be doubted because the relation between Roman and Egyptian calendar is established by countless documents, but I cannot see why we must assume that he had actually written the correct date and I see still less reason to consider this corrected text to be of basic importance for Egyptian chronology. Even if this document were sufficiently reliable to tell us in which of four possible years the step of the rise of Sothis by one day was assumed, this knowledge would not affect Sothic dates from ancient Egypt because the idea that we are able to calculate cyclically backwards in steps from four to four years is astronomically incorrect, as is shown by the little table (51) of p. . In other words the assumption of an exact Sothic period of 1460 years is only a Hellenistic assumption, followed by many modern historians, but contradictory to the astronomical facts. Whatever Censorinus might have said, we will never obtain by cyclic calculation a higher accuracy than about one decade margin; it is therefore quite unimportant which year Censorinus considered the beginning of such a cycle.

b. The era of Menophris.

In discussions about Egyptian chronology it is considered a well-known fact that the astronomer Theon Alexandrinus[573] computed the date of

573) He is known as commentator of the Almagest. His lifetime is determined by his observation of the total solar eclipse of 364 VI 16 (cf. Rome [3] p.212 note 2).

the heliacal rising of Sothis for the year Diocletianus 100 and that he called this year "the 1705th year of Menophris". Because Diocletianus 100 ≈ 383/4, the year Menophris 1 must correspond to -1321/20; moreover, it follows from Theon's calculation that Menophris 1 I(e) 1 is considered to be a day of the heliacal rising of Sothis. What remains for obtaining a new chronological fixed point is therefore only the question which Egyptian king is hidden behind the name "Menophris". This question has been frequently discussed and the answer given has naturally depended on the chronology prevailing at the time. According to our present knowledge Sethos I could have been ruling around 1320 B.C., and Struve and Sethe therefore tried to explain how this king could be called "Menophris". If we accept the results of these scholars, obtained by independent and to a large extent contradictory arguments,[574] the XIXth Dynasty would be dated astronomically.

574) Struve [1] and Sethe [1], accepted by Borchardt MZ p.17 f. For solutions proposed earlier cf. Lepsius, Chron. p.172 ff.

Unfortunately, each step in this conclusion is very weak. First of all, we know that there exists nothing like an invariable "Sothic period" of exactly 1460 years which is the basis of Theon's calculation. In other words, Theon's sources cannot have been exact but were modified to fit a certain scheme of computation. It is not the small deviation of the "Sothic period" of 1460 years from the real facts which is here of importance but the evidence that the whole calculation is built on a simple computation in a backwards direction, with no quaranty that the endpoint reached is historically precisely defined. It is just as plausible that Theon had found by adding regnal years given in some kinglist, that a king "Menophris" ruled 1460 years before the famous "Apokatastasis" of 139 A.D. As long as this possibility cannot be excluded, the date of Menophris might be the result of the dynasty scheme of a chronographer like Manetho and therefore with no astronomical value.[575] Lepsius assumed[576] that "Menophris" corresponds to

575) When I mentioned this possibility to Prof. A.Rome, he kindly informed me that Fotheringham had written him exactly the same. Cf. also Scharff [1] p.8 note 1.

576) Lepsius, Chronologie p.172.

Merneptah, which seems to be the most plausible explanation given for this name. According to our present knowledge Merneptah rubed about one century after -1320 and therefore Lepsius' assumption has been discarded. But if we accept the above mentioned possibility, Lepsius' proposal seems to be worthy of further consideration.

We turn now to the method of calculation itself. Here too, we stand on very unsafe ground. It is only of minor importance that Theon's authorship is doubtful and that the whole passage in question seems rather to belong to an obscure astrological treatise[577] (although this might be re-

577) This has been shown by Rome [2] p.290 note 1. The passage in question seems not only to be an interpolation in Theon's commentary to Ptolemy's "Handy Tables" but the same rule for computing the rise of Sothis

appears independent of Theon in an astrological codex (CCAG 6 p.79 f. in Codex Vindob. phil. gr. 115) and in Cod. Vat. gr. 1038 containing Euclid, Ptolemy etc. but not Theon.

sponsible for some difficulties in the calculation). The procedure consists in the following steps:[578)]

578) The text (not clear in all details) is reproduced, e.g., in Lepsius Chron. p.169 note 5 and (less completely) in Meyer (Ed.) Aeg.Chron. p.29 note 1. A critical edition is still lacking.

(1) Diocletianus 100 = Menophris 1705

(2) $\frac{1}{4} \cdot 1705 \approx 426$

(3) add 5, giving you 431.

(4) subtract $\frac{1}{4} \cdot 408 = 102$, and you get $N = 329$.

(5) Because $N = 10 \cdot 30 + 29$, the date of the heliacal rise of Sothis in Diocletianus 100 is XI(a) 29 .

In order to explain this process, let us assume that Diocletianus 100 ≈ Menophris 1705 and that both eras are counted in Julian years (fig.73). Now 1705 Julian years contain $\frac{1}{4} \cdot 1705 \approx 426$ more days than 1705 Egyptian years. Let us suppose that the first day of Menophris 1 was the date of a heliacal rising of Sothis. Under the assumption that the Sothis-year has the length of a Julian year, the date of the rise of Sothis 1705 Julian years later would fall 426 days later than in the first year (step 1 and 2). If we now wish to calculate the date of the rise of Sothis in the Alexandrian calendar instead of in the Egyptian calendar, we have to take into account the fact that the date of the rise of Sothis remained stable since Augustus' reform of the calendar (again assuming that Sothis-year = Julian year). The first intercalation of the Augustan calendar took place in the year Augustus

4, at least according to the later scheme.[579] From Augustus 4 to Diocletianus 100 = Augustus 413, 409 years elapsed with no change in the date of the rise of Sothis in the Alexandrian calendar. Therefore, $\frac{1}{4}$ 409 days too many have been taken in our previous calculation and therefore should be substracted (step 4). Hence the total number of days which should be added to the I(e) 1 in the year Menophris I must be 426 - 102 = 324 and the resulting date in the Alexandrian calendar would be the 325th day, i.e., XI(a) 25. The text, however, adds in step (2) 5 more days, thus obtaining 329, and considers on the other hand only the 329th day instead of the 1 + 329th day. The result is therefore (step 5) XI(a) 29 as the date of heliacal rising in the year Diocletianus 100.

It is a total mystery why the 5 days are added in step (2).[580] These same 5 days occur in the later examples of the same calculation[581] and are there confirmed by the corresponding Julian date given, namely, XI(a) 29 = VII(j) 23. Nothing remains but to admit that a group of documents assumes the heliacal rise of Sothis on the 23rd of July[582] - a good illustration

579) Cf. above p. 109 note 411. From fig.73, it follows that XI(a) 25 = VII(j) 18 must be considered as a fixed Sothis date if the following assumption hold: (a) Menophris 1 I(e) 1 is a date of the rise of Sothis (for the first time in four years); (b) Menophris 1705 = Diocletianus 100 (the years counted as Julian years); (c) Augustus 1 I(a) 1 = -29 VIII(j) 30.

580) Borchardt MZ p.17 makes the ad hoc assumption that the text refers to a geographical latitude of 36°, but there is no textual basis for this hypothesis.

581) CCAG 6 p.79, computing the rise of Sothis for the years 829 and 919.

582) Perhaps one should also mention in this connection the date given by Censorinus: VII(j) 21 (cf. above p. ###).

for the weakness of all modern attempts to interpret such dates as precise astron mical observation. I have no doubts that the date assumed for the rise of Sothis was subject to irregularities of the same kind as Easter dates in early Christianity and that at no time did Sothis dates give more than the approximate date of the phenomenon, neither in Graeco-Roman nor in Old-Egyptian times.

§ 4. Orientation.

Almost no method of astronomical chronology has been applied and discussed more frequently and less successfully than the dating of buildings by their orientation. Indeed, the number of astronomical phenomena is so great that it is extremely improbable not to be able to find a relation, say, between the axis of a temple and the rising, setting, or culmination of a bright star, or a date on which the sun does enter into a characteristic position with respect to an architectural structure. The first requirement should therefore be to establish in each specific case that the building has been erected according to welldefined rules of orientation, and textual evidence must be found for these rules and for the specific relation between the building, the date of its foundation and an astronomical phenomenon. The method usually applied, to take the fact of orientation as granted and to consider the first relationship discovered as <u>the</u> actual orientation is almost without value.

Another point must be taken into consideration. Consciously applied orientation, say towards east, or towards Jerusalem or Mekka, must by no means habe been meant to be more than a general direction. If we now measure the direction of 100 temples directed towards the east, it would be highly improbable not to find a relatively high percentage of very accurate orientation. This accuracy, however, does not mean anything more than an accidental success among a great number of not very accurate original measurements. The evaluation of orientations for astronomical chronology requires, however, a high accuracy of the directions considered, and it is by no means evident which measurements should be considered as accidentally exact and which as real.

Finally, even if we assume ideal conditions, i.e., the knowledge of the kind of orientation intended and a clear judgment as to the accuracy to be expected, the chronological result would even then usually permit a margin of uncertainty of at least one century because the stellar phenomena involved change their appearance very slowly. It can, therefore, hardly be expected that this method leads to results which are not already known in advance and with much higher accuracy from archaeological considerations. The most favorable conditions will prevail in the case of sunset and sunrise around the equinoxes because at these periods the variation of the place on the horizon where the sun appears or disappears is comparatively great. Stellar phenomena, however, depend mainly on their rectascension and declination, and these coordinates change only at the rate of the precession of the equinoxes, i.e., by fractions of a degree per century. Only if the original measurement reaches at least the same accuracy, can the astronomical date be of interest.

As will be clear from these remarks, the dating by orientation must lead to the discussion of individual cases, which is not the scope of this book. We shall therefore restrict ourselves to a few special problems intended to supplement the preceding general considerations.

65. Egypt and Mesopotamia.

The pyramids are the inexhaustible subject of astronomical and chronological theories which have nothing in common but the author's belief in a secret destiny of these buildings and the disregard for all archeological and historical facts.[583] Also speculative minds can hardly be convinced

583) Only as an example of the results obtained by this kind of astronomical chronology might be mentioned that in the popular book "The Romance of the Calendar" by P.W. Wilson (New York 1937) the pyramids are assumed to belong to the period from 4700 to 4550 B.C., i.e., about two millenia to early.

by mere facts, it might be useful to quote the articles of N.F. Wheeler in Antiquity 9 (1935) devoted to a systematic survey of our present knowledge about the purpose and construction of all Egyptian pyramids. No basis is left for any theory of the astronomical purpose of these buildings. It is no contradiction to this statement to say that a north-south or east-west direction of many Egyptian buildings was intended. We know this not only from the preserved ruins but also from texts describing the ceremonies to be executed at the foundation of temples.[584] The king directs his eyes towards the Great Dipper[585] stretching the rope in the intended axis. But this shows nothing more than a general direction towards a northern constellation; higher accuracy in determining the culmination of a star can hardly be obtained with Egyptian water-clocks.[586] Of course, as said before, occasional

584) Cf. Borchardt AZ p.54 note 2 (also Nissen, Cr., p.32 f. with slightly incorrect translations).

585) As mentioned above (note ???) Borchardt assumes that ursa minor is meant, because this constellation is nearer to the northern pole.

586) This is evident from Borchardt's systematic investigation of the extant examples (Borchardt AZ).

high accuracy cannot be avoided among a great number of buildings of roughly the same orientation, but this cannot be a sufficient basis for astronomical dating by means of orientation.

that the Egyptian architects felt themselves free to adapt their plans to local conditions[587] – which makes it perfectly hopeless to consider the orientation of a building as astronomically significant. An orientation with respect to different fixed stars, as assumed by Nissen,[588] seems not to be confirmed by any textual evidence.

587) Cf. Kees, Hdb, p.295 (and pp. 151, 304).

588) Nissen, Or. p.59.

In recent years, also Mesopotamian temples have been investigated for their orientation as a basis for chronological studies. G.Martiny has published various articles on this subject[589] but in such a form that the basic idea is hard to discover. The astronomical background of this theory was brought to a clear form by P.V.Neugebauer,[590] who considered Martiny's arguments very convincing. There are, however, very serious objections[591] against the basic assumptions made by Martiny which must be discussed briefly here.

589) Cf. the bibliography p.[illegible].

590) Neugebauer (P.V.) [4] (1934) and Neugebauer (P.V.)-Schott [1].

591) Cf. the careful discussion of Martiny's original theory by Weissbach [3].

Martiny originally distinguished between two types of temples, the "Assyrian" and "Babylonian" temples. but this distinction does not coincide with the usual meaning of these words but only characterizes two different methods of orientation. In order to avoid this misleading terminology we shall better distinguish between two "classes" A and B where B means the usually assumed orientation with respect to the heliacal rise of a certain fixed star and A means a new type of orientation discovered by Martiny. He assumes that around 3000 B.C. one distinguished a certain hour circle passing through the stars α Virginis, α Draconis (at this time polar star) and α Cassiopeiae. The intersection of the plane of this circle with the plane of the horizon observed at sunrise 8 days after the vernal equinox gives the axis of a temple of class A. Martiny assumes furthermore that this great circle was defined by means of fixed stars (as mentioned above) and not by means of the actual celestial pole. Because of the precession of the equinoxes, however, this circle will not remain an hour circle but become more and more displaced. On the other hand, the observation of its intersection with the horizon is observed on a date with fixed distance from the equinoxes. Hence the line of intersection, i.e., the direction of orientation, will slowly change in proportion to the precession by an angle of about $1\frac{1}{2}^{\circ}$ per century, measured on the horizon. The direction of a temple of this type would therefore be a direct index of its date of foundation.

This is not the place to repeat all the very serious objections to be raised against the archealogical and historical elements assumed by Martiny.[592] It is sufficient to show that the fundamental astronomical as-

592) Cf. Weissbach [3].

sumption of Martiny's theory cannot be accepted as correct. As is clear from the preceding description of the orientation of temples of class A, the essential point consists in the observation of the fundamental circle through

Draconis at a date which has a fixed relation with respect to the vernal point, a date which Martiny assumes to be the New Year's festival. Such a relation does not exist, however, because the New Year is connected with the month Nisan, which is a month in a lunar calendar which fluctuates very irregularly around the vernal point during the whole period in question. In other words, the fixed date on the solar calendar selected by Martiny as date of orientation has no fixed relationship at all to the actual Babylonian calendar. Hence the whole theory of orientation of temples of class A collapses.

The orientation of type B assumes another principle. Here a coordination between a deity worshipped in the temple and a certain fixed star is assumed. This theory has been built on such arbitrary assumptions that Martiny himself more or less explicitly admitted the incorrectness in the case of 8 out of 10 temples.[593] He therefore replaced this theory by another which assumes that temples are oriented "geographically", i.e., they

593) Martiny [2].

are directed toward the "mother-temple" in another city, where the original cult is supposed to have originated. It did not occur to Martiny that such an orientation between points hundreds of miles apart would require methods of mathematical geography which did not exist before Hellenistic times - not to mention the total lack of evidence for such ideas in Mesopotamian religion. That Martiny himself knows only two(!) temples following this principle is almost unnecessary to add. What remains is nothing but the postulate of the existence of some kind of "orientation" no matter how it is to be found.

A totally different theory of orientation has been proposed by Unger,[594] who assumes the directions of the winds as the responsible elements.

594) Unger BHS.

Fortunately, no chronological conclusions have yet been drawn from this speculation, so we spare ourselves the trouble of going into details It is only surprising that Unger at the same time also assumes an astronomical orientation of streets and walls of Babylon, brought into relation with the summer solstice.[595] He connects this with the intercalations of the lunar calendar, not realizing that such a "Normal-Clock for Babylon" would lead to much more regular intercalations than are actually attested.[596]

595) Unger BHS p.382 the solstice of 2500, lowered in Unger [1] p.317 f. to 2000, at that time assumed to be Hammurapi's date.

596) Cf. above p.???.

What remains is, here too, the postulate of the existence of an orientation. That the same facts fit the most contradictory theories is not considered an argument against the value of the basic assumption.

66. Greece.

The planning of Greek cities was influenced, at least in theory, by the consideration of the prevailing direction of winds,[597] and in practice certainly still more by the frequently very difficult conditions of the locality and by aesthetic reasons. Astronomical orientation of projects of this size is practically excluded, and it can therefore not be reasonably expected that temples which are in perfect agreement with the net of streets are subject to individual orientation. It is hard to understand why certain temples should not have been subject to astronomical orientation, while the plans of other temples should have been determined exclusively by orientation. If a religious ceremony of this kind was considered essential, one should expect its general acceptance. Also the principle of orientation itself should have been of a very arbitrary character: whereas most of the temples show an east-west orientation (which makes it possible to bring their axis into relation with the place of sunrise on a certain day of the year),

597) Vitruvius I,6 requires that these directions be avoided for the main streets.

there remain many temples where this relationship is excluded. The other principles, like orientation of the minor axis (which is of no significance for the building) or orientation with respect to fixed stars, have been adduced.[598] It is therefore not surprising that the hypothesis of astronomical orientation now finds very little credence.[599]

598) Nissen, Or. e.g. p.124 f.

599) Cf. e.g., the article "Tempelorientierung" in RE Suppl.7 (1940). (Doxiadis [1]) and Gerkan GSt p.74 ff.

In spite of all these difficulties, W.B. Dinsmoor undertook to reinvestigate the problem in a number of cases where the circumstances were sufficiently favorable to judge the value of the results obtained.[600] The

600) Dinsmoor [1] and Archon list p.206.

two main requirements are the dating of the building, or still better of the foundations of the building, within narrow limits by archaeological means, and, moreover, the knowledge of the date of the festivals which might be considered essential for the foundation of the temple. The greatest difficulties lie in the undetermined relation of the lunar calendar with respect to the year. It turns out, however, that it is possible to make assumptions such that 10 temples can be dated within the given limits by the appearance of the sun on the actual horizon (mountains and even nearby buildings). I think one must admit that these results speak very much in favor of an astronomical orientation in these cases, although I would still not risk using observed orientations for the restoration of the calendar. As long as the calendar is not determined on independent grounds, the possibility of accidental coincidemces cannot be denied. For chronological purposes, the dating by orientation cannot become more than an auxiliary method which can be applied only if the main problem of dating has already been solved.

§ 5. Bibliography to chapter IV.

67. Astronomical and general part.

A modern star catalogue is given in Schlesinger CBS, to which corresponds the star map of Deporte AC. A star atlas of smaller size but with the modern limits of the constellations is the 6-th edition of Schurig-Götz, Tabulae coelestes (1933).[601] For the traditional configurations the atlas

601) The last mentioned atlas is more convenient than the atlas of Delporte in so far as it prints the names of the stars on the map while the map of Delporte only gives the places and adds the names in a separeted list.

and the catalogue of Heis NHA is very useful. For older star catalogues, see Knobel [1]. The best available star map for Babylonian constellations is given in Meissner BA II. This map is based on identifications accepted by E.F. Weidner. It is impossible to compose such a map in the present state of affairs without making arbitrary decisions which might eventually turn out to be false. One must therefore expect no more than an arrangement correct in general but amenable to change in details. – No successful attempt has been made until now to compose an Egyptian star atlas.

Tables for the calculation of heliacal phenomena are given in Neugebauer (P.V.) TAChr.III with corrections in AChr.I p.155 ff. For the coordinates of Greek star configuration, Peters-Knobel PCS and Vogt [1] and [2] should be taken into consideration. For the history of the configurations in general see Gundel, Dekane and Boll-Gundel [1], where further references are given. The ancient observations of stellar colors are discussed in Boll [4].

68. Special topics.

Parapegmeta. The only two preserved specimens are the fragments excavated in 1902 at Miletus. These unique texts are, however, not yet included in the official publication of Milesian inscriptions; only preliminary notices and unsatisfactory photographs of two main fragments are publishe (Diels - Rehm [1], Dessau [1], Rehm [1] and Diels AT, p.7 and pl.I). The ancient literary tradition about stellar calendars is collected by Wachsmuth in Lydus, De ost. and in part republished in the editions of Geminus (EA p.211 ff.) and Ptolemy (opera II, 1 ff.).[602] A detailed investigation of

602) Cf. also Grenfell-Hunt, Hibeh No.27.

this material can be found in the studies on the Greek calendars edited by Boll (G.K.); cf., moreover, the articles "Episemasiai" (Rehm [3]) and "Septi zonium" (Dombart [1]) in RE.

Egyptian "Diagonal-Calendars". The publication of the stellar calendars on coffin lids of the Middle Kingdom is in a very unsatisfactory state. Not a single one of these texts is scientifically published. The publications of Lacau SANE II and Chassinat-Palanque, Assiout, reproduce the texts in type-print only and are very unreliable for details;. The articles by Pogo ([5][6][7][603]) contain photographs, but they are difficult to read Winlock [2] is only a preliminary report.[604]

603) The coffin of Hekat comes from Assuan, that of Aashait fr Thebes (not from Synt, as Pogo says).

604) from this excavation, however, a scientific publication c be expected; I had the opportunity of using Dr.Winlock's edition of the cof fin of Aashait.

Orientation. The bibliography given by Doxiadis [1] does not cover oriental material. Astronomical orientation of Mesopotamien temples was proposed by Martiny (KM and [1]), was supported by Neugebauer (P.V.) [4] and Neugebauer (P.V.)-Schott [1], but contradicted by Weissbach [3]. The new theory of geographical orientation was thereafter proposed by Martiny [2] and [3], but contradicted by Neugebauer (O.) [10]. Martiny BAT is mainly devoted to the archaeological part of his doctrine. Previous literature concerning orientation of oriental buildings can be disregarded (e.g. , Nissen, Or.) because of lack of archaeological material.

Bibliography and Abbreviations.

(a) Alexandrian calendar (cf. p.###)

AA Astronomische Abhandlungen. Ergänzungshefte zu den Astronomischen Nachrichten.

ABAW Abhandlungen der Königl.Bayerischen Akademie der Wissenschaften, Philos.-philol. u.histor.Klasse

AfO Archiv für Orientforschung

AfP Archiv für Papyrusforschung

Airy, Gravitation G.B.Airy, Gravitation, an elementary explanation of the principal perturbations in the solar system. 2nd ed., London Macmillan, 1884

AJA American Journal of Archaeology

AJSLL American Journal of Semitic Languages and Literatures

AKM Abhandlungen für die Kunde des Morgenlandes

Albright [1] W.F. Albright, New light on the history of western Asia in the second millenium B.C. BASOR <u>77</u> (1940) p.20-32 and <u>78</u> (1940) p.23-31

Albright [2] W.F. Albright, A revolution in chronology of ancient Western Asia. BASOR <u>69</u> (1938) p.18-21

Almagest see Ptolemaeus

Al-Battani Al-Battānī sive Albatenii opus astronomicum. Editio C.A.Nallino pars I = Pubblicazioni del Reale ossevatorio di Brera in Milano <u>40</u> parte 1. (1903)

AN Astronomische Nachrichten

An.Or. Analecta Orientalia, commentationes scientificae de rebus orientis antiqui cura Pontificii Instituti Biblici editae

APAW Abhandlungen der Königl.Preussischen Akademie der Wissenschaften

Aristoteles opera Aristotelis opera ed. Acad.reg.Borussica Berlin, Reimer 1831 ff.

ASSB Annales de la Société scientifique de Bruxelles

ÄZ Zeitschrift für aegyptische Sprache und Altertumskunde

(b) Babylonian calendar (cf. p.___)

BASOR Bulletin of the American Schools of Oriental Research

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BM — Bibliotheca Mathematica, Zeitschrift für Geschichte der mathematischen Wissenschaften

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CAH The Cambridge Ancient History (1928 ff.)

Cat.gén. Service des antiquités de l'Egypt, Catalogue générale des antiquités égyptiennes du musée du Caire

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CR   Comptes rendus

CT   Cuneiform Texts from Babylonian Tablets, etc., in the British Museum

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Not. d. Scavi Notizie degli Scavi di Antichità comunicate alla R. Accademia Nazion[ale] dei Lincei

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QFZ   Quellen und Forschungen zur Zeitbestimmung der ägyptischen Geschichte

QS Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik

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VAG Vierteljahresschrift der astronomischen Gesellschaft

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WVDOG	Wissenschaftliche Veröffentlichungen der Deutschen Orient-Gesellschaft
ZA	Zeitschrift für Assyriologie
ZDMG	Zeitschrift der deutschen morgenländischen Gesellschaft

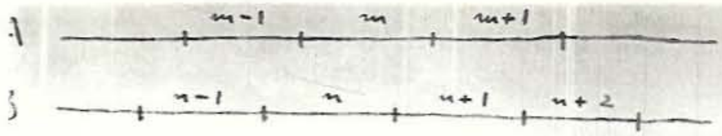
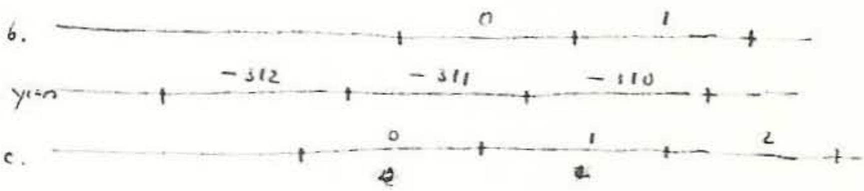


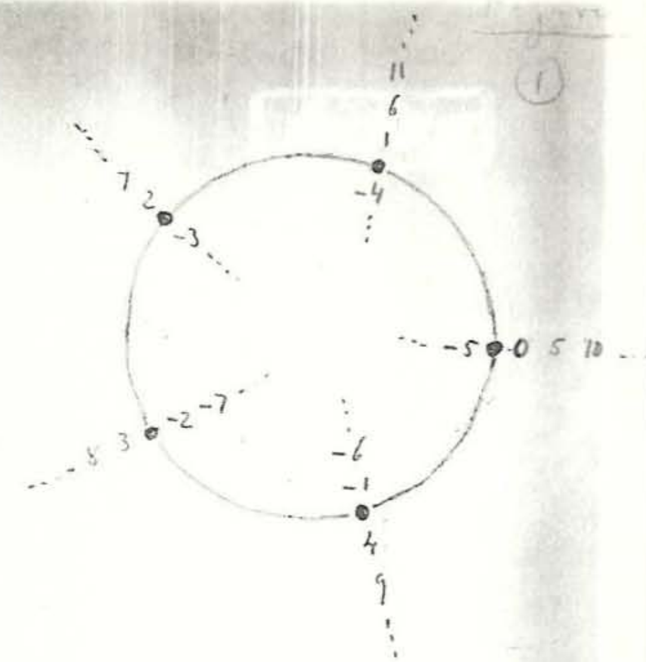
Fig. 1

Overlapping eras, illustrating formulae (14a) and (14b)



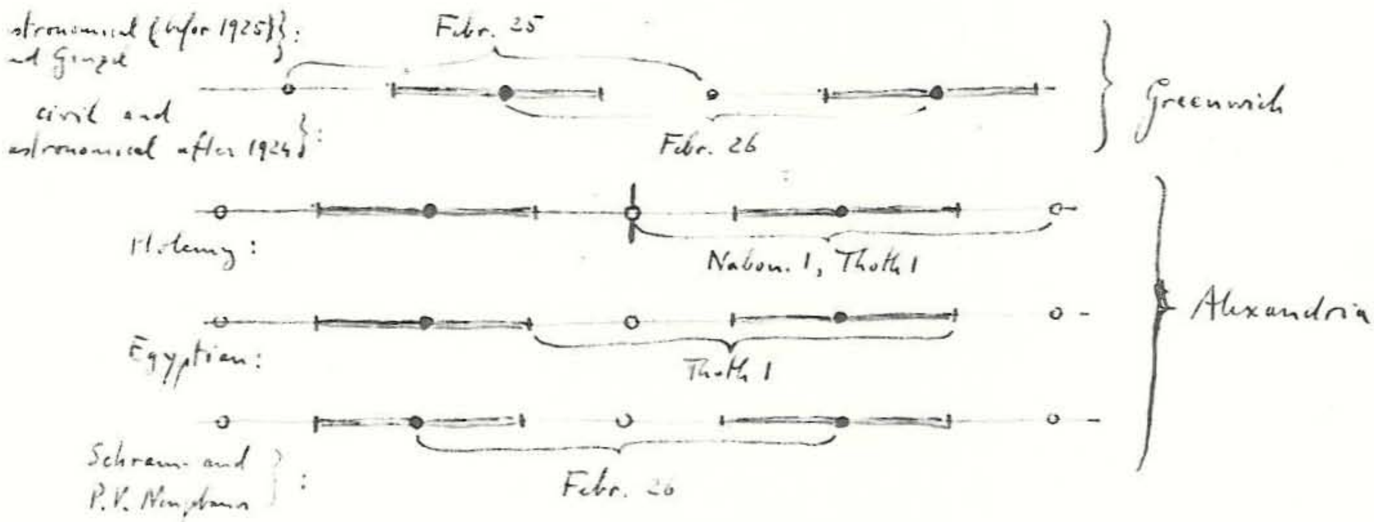
Babylonian and Macedonian form of the Seleucid era; cf. (18)

Fig. 2.



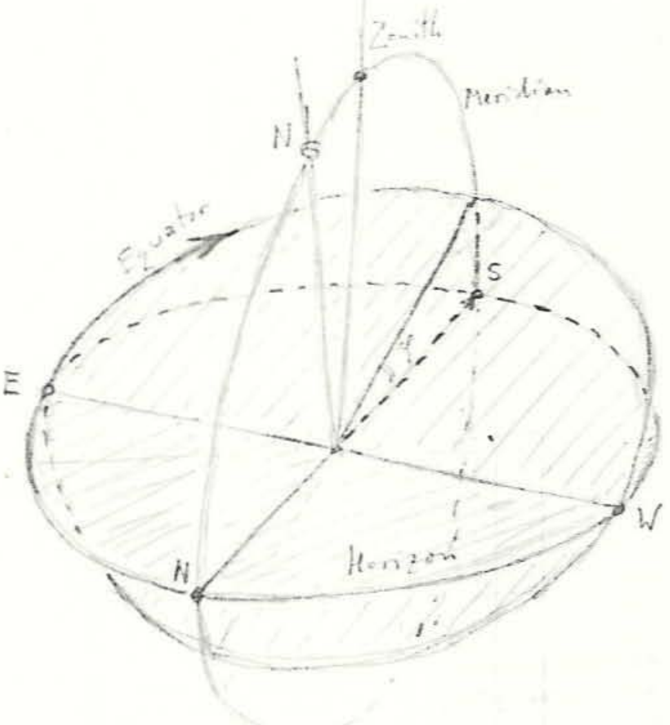
Cyclic arrangement of congruent numbers

Fig. 0



The beginning of the era Nabonassar (-746 Febr. 26) with respect to different epochs for counting dates.

Fig. 3.



The plaines of horizon, equator and meridian for ~~an observer~~ a place of latitude φ

Fig. 4.

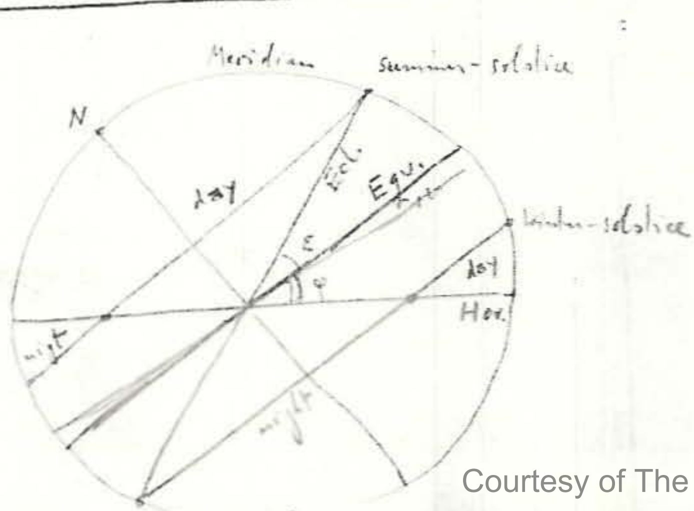
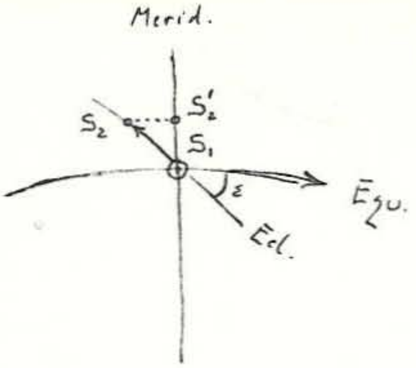
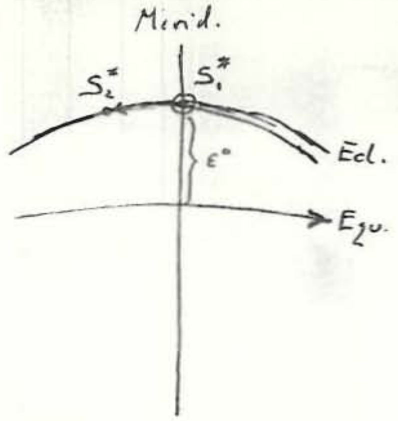


Fig. 5

Intersection of horizon, equator and ecliptic with the meridian showing the parallel circles of the

fig. (3)

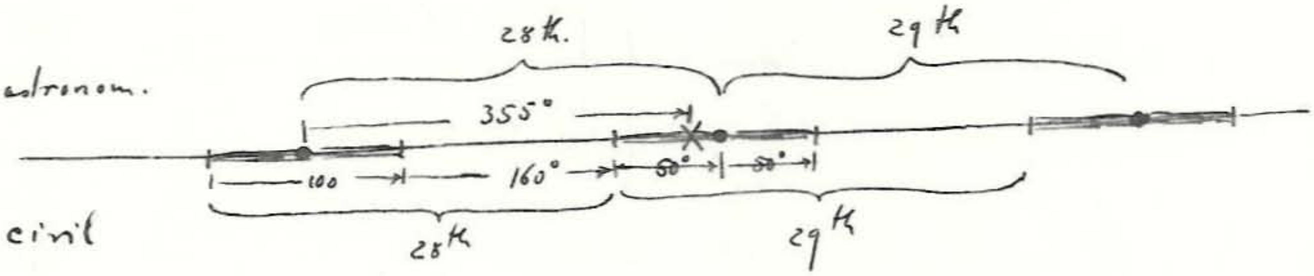




(a) Spring Equinox (b) Summer solstice

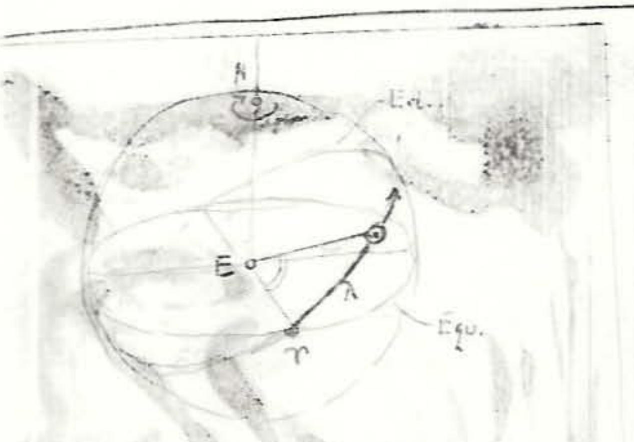
Position of Equator and ecliptic at noon time and comparison of the influence of the ~~assuming that the~~ daily movement $S_1S_2 = S_1^*S_2^*$ of the sun ~~[illegible]~~ on the length of the day.

Fig. 6



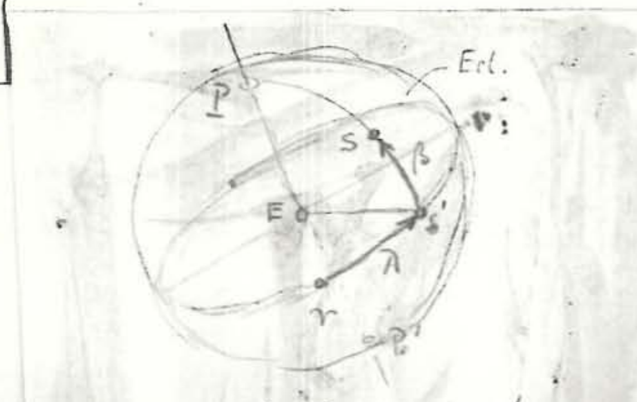
New moon (X) expressed in astronomical and civil epoch according to Babylonian calculation.

Fig. 7.



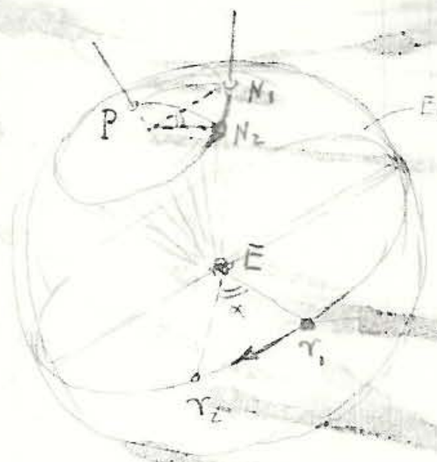
The sun's "longitude"

Fig. 8



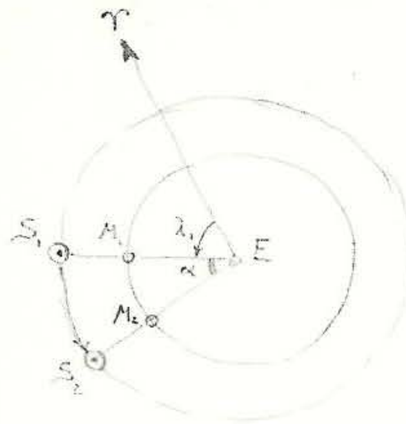
The ecliptical coordinates longitude λ and latitude β

Fig. 9.



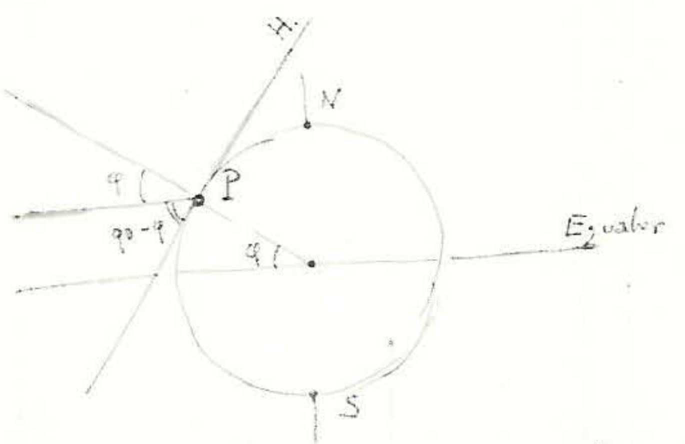
The precession of the equinoxes; the pole N of equator rotates around the pole P of the ecliptic.

Fig. 10



Two successive conjunctions; the suns movement = α; the moons movement = 360 + α.

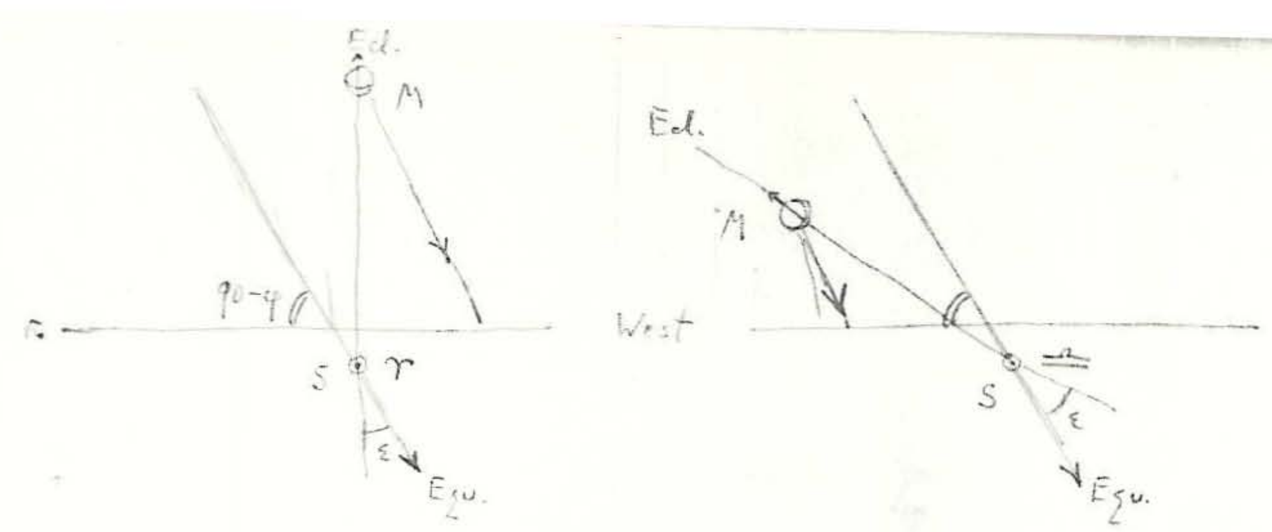
Fig. 11



intersection of the sphere of the earth with the plane of the meridian of a given place P of latitude φ. The inclination of the plane of the equator to the horizon H is 90 − φ.

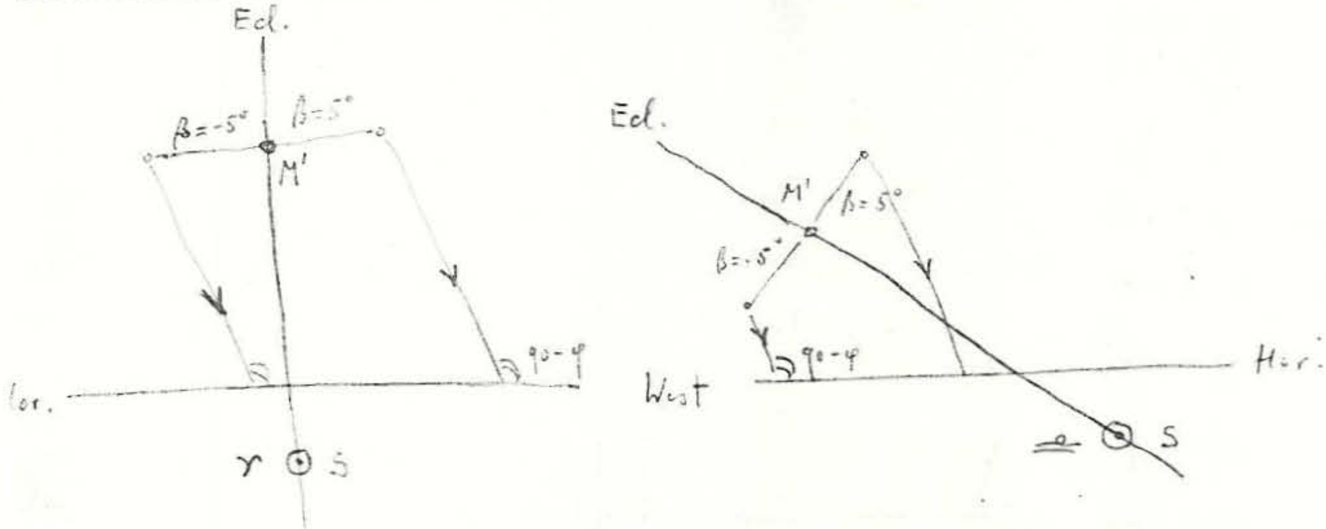
Fig. 12

fig. (5)



Assuming the same elongation of the moon (M) from the sun (S) the moon will be higher above the horizon at spring equinox than at autumn equinox, the sun being equally much below the western horizon.

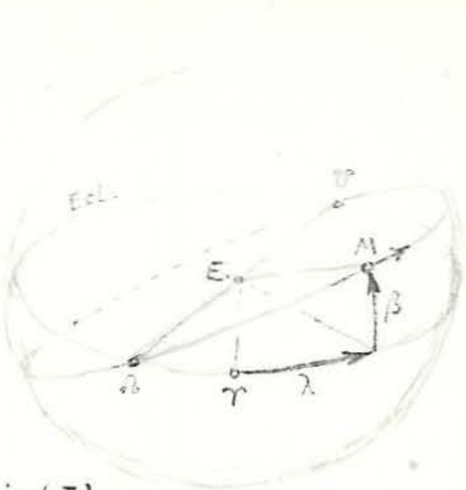
Fig. 13.



nfluence the the moon's latitude (β) on the visibility of the moon bove the western horizon at the equinoxes. SM' is in both cases he same difference in longitude; cf. fig. 13.

Fig. 14.

fig. 6

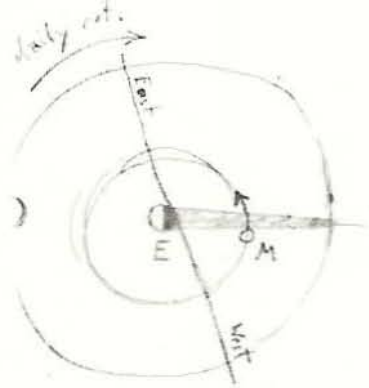


...entric (E)
...ngitude (λ) and latitude (β) of the
...n (M) of the moon

fig. 15

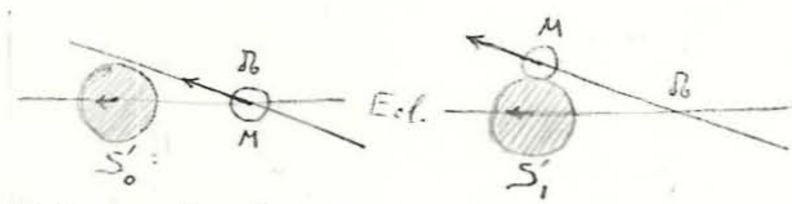
Lunar eclipse.

fig. 16



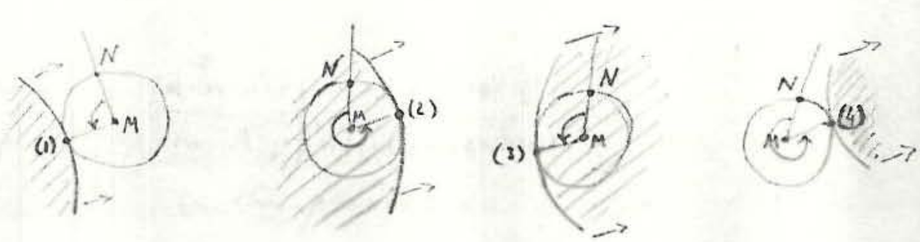
lunar eclips begins
the eastern part of
moon (H is the
zon for some observer
the night-side of the
th).

fig. 17



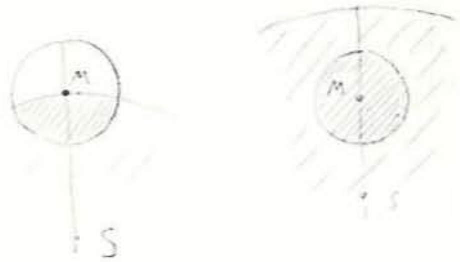
Ecliptic limits. The center of the shadow S'_0 is not in the node when the moon M crosses the ecliptic; but the moon can still reach contact with the shadow in S'_1.

fig. 18



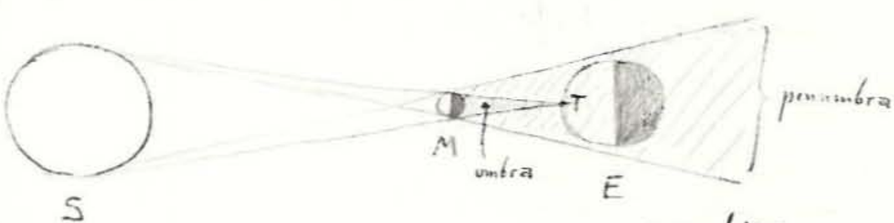
The four points of beginning of total lunar eclipse and their (positional) angles, counted from the north point N.

fig. 7



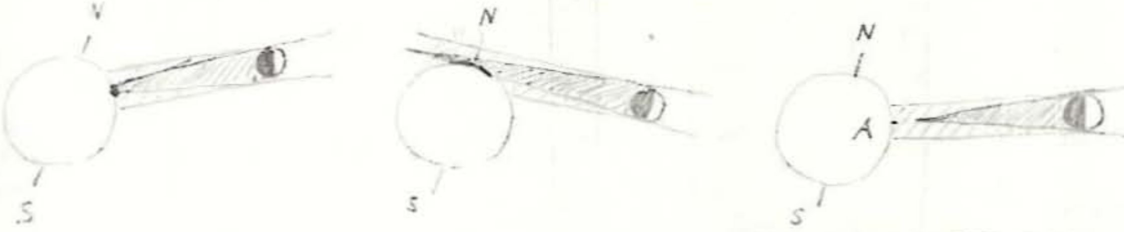
Magnitude 0.5 (or 6) Magnitude 1.5 (or 18)
S = center of the umbra, M center of the moon. Moment of deepest imergence.

fig. 20



Solar eclipse, total in T. [The ~~dimensions~~ proportions of this figure are incorrect; the penumbra never contains the hole earth.]

fig. 21.

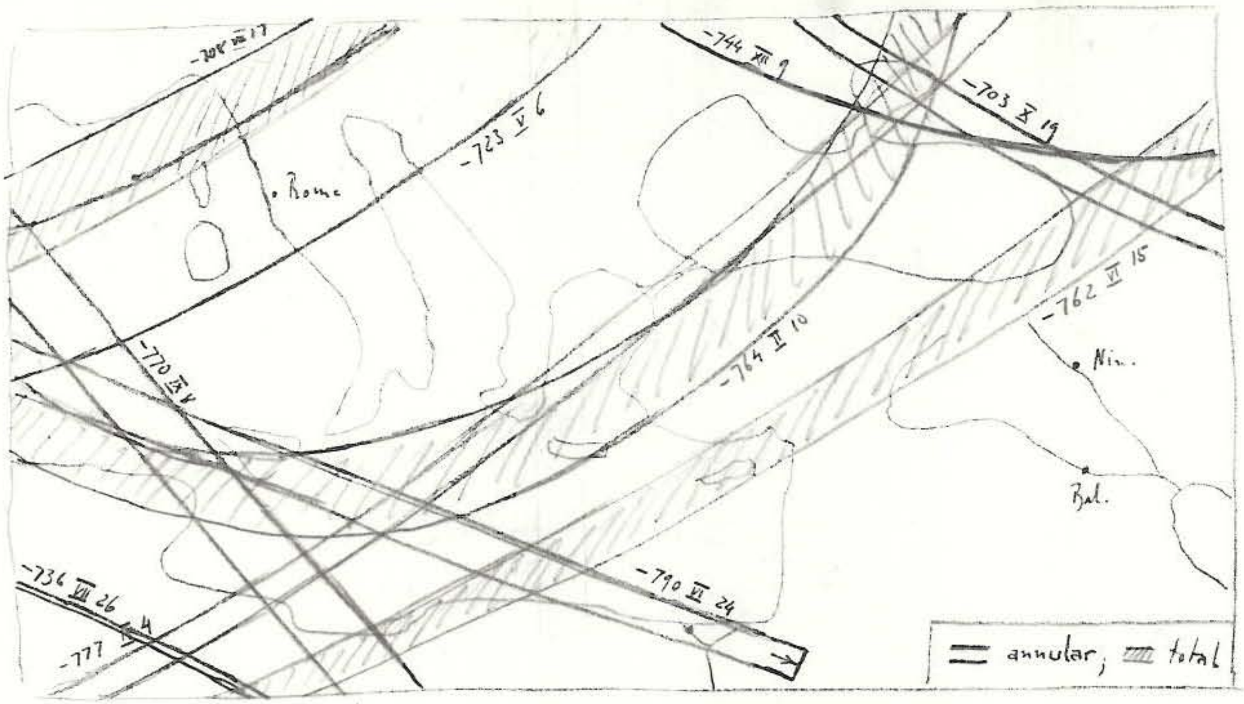


Total sun eclipse in different geographical latitudes, darkening areas of different extention.

(Annular) Solar eclipse in A, partial elsewhere in the penumbra.

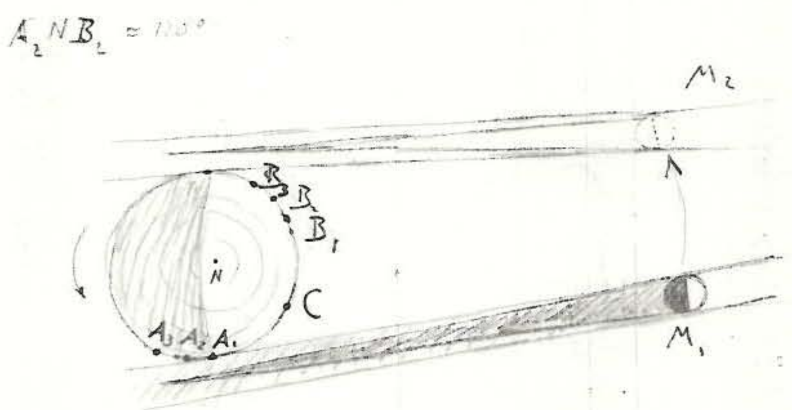
fig. 22

fig (8)



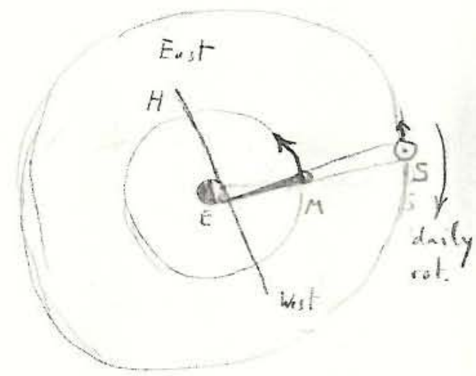
Solar eclipses ~~[illegible]~~ between −800 and −700 ~~[illegible]~~ visible in the Mediterranean area

fig. 23



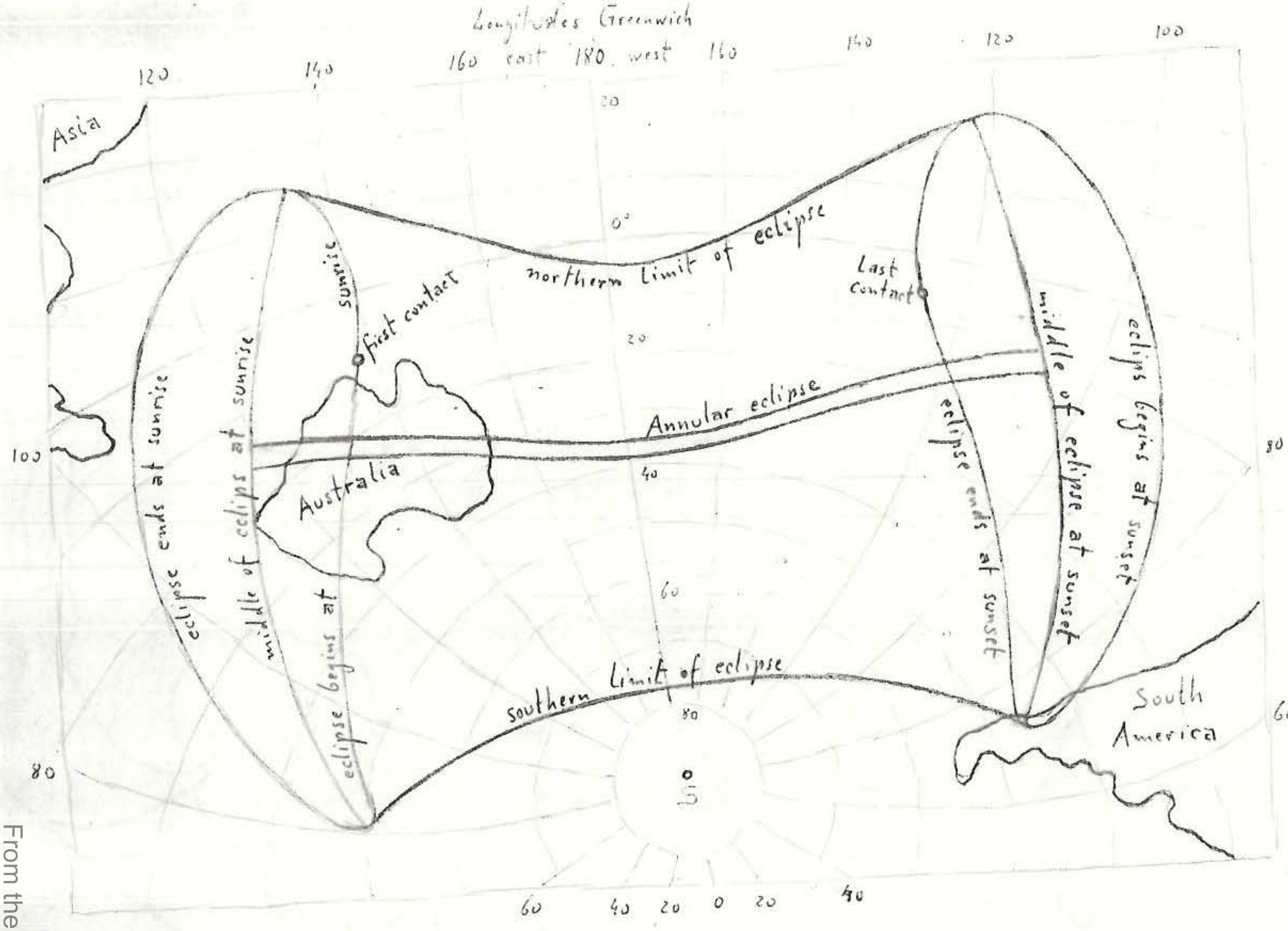
~~Total solar eclipse begins at A_1 at sunrise~~
At sunrise in A_1 the sun begins to appear partially eclipsed, at A_2 totaly, while from A_3, B_3 no eclipse is visible. The sun will be totaly eclipsed at sunset in B_2 and the sun emerges from the shadow at sunset in B_1. The eclipse will be total at C at noon.

fig. 25



A solar eclipse begins at the western part of the earth

fig. 24

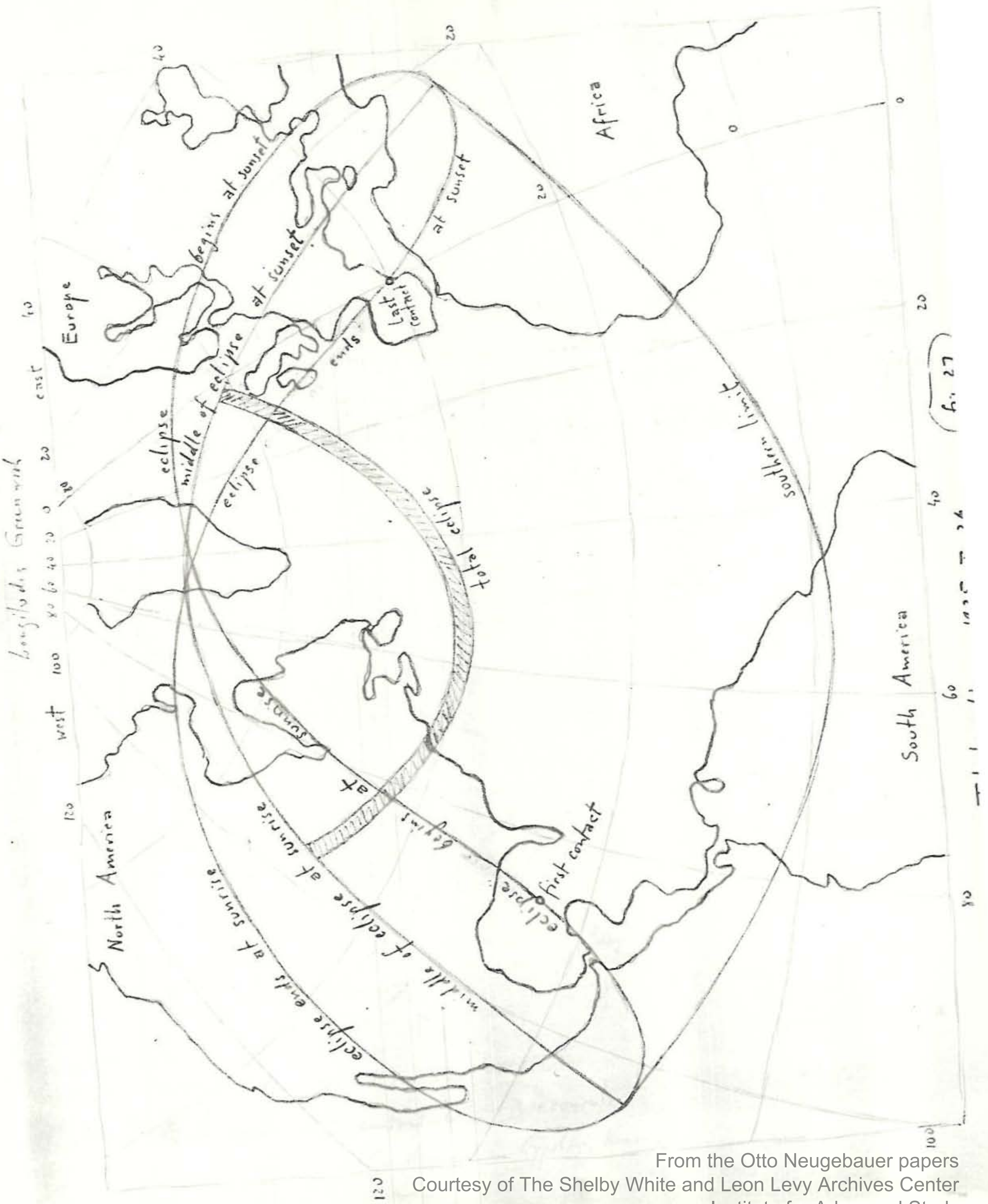


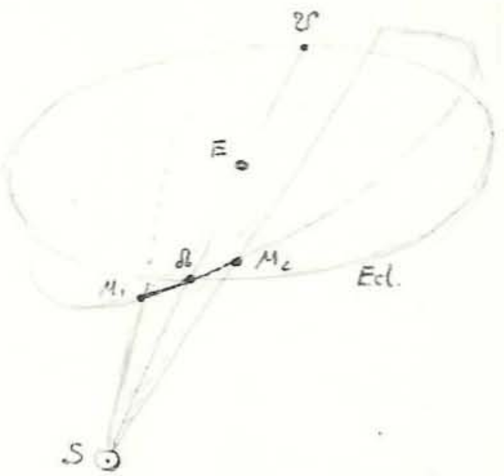
Annular eclipse 1936 XII 13-14

fig. 26.

fig (1)

p.23 (10)


Longitudes Greenwich
west
east
Europe
Africa
North America
South America
eclipse begins at sunset
middle of eclipse at sunset
eclipse ends at sunset
Last contact
total eclipse
southern limit
eclipse ends at sunrise
middle of eclipse at sunrise
eclipse begins at sunrise
first contact
Fig. 27



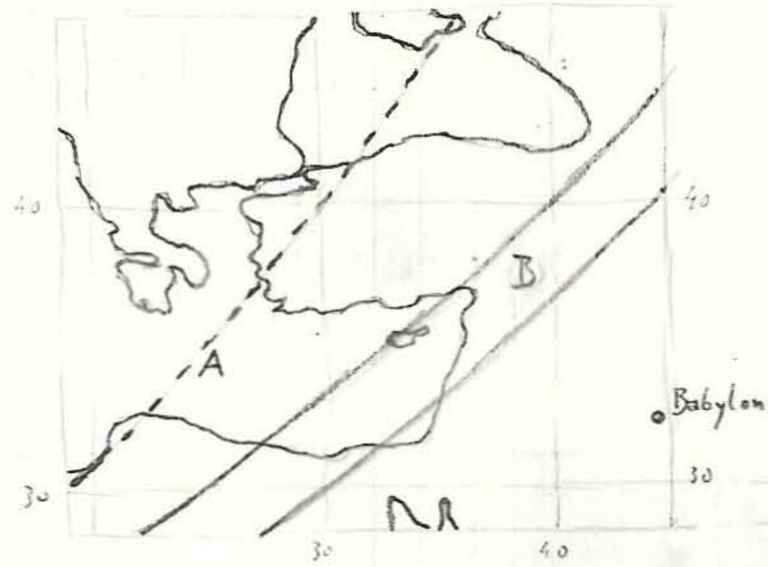
...un S and any part $M_1 M_2$ of the moon's ~~orbital plane ... of the moon~~
... orbit define a plane, identical
...th the plane of the moons orbit, if
...d only if, the ~~sun~~ stands in the
...odal line.

fig. 27

Photographic reproduction of Oppolzer Kanon No. 16

Sun eclipses visible on the northern hemisphere from −890 X to −846 XII according to Oppolzer Kanon Chart No. 16.

fig. 28

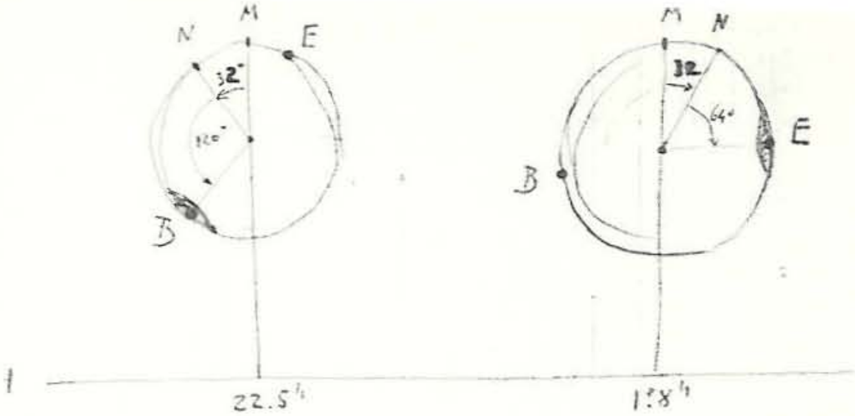


Annular solar eclipse −880 V 1

A approximate central line, B accurate according to the elements in Oppolzer, Kanon.

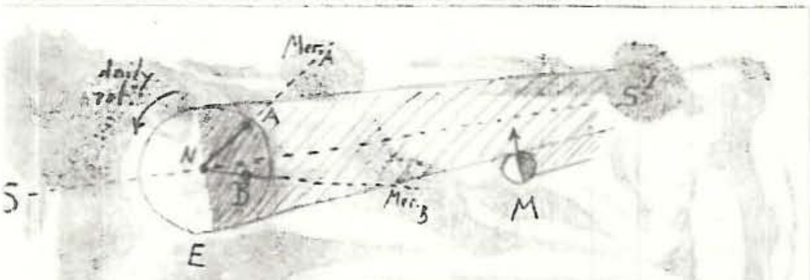
fig. 29

fig. 12



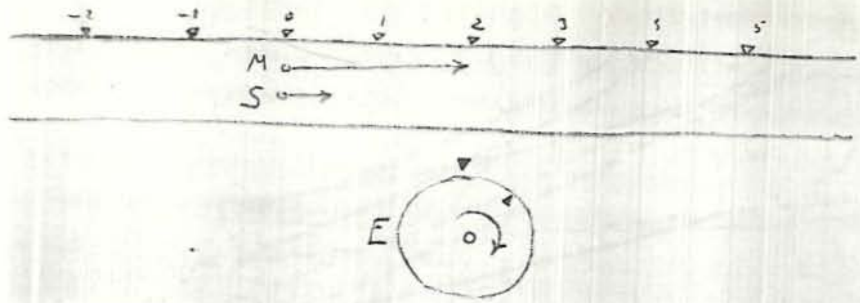
Angles of position of beginning (B) and end (E) of the total lunar eclipse of − 2015 IV 24/25 with reference to the horizon of Babylon (H) and assuming 1.5^h earlier beginning as calculated.

fig. 30



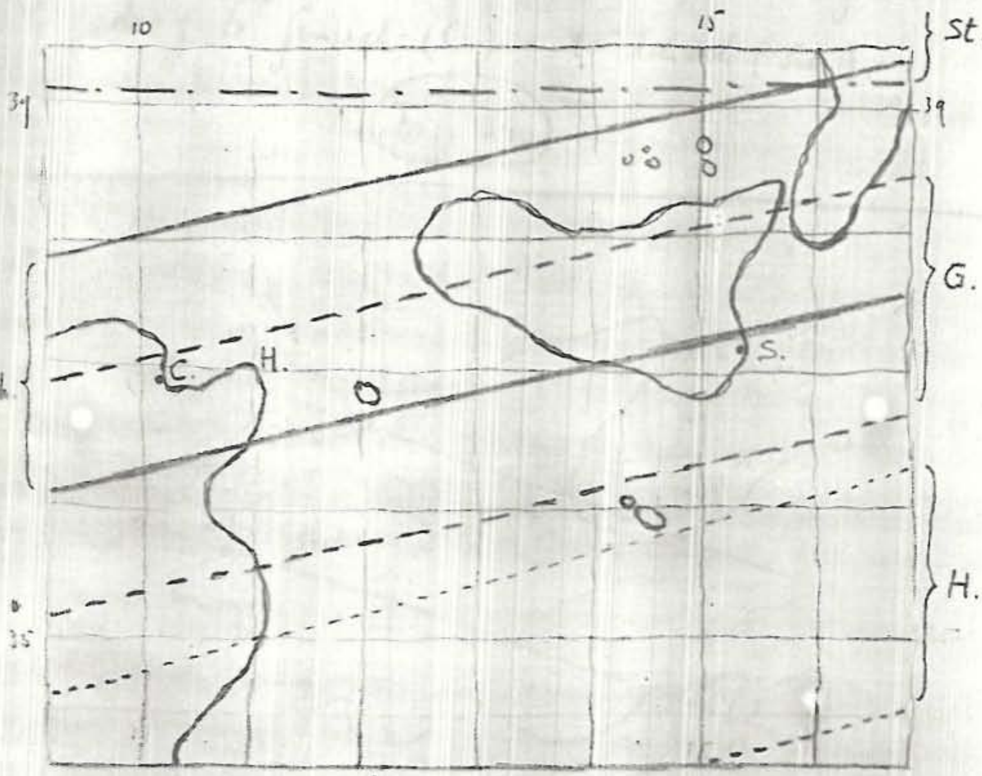
From two places, A and B on the earth E the beginning of a lunar eclipse is seen. For A, however, this moment is 3^h after midnight, for B one hour before, because the angle ANS' is 45°, BNS' 15°.

fig. 31



M and S travel on a road, marked with milestones. Their "velocity" is expressed by an observer on the rotating disc E by counting their mileage during one complete rotation of E. According to this definition their "velocity" of M and S will be called increasing if friction reduces the speed of E.

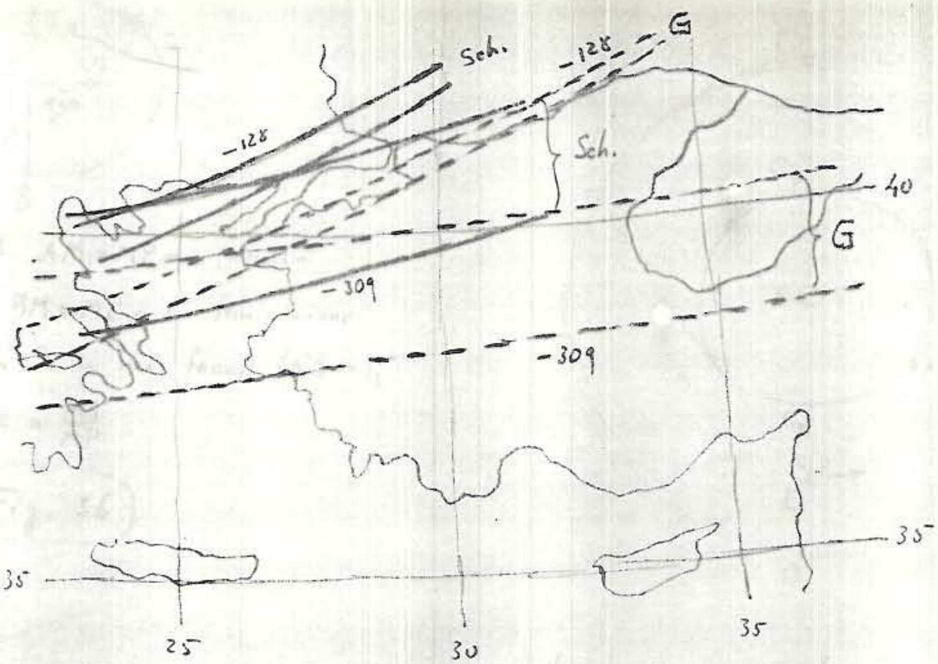
Fig. 32.



Agathocles eclipse (-309 VIII 15) according to Ginzel (G), Hansen (H), Schoch (Sch.) and Stockwell (St.).
[C. = Carthago, H. = Cap Hermaeum, S. = Syracus.]

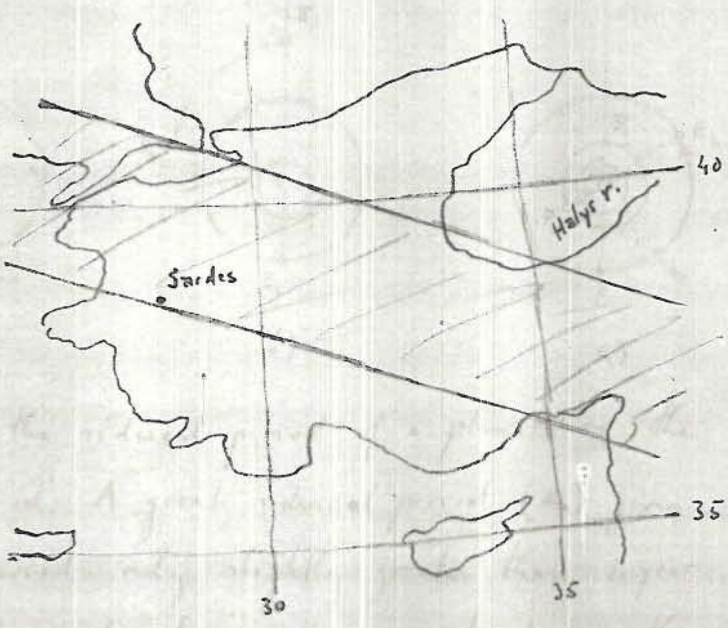
Fig. 33.

fig. 14



The totality of the eclipses −309 VIII 15 and −128 XI 20 in the Bosporus region according to Ginzel (G) and Schoch (Sch.).

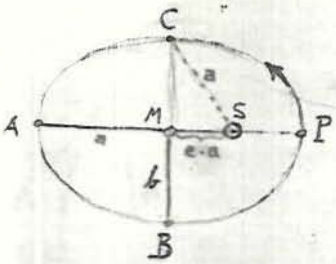
Fig. 34.



Zone of totality of the "Thales-eclipse" (−584 V 28) according to Schoch

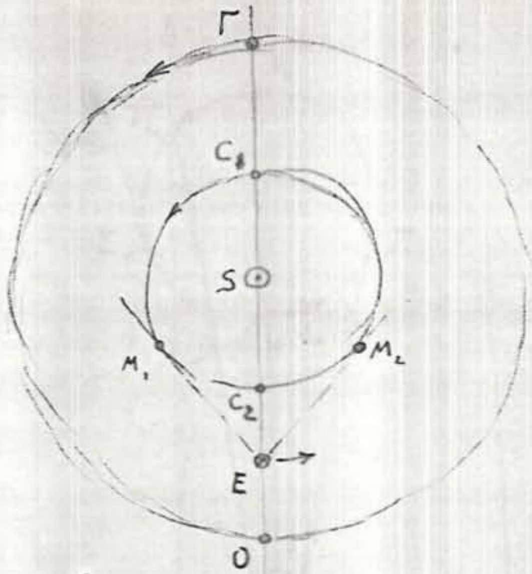
Fig. 35.

fig. (15)



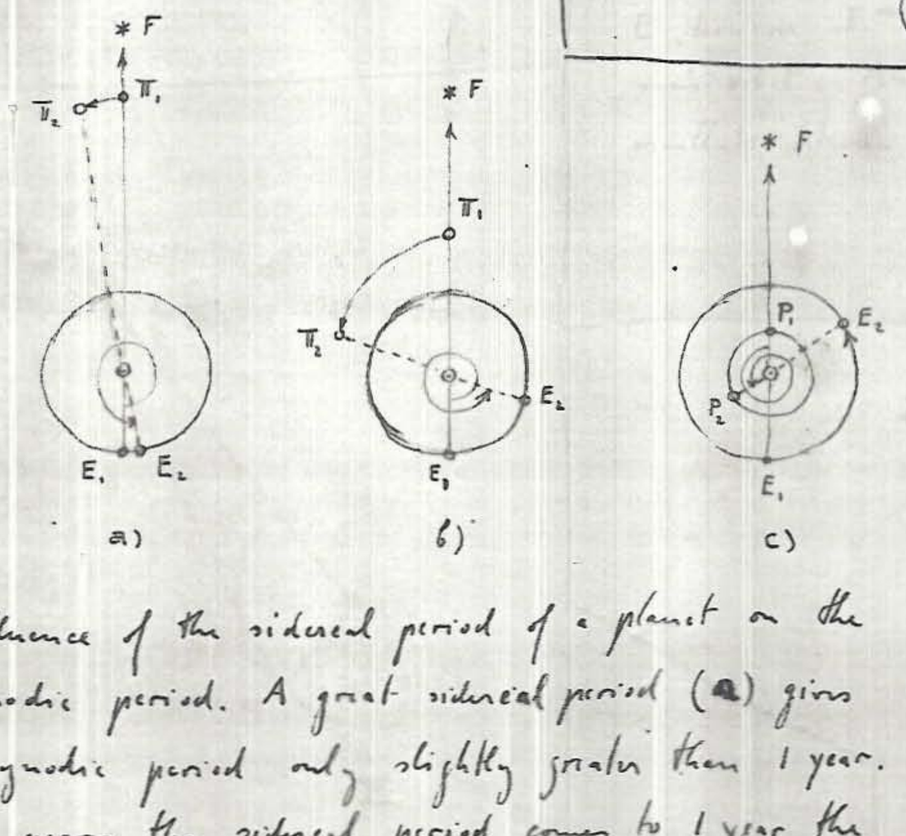
[ell]iptic orbit; AM = MP = a semi-[maj]or-axis, BM = MC = b semi-minor [axis]. The sun S in one focus (CS = a); [ecce]ntricity $e = \frac{MS}{MP}$.

Fig. 36.



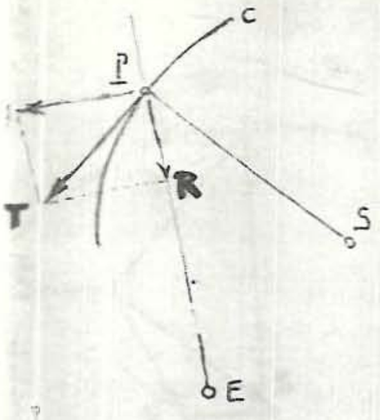
Outer and inner planets; S = sun, E = earth. Γ = conjunction, O = opposition of an outer planet. C_1 = (inferior), C_2 = (superior) conjunction of a inner planet, M_1, M_2 its maximal elongation

Fig. 37.



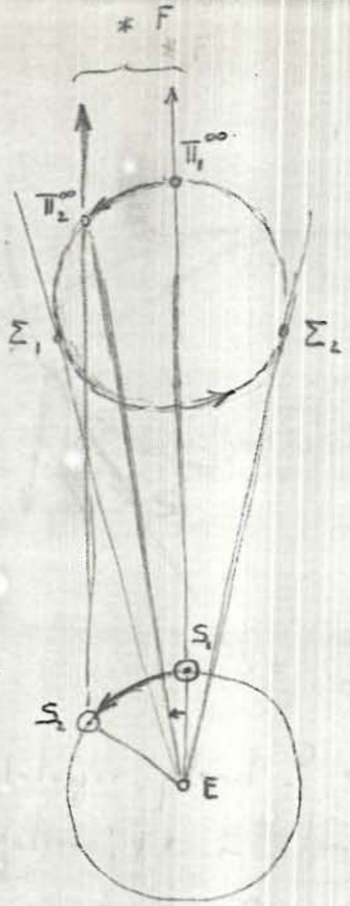
[In]fluence of the sidereal period of a planet on the [sy]nodic period. A great sidereal period (a) gives [a] synodic period only slightly greater than 1 year. [The] nearer the sidereal period comes to 1 year the [gre]ater will the synodic period be (b). [A] small sidereal [pe]riod (c) produces again a short synodic period.

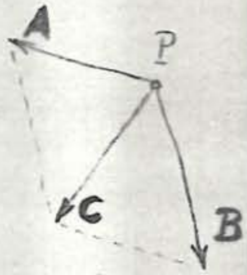
Fig. 38



Motion of a point P on a circular orbit c around S as seen from an observer in E. If **T** represents the momentaneous velocity of P only the component **N** normal to the direction from E to P is visible in E.

Fig. 39.



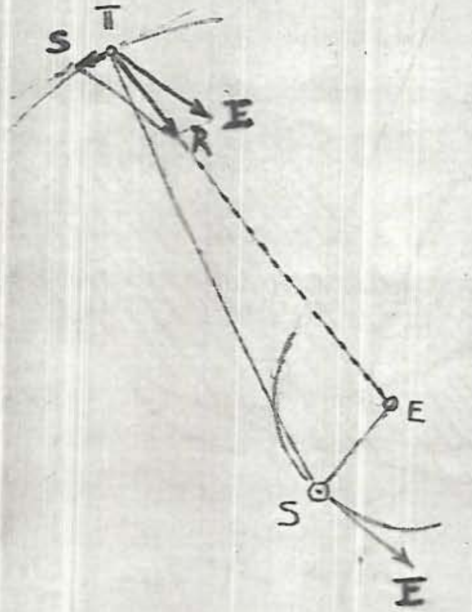


Composition of a vector from two components

Fig. 40

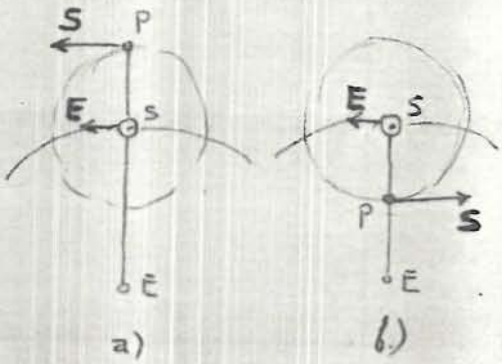
Limiting case of outer planet Π^∞ with no sidereal movement around the sun S. With respect to the earth E, however, Π^∞ describes an orbit congruent to the sun's orbit. An observer in E will therefore see Π^∞ oscillate between to limits Σ_1 and Σ_2.

Fig. 41



Stationary point of an outer planet Π. The resultant **R** of **E** (sun's movement around E) and **S** (Π's movement around the sun) points towards E.

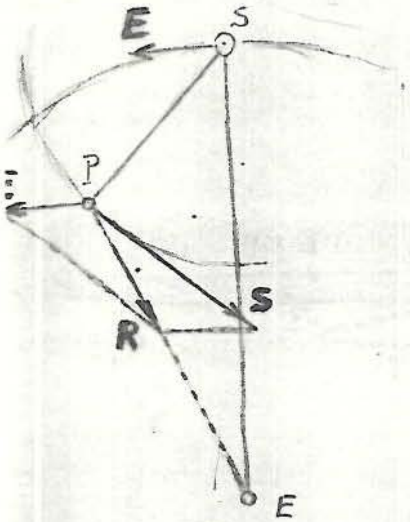
Fig 42



Velocities at superior conjunction (a) and inferior conjunction (b) of an inner planet.

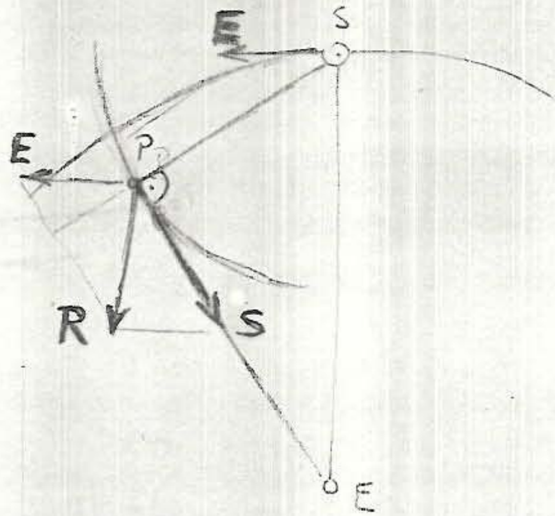
Fig. 43.

fig. (17)



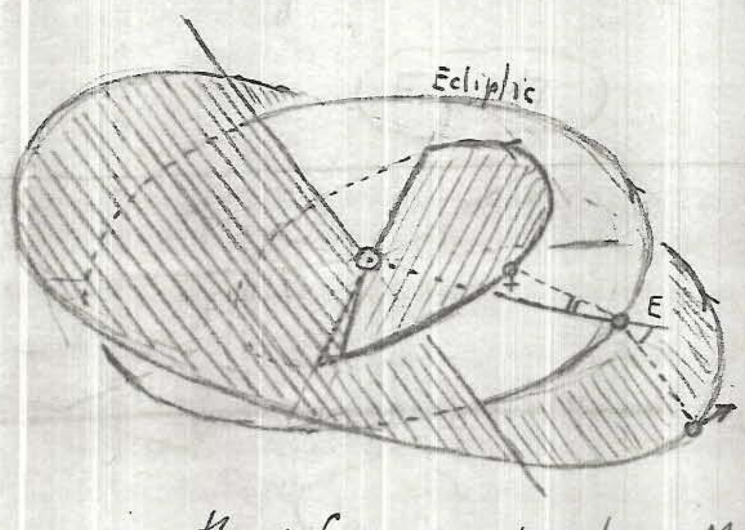
ationary point of an inner
net P. The resultant **R** of **E**
d **S** points towards the earth E.

Fig. 44.



Interior planet P at its maximal elongation, i.e. EP tangential to the orbit around S. The planets movement as seen from E is still direct.

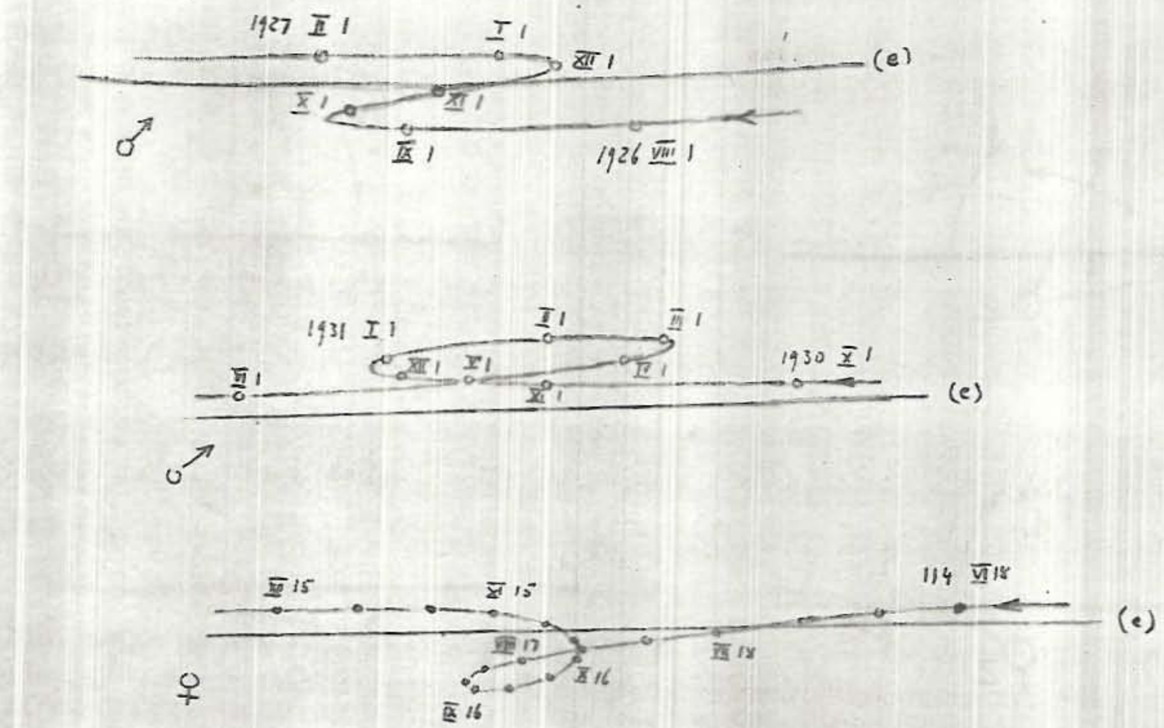
Fig. 45



enus near the inferior conjunction, Mars near
position, therefore both appearing moving retro-
rad, as seen from the earth. The geocentric latitudes
e in this situation especially great

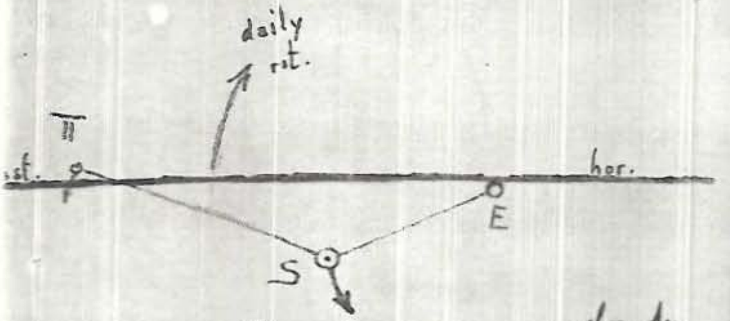
Fig. 46

fig. (18)



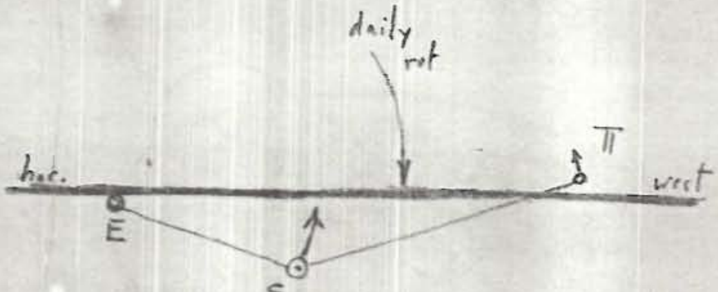
Examples of apparent orbits of planets during their retrograde movement. [(e) = ecliptic].

Fig. 47.



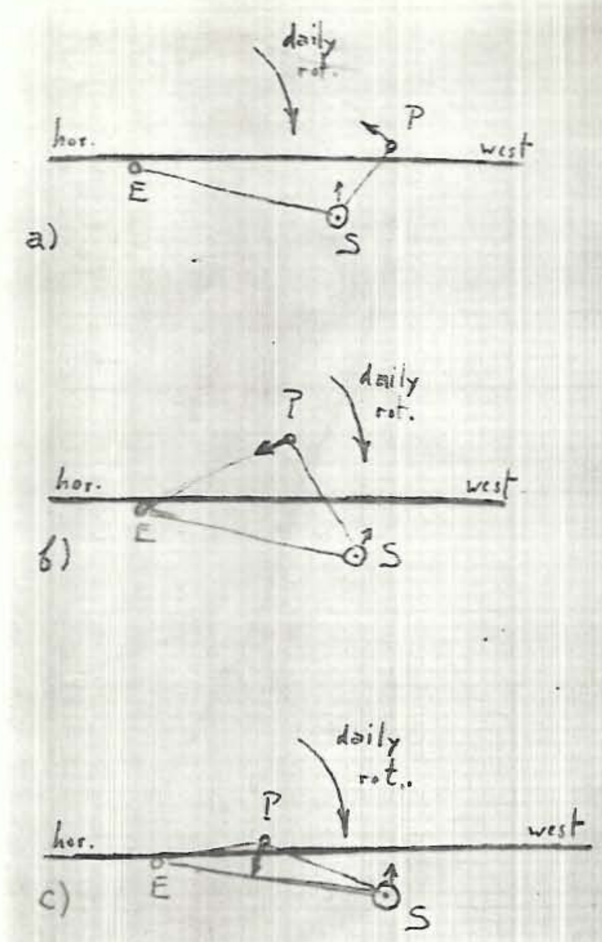
Outer planet Π heliacal rising, i.e. already visible before sunrise in the eastern horizon.

Fig. 48



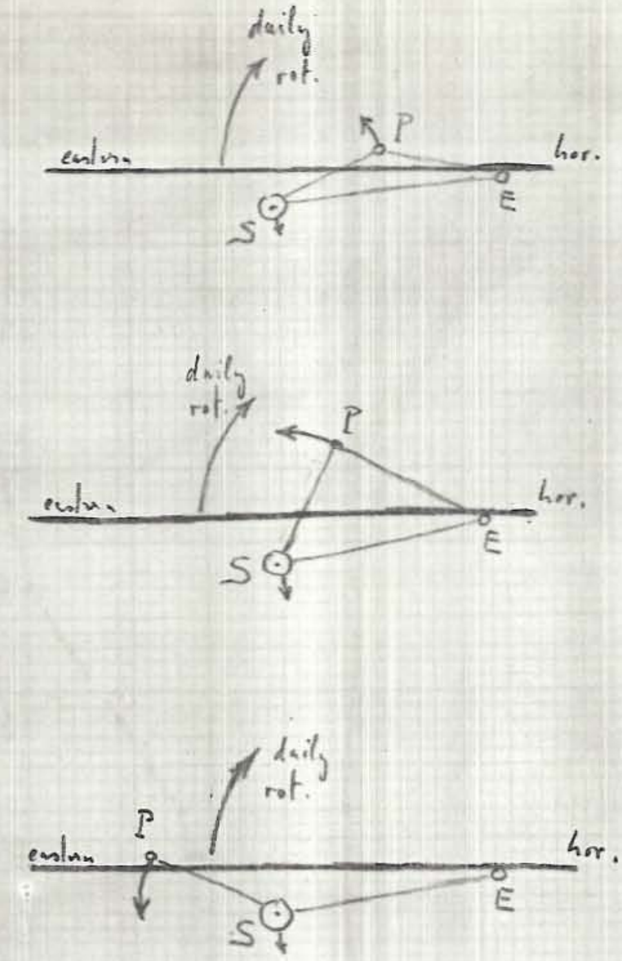
Outer planet Π acronychically setting i.e. still visible ~~before~~ after sunset in the western horizon

Fig. 49



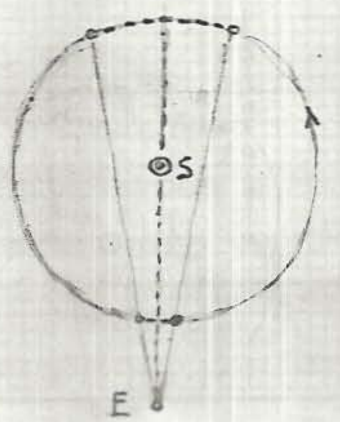
Inner planet as evening star; (a) western rising, (b) maximal elongation, (c) western setting.

Fig. 50



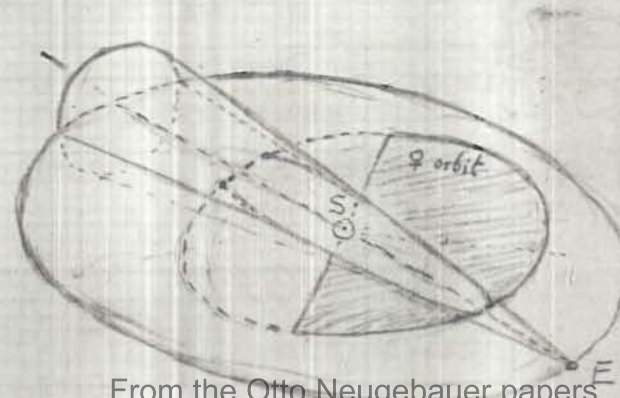
Inner planet as morning star; (a) eastern rising, (b) maximal elongation, (c) eastern setting.

Fig. 51



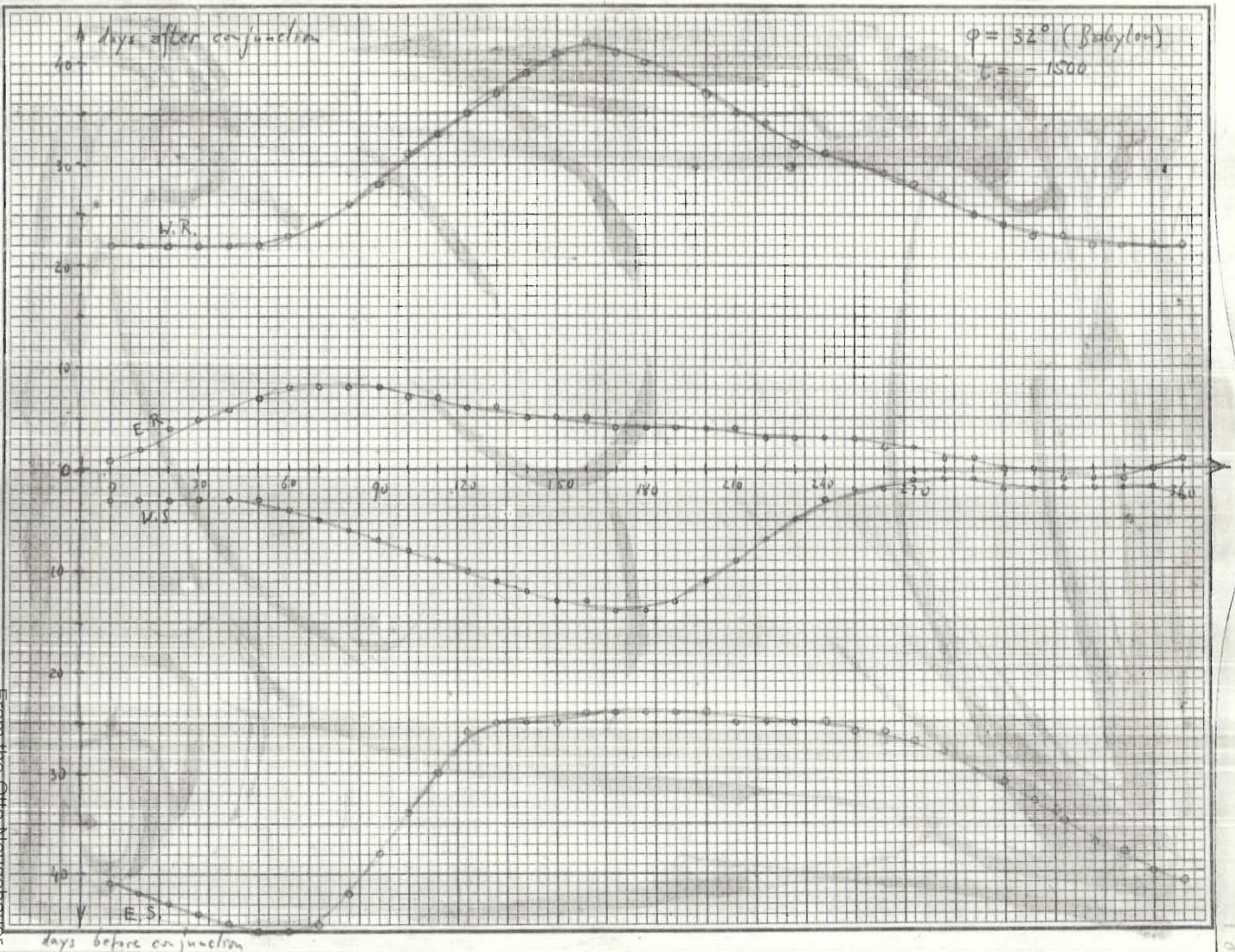
The same elongations limit a much longer arc invisibility around exterior conjunction than near inferior conjunction

Fig. 52



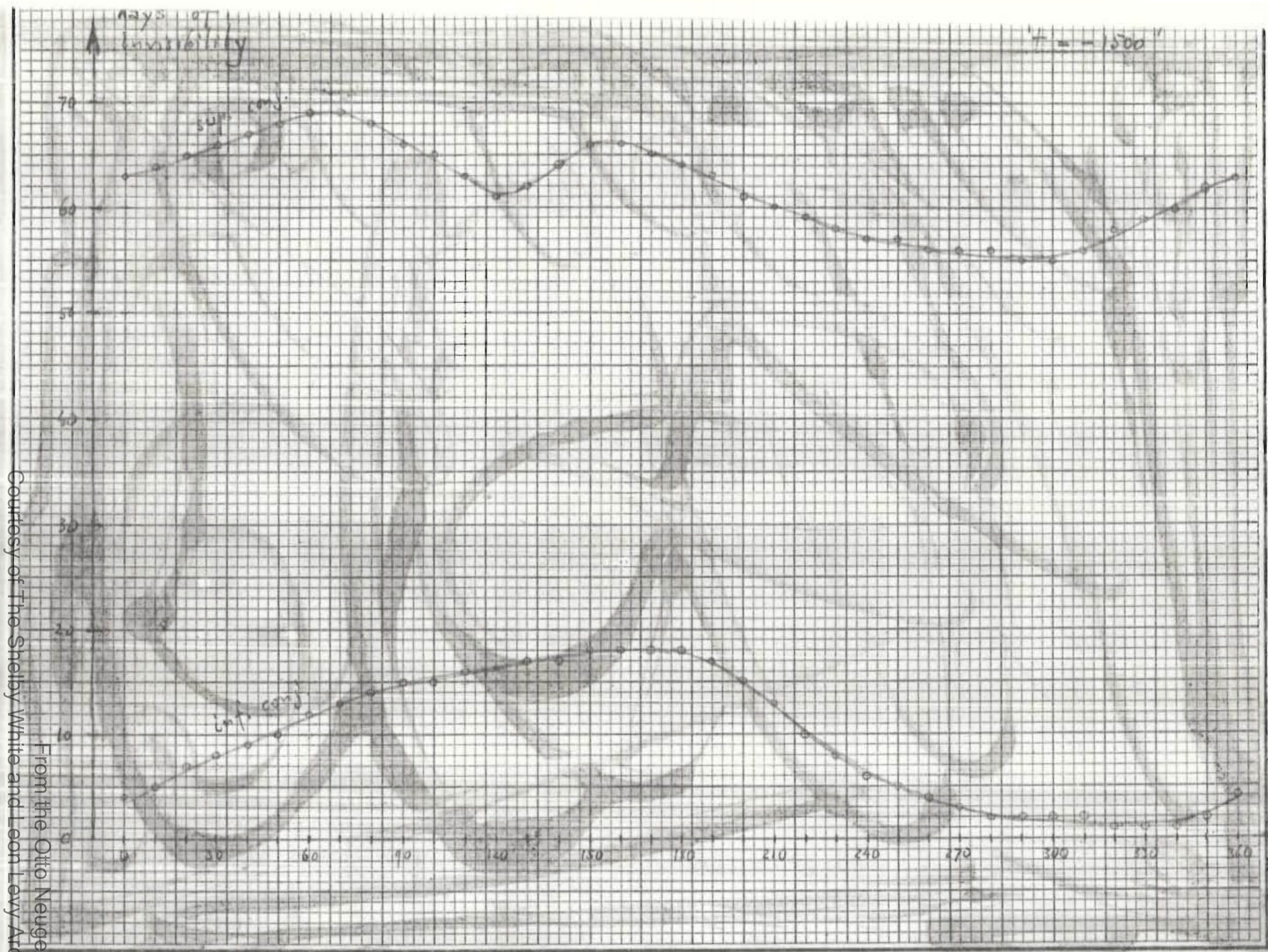
Cone of invisibility for Venus.

Fig. 53.



Appearance and dissappearance of Venus depending upon the seasons, (i.e. $\lambda_\odot$).

Fig. 54.



Duration of invisibility of Venus depending upon the seasons.

Fig. 55

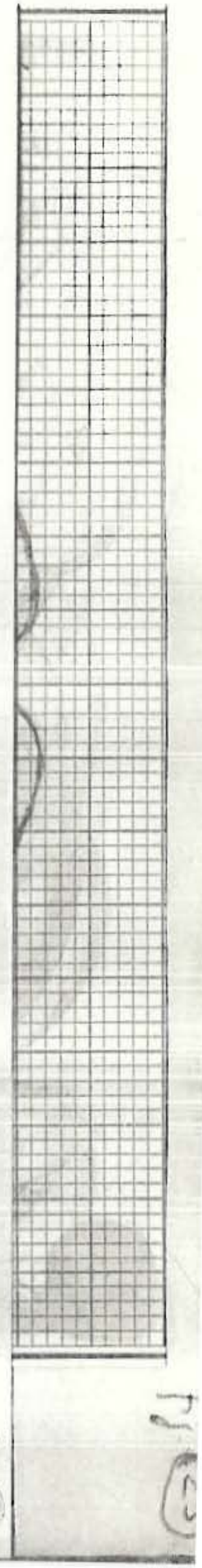
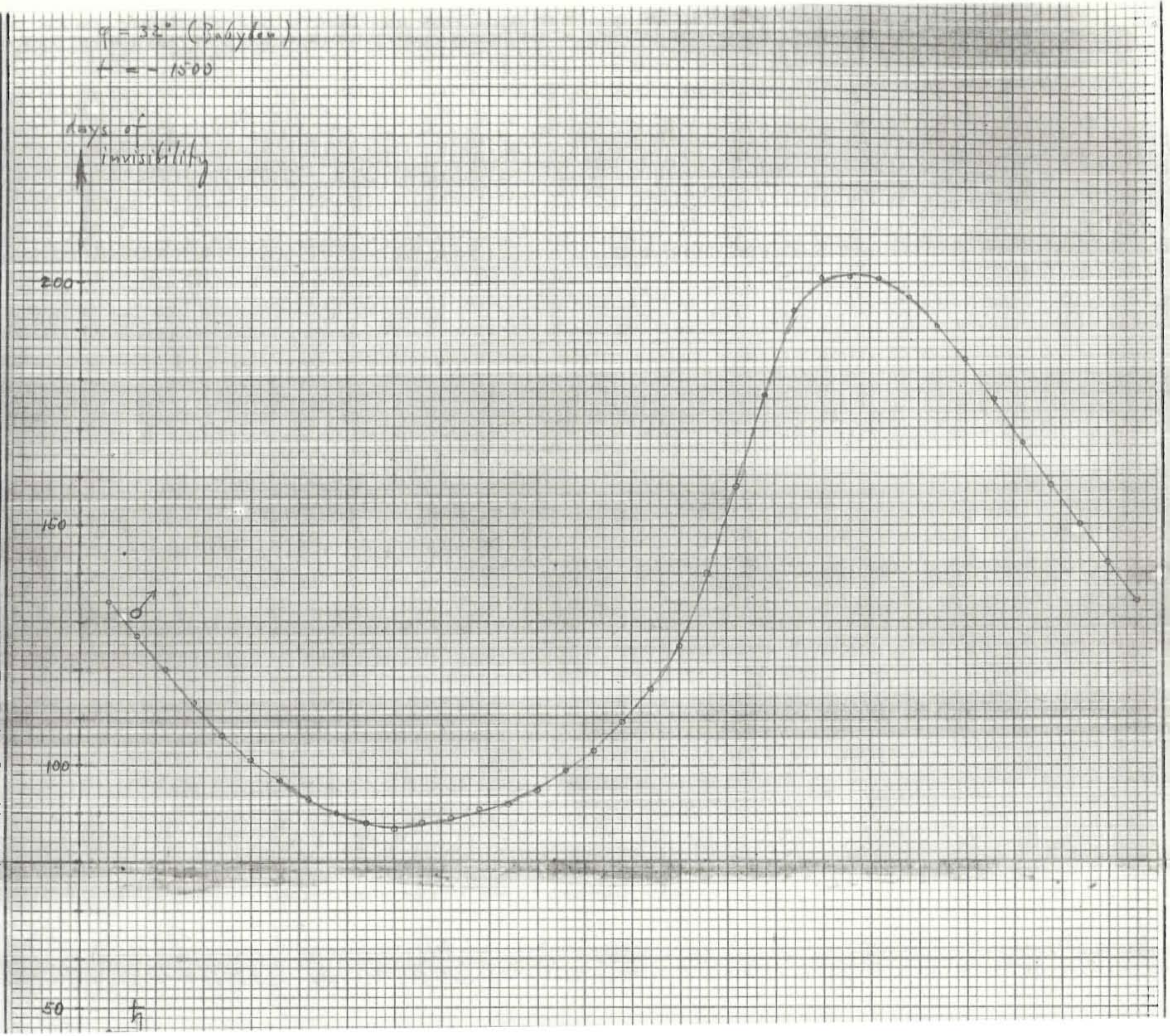
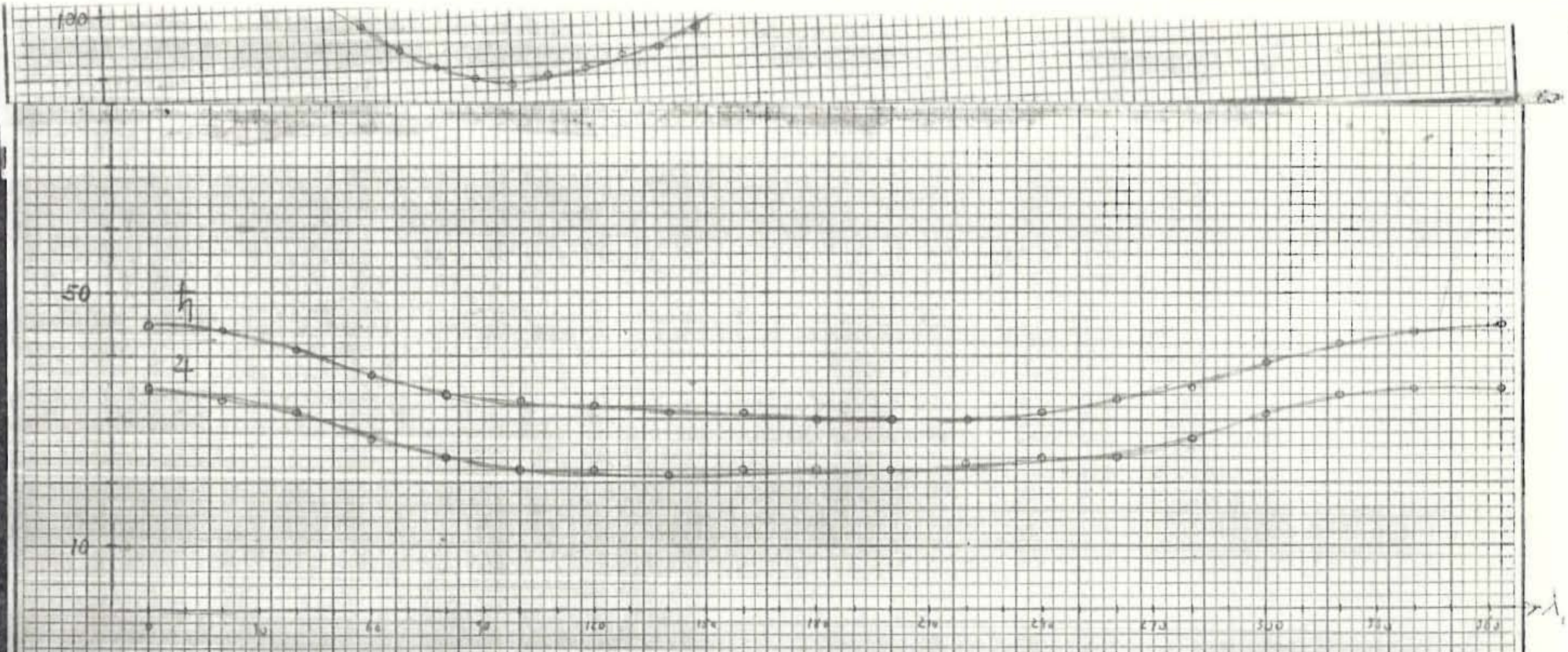


fig. 22

Duration of invisibility of the outer planets
depending upon the season

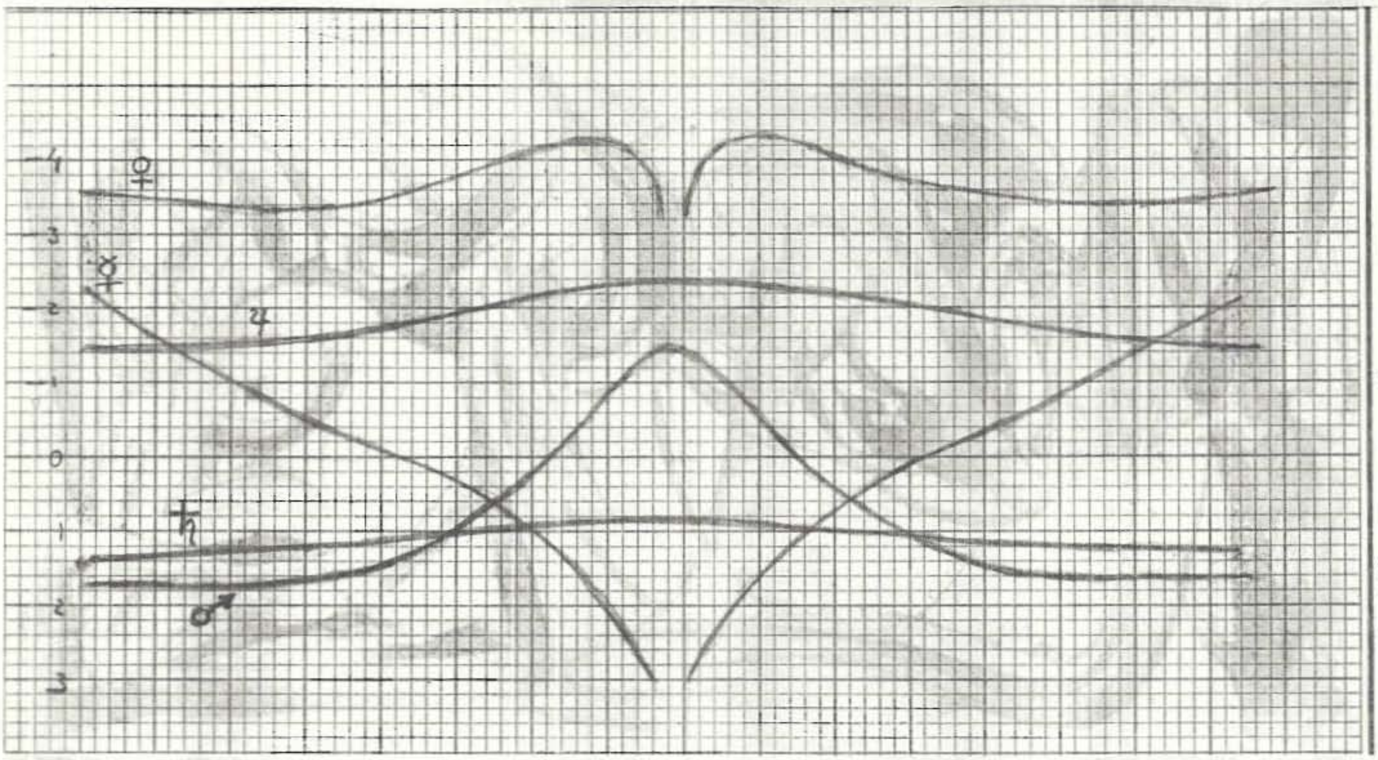
Fig. 56.


φ = 32° (Babylon)
t = −1500
days of invisibility
200
150
100
50
♂
♄



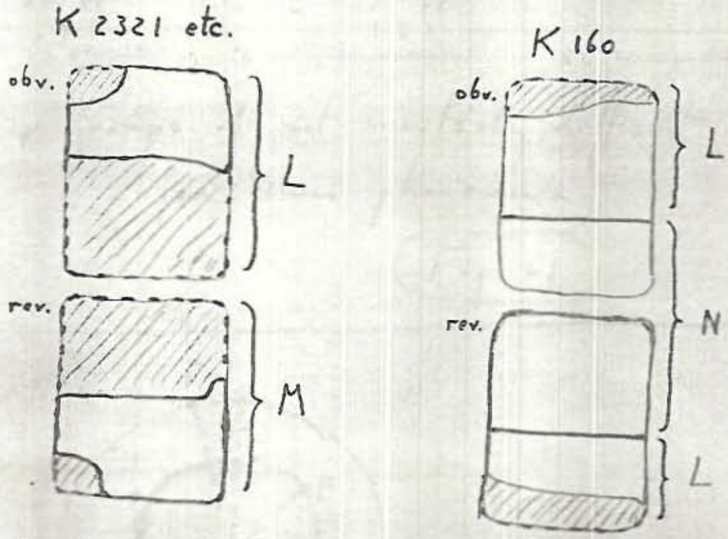
Duration of invisibility of the outer planets
depending upon the season

Fig. 56.



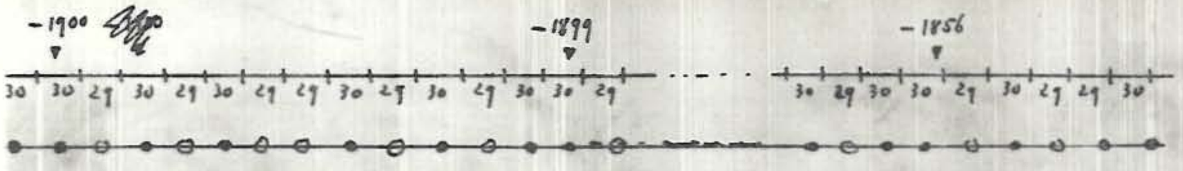
The variation of brightness of the five planets during their synodic period (inferior conjunction and opposition are in the middle of the graphs)

Fig. 57



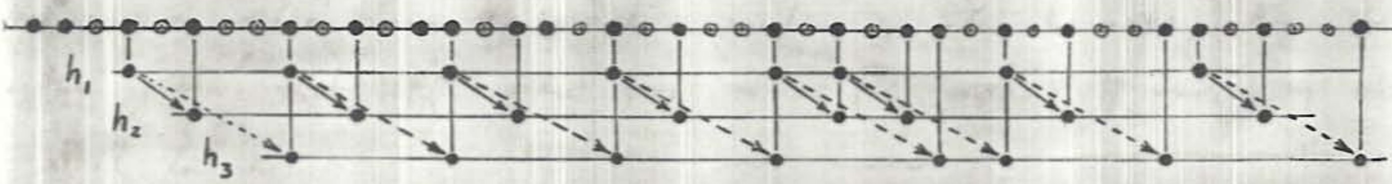
The distribution of the 'documents' on the Venus tablets of Ammizaduga.

Fig. 58.



The calculated sequence of month of 29 or 30 days lengths represented by black and white points

Fig. 59.

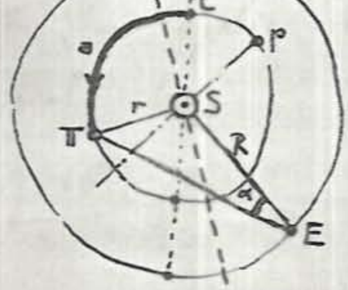


The movement of the sequence h_1 into the positions h_2 and h_3 does not disturb the agreement with T.

Fig. 60

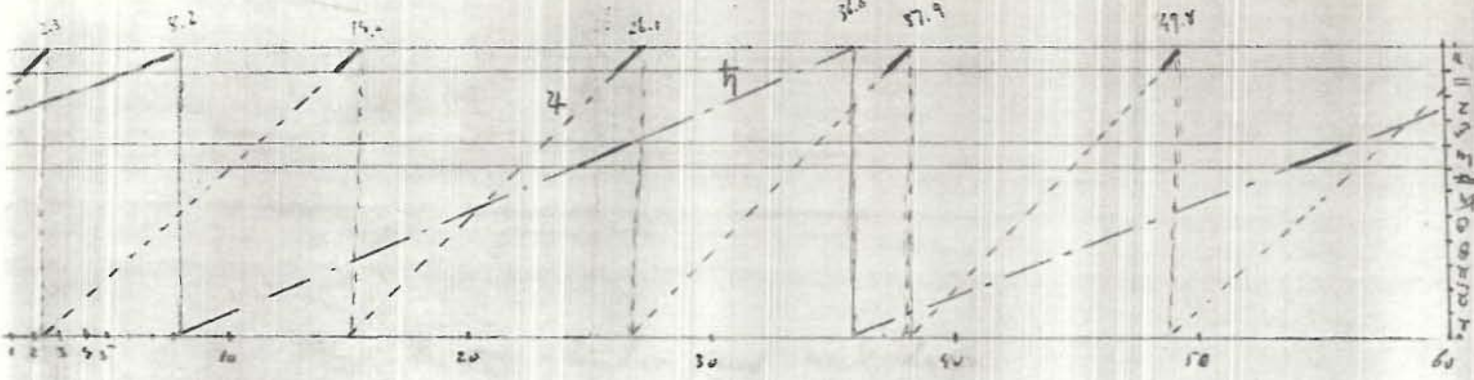
. Groups of not essentialy different chronologies for Venus phenomena

Fig. 61



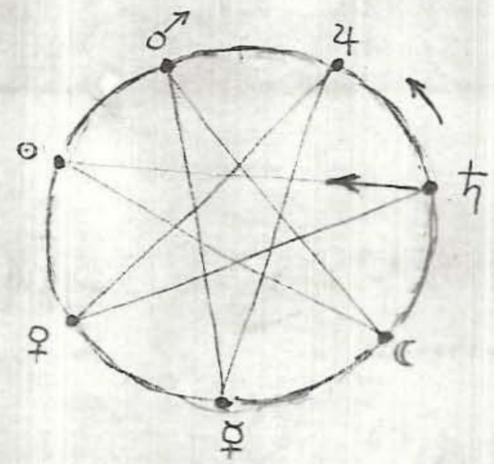
e elongation α of a planet Π is ~~known~~ determined if
e longitudes of the earth E, the planet is known

Fig. 62.



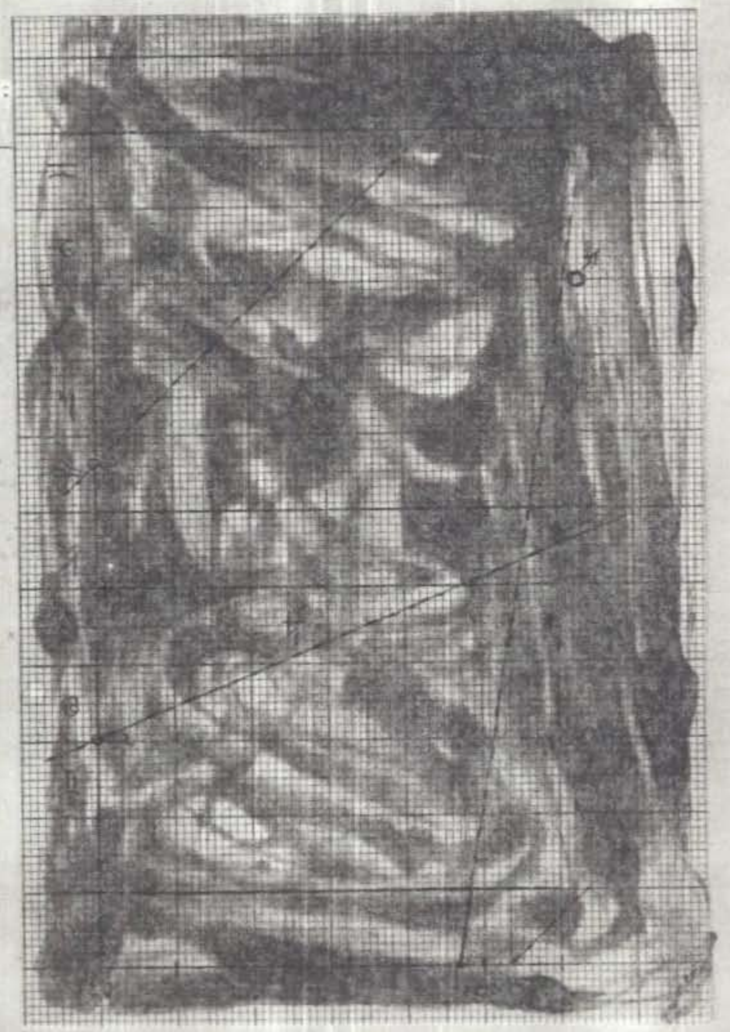
Average movement of ♃ and ♄ during 60 years (in the present example is taken as −600 hence the period in question is −600 to −540). From this iagram follows that only in the year n+25 (i.e. −575) ♄ was in ♍ while stood in ♋.

Fig. 63



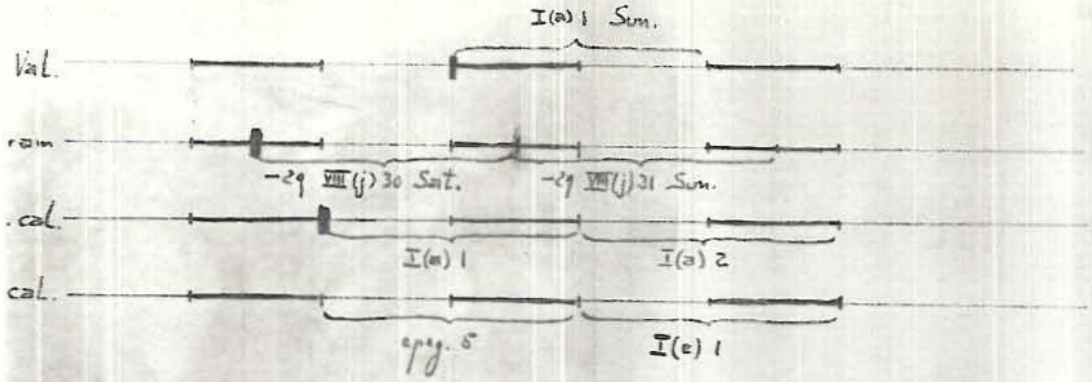
The ruling planet of the week day an be found by omitting alway wo planets in their cyclic arrange-nt in natural order

Fig. 65



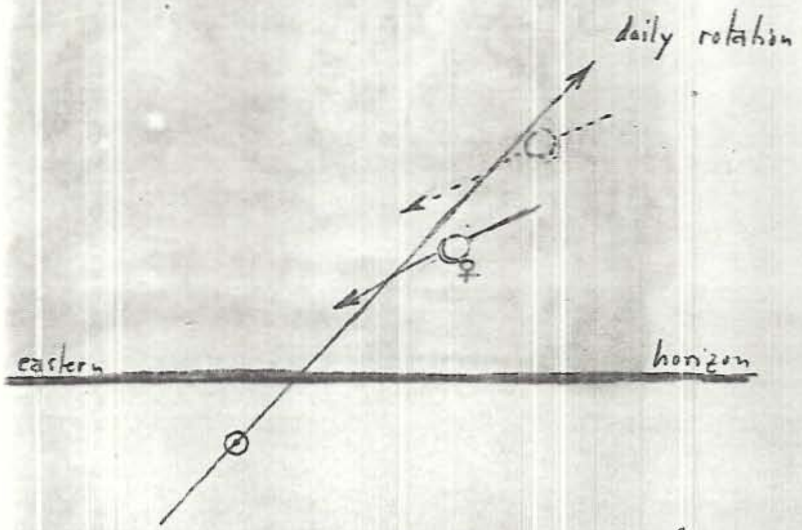
Average movement of the three outer planets from 120 to 136 A.D.

Fig. 64



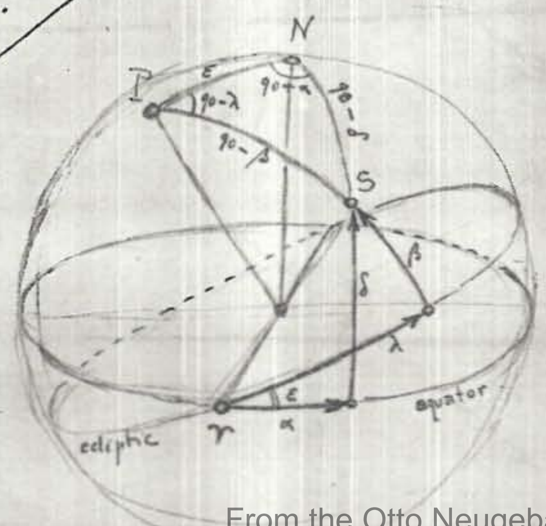
Epoch of the Alexandrian calendar and Week-days
cording to different countings.

Fig. 66



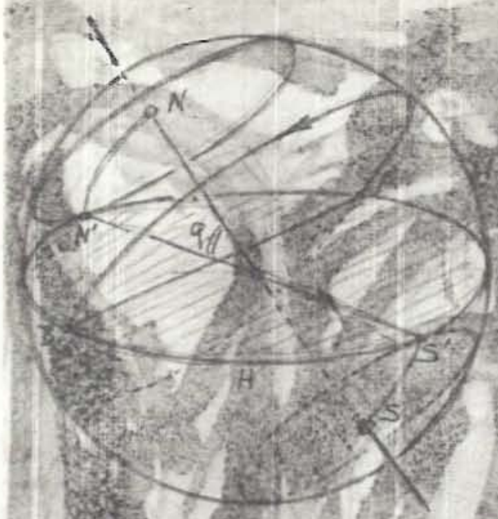
Different elongation of the moon changes
e conditions for an occultation of Venus.

Fig. 67.



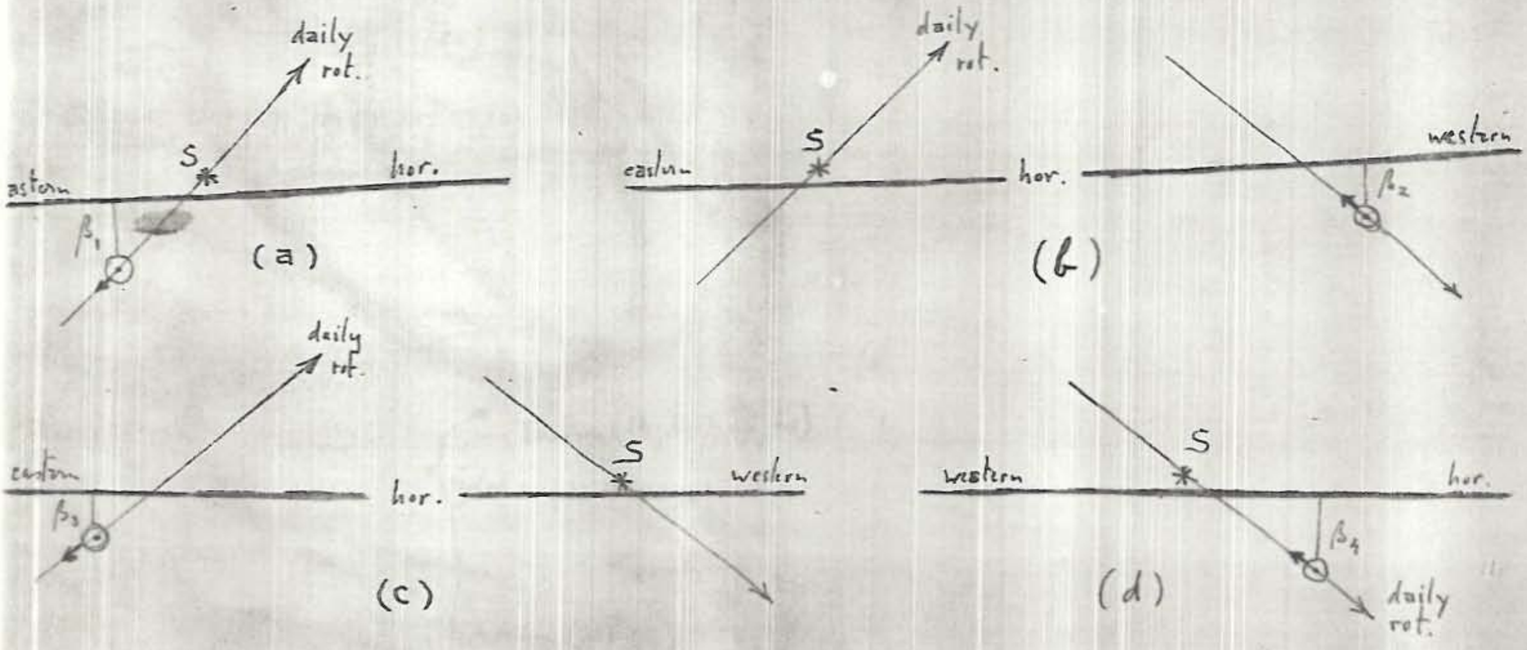
The geocentric spherical coordinates of a star S with reference to the ecliptic are λ and β, with reference to the equator α and δ.

Fig. 68



...represents the horizon of an observer of ...raphical latitude φ, hence NS the ...s of the daily rotation, N'S' the north-...th direction in H. Stars nearer to N ... N' are never setting, stars nearer to ... than S' never visible.

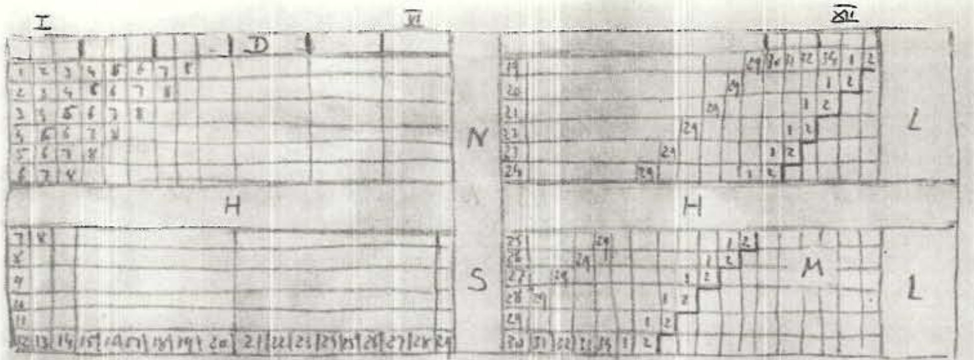
Fig. 69.



Schematic representation of first and last visible rising and setting of a fixed star S in relation to the sun ⊙, beginning with heliacal rising (a). It follows "acronychic rising" (b) and "heliacal setting" (c) until "acronychic setting" (d) precedes a period of total invisibility.

Fig. 70

fig. 28



heme of an Egyptian "Diagonal Calendar". D: List of the 36 decads (I–XII) the 12 months. N–S: Sky-goddess Nut; Great Dipper, Orion, Sirius. H: "Offering-mula invoking the sun and the Meta-Decans. M: Meta-Decans. L: List the decans and meta-decans. 1–34: The Decans (29 = Sirius).

Fig. 71

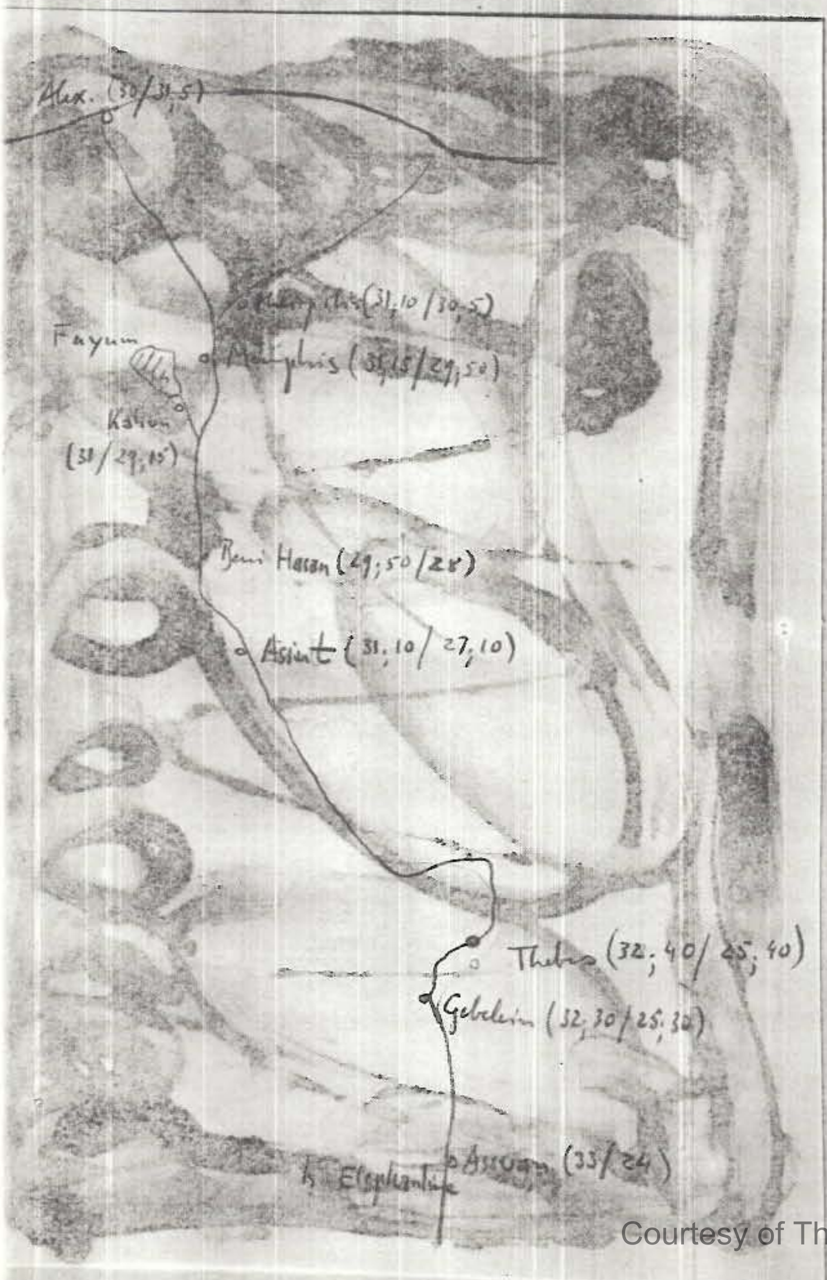
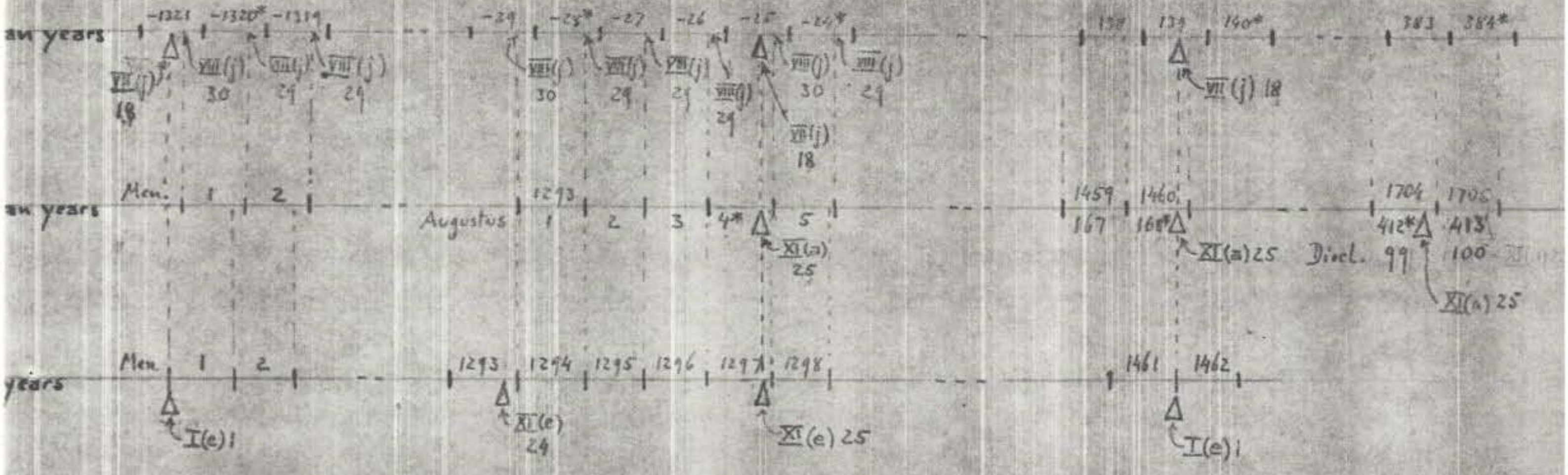


Fig. 72

fig. (29)



Heliacal rise of Sothis (Δ) according to ~~cyclic calculation~~ ~~[illegible]~~ Leap-years are marked by *; the intercalated days are II(j) 29 in the Julian, epag. 6 in the Alexandrian calendar. The first line gives the division of the time axis according to our present day historical counting, the second line the "Era Menophris" in Julian years which coincides with the Alexandrian calendar (beginning with Augustus and continued into the era Diocletianus). The third line represents the "era Menophris" in Egyptian years, beginning with I(e) 1 which is also a date for the rise of Sothis (the first time after epag. 5). ~~This latter assumption, combined with the relation Augustus I I(a) 1 = -29 VIII(j) 30 results in VII(j) 19 as fixed "Sothis date"~~

Fig. 73.

Ahm. J. Pacific

after sunset during the first half of March. It reaches greatest eastern elongation, 18°, on March 9. It is in conjunction with Venus and 5° north of it on March 18. Mercury is at inferior conjunction on March 26 and at greatest western elongation, 27°, on April 23. It should be visible low in the eastern sky just before sunrise during the last half of April.

Venus is separating from the sun in the evening sky, setting a little less than two hours after the sun by the end of April. At that time it is just south of the Pleiades.

Mars passes 3° north of Saturn on March 18; this is the third conjunction of these planets in six months. Mars and Saturn, which are just south of Castor and Pollux, have been a striking display all winter. (For a figure showing the apparent paths and conjunctions of these planets, see *Pub. A.S.P.*, **57**, 305, 1945.) On the evening of April 8 at $22^h\ 39^m$ the moon will be close to Mars. On April 18, Mars is in quadrature with the sun.

Jupiter is in opposition on April 12, rising in the east at sunset and remaining above the horizon all night long. While in retrograde motion, it passes 4° north of Spica on April 19.

Saturn, which is in conjunction with Mars on March 18, is stationary on March 19, then resumes its eastward motion among the stars. It is in quadrature with the sun on April 8.

Uranus is in quadrature on March 4. It will move during March and April from R.A. $4^h\ 48^m$ and Decl. $+22°\ 27'$ to $4^h\ 56^m$ and $+22°\ 41'$.

Neptune is in opposition on March 28. It will move during March and April from R.A. $12^h\ 32^m$ and Decl. $-1°\ 47'$ to $12^h\ 26^m$ and $-1°\ 9'$.

The sun reaches the vernal equinox on March 20 at $21^h\ 33^m$.

⊙₁ — centuries (interpolate years)

day: ordin. year	day: leap year	−1000	−900	−800	−700	−600	−500	−400	−300	−200	−100	0	+100	+200	+300	+400
I 0	I 1*	272°1	272°8	273°5	274°2	274°9	275°6	276°3	277°0	277°7	278°4	279°1	279°9	280°6	281°3	282°0
10	11*	282.2	282.9	283.6	284.3	285.0	285.7	286.4	287.2	287.9	288.6	289.3	290.0	290.7	291.4	292.1
20	21*	292.2	293.0	293.7	294.4	295.1	295.8	296.5	297.3	298.0	298.7	299.4	300.1	300.8	301.5	302.2
30	31*	302.2	303.0	303.7	304.4	305.1	305.8	306.5	307.3	308.0	308.7	309.4	310.2	310.9	311.6	312.3
II 9	II 10*	312.2	313.0	313.7	314.4	315.1	315.8	316.5	317.3	318.0	318.7	319.4	320.2	320.9	321.6	322.3
19	20*	322.1	322.9	323.6	324.3	325.0	325.7	326.4	327.2	327.9	328.7	329.4	330.1	330.8	331.6	332.3
III 1		331.9	332.7	333.4	334.1	334.8	335.6	336.3	337.1	337.8	338.5	339.2	340.0	340.7	341.5	342.3
11		341.7	342.5	343.2	343.9	344.6	345.4	346.2	347.0	347.7	348.4	349.1	349.8	350.5	351.3	352.0
21		351.4	352.2	352.9	353.6	354.3	355.1	355.8	356.6	357.3	358.1	358.8	359.6	0.3	1.1	1.8
31		1.2	2.0	2.6	3.3	4.0	4.8	5.5	6.3	7.0	7.8	8.5	9.3	10.0	10.8	11.5
IV 10		10.7	11.5	12.2	12.9	13.7	14.5	15.2	16.0	16.7	17.5	18.2	19.0	19.7	20.5	21.2
20		20.3	21.1	21.8	22.5	23.3	24.1	24.8	25.6	26.3	27.1	27.8	28.6	29.4	30.2	30.9
30		29.9	30.7	31.4	32.1	32.8	33.6	34.4	35.2	35.9	36.7	37.4	38.2	39.0	39.8	40.5
V 10		39.4	40.2	40.9	41.6	42.4	43.2	44.0	44.8	45.5	46.2	47.0	47.8	48.5	49.3	50.0
20		48.9	49.7	50.4	51.1	51.9	52.7	53.5	54.3	55.0	55.8	56.6	57.4	58.1	58.9	59.6
30		58.5	59.3	60.0	60.7	61.4	62.2	63.0	63.8	64.5	65.3	66.1	66.9	67.6	68.4	69.2
VI 9		68.0	68.8	69.5	70.2	70.9	71.7	72.5	73.3	74.0	74.8	75.6	76.4	77.1	77.9	78.7
19		77.5	78.3	79.0	79.7	80.5	81.3	82.1	82.9	83.6	84.4	85.1	85.9	86.7	87.5	88.2
29		87.1	87.9	88.6	89.3	90.0	90.8	91.6	92.4	93.2	94.0	94.7	95.4	96.2	97.0	97.7
VII 9		96.6	97.4	98.1	98.8	99.6	100.4	101.2	102.0	102.7	103.5	104.2	105.0	105.8	106.6	107.3
19		106.3	107.1	107.8	108.5	109.2	110.0	110.8	111.6	112.3	113.1	113.8	114.6	115.4	116.2	116.9
29		115.9	116.7	117.4	118.1	118.9	119.7	120.4	121.2	121.9	122.7	123.4	124.2	125.0	125.8	126.5
VIII 8		125.7	126.5	127.2	127.9	128.7	129.5	130.2	130.9	131.6	132.4	133.1	133.9	134.7	135.5	136.2
18		135.5	136.3	137.0	137.7	138.4	139.2	139.9	140.6	141.3	142.1	142.9	143.7	144.4	145.2	145.9
28		145.3	146.1	146.8	147.5	148.2	149.0	149.7	150.5	151.2	152.0	152.7	153.4	154.2	155.0	155.7
IX 7		155.2	156.0	156.7	157.4	158.1	158.9	159.6	160.3	161.0	161.8	162.5	163.3	164.0	164.8	165.5
17		165.2	166.0	166.7	167.4	168.1	168.9	169.6	170.3	171.0	171.8	172.5	173.2	173.9	174.7	175.4
27		175.2	176.0	176.7	177.4	178.1	178.9	179.6	180.3	181.0	181.8	182.5	183.2	182.9	184.7	185.4
X 7		185.3	186.0	186.7	187.4	188.1	188.9	189.6	190.3	191.0	191.8	192.5	193.2	193.9	194.7	195.4
17		195.4	196.1	196.8	197.5	198.2	199.0	199.7	200.4	201.1	201.9	202.6	203.3	204.0	204.7	205.4
27		205.6	206.3	207.0	207.7	208.4	209.1	209.8	210.5	211.2	212.0	212.7	213.4	214.1	214.8	215.5
XI 6		215.8	216.5	217.2	217.9	218.6	219.3	220.0	220.7	221.4	222.1	222.8	223.5	224.2	224.9	225.6
16		226.0	226.7	227.4	228.1	228.8	229.5	230.2	230.9	231.6	232.3	233.0	233.7	234.4	235.1	235.8
26		236.2	236.9	237.6	238.3	239.0	239.7	240.4	241.1	241.8	242.5	243.2	243.9	244.6	245.4	246.1
XII 6		246.5	247.1	247.8	248.5	249.2	249.9	250.6	251.3	252.0	252.7	253.4	254.1	254.8	255.6	256.3
16		256.7	257.3	258.0	258.7	259.4	260.1	260.8	261.5	262.2	262.9	263.6	264.3	265.0	265.8	266.5
26		266.8	267.5	268.2	268.9	269.6	270.3	271.0	271.7	272.4	273.1	273.8	274.5	275.2	275.9	276.6
36		277.0	277.6	278.3	279.0	279.7	280.4	281.1	281.9	282.6	283.3	284.0	284.7	285.4	286.1	286.8

⊙₂ — correction for years

0*	0°0	25	0.0	50	−0°1	75	−0.2
1	−0.2	26	−0.3	51	−0.3	76*	+0.6
2	−0.5	27	−0.5	52*	+0.4	77	+0.4
3	−0.7	28*	+0.2	53	+0.2	78	+0.1
4*	0.0	29	0.0	54	−0.1	79	−0.1
5	−0.2	30	−0.3	55	−0.3	80*	+0.6
6	−0.5	31	−0.5	56*	+0.4	81	+0.4
7	−0.7	32*	+0.2	57	+0.2	82	+0.1
8*	+0.1	33	0.0	58	0.0	83	−0.1
9	−0.2	34	−0.2	59	−0.3	84*	+0.6
10	−0.4	35	−0.5	60*	+0.5	85	+0.4
11	−0.7	36*	+0.3	61	+0.2	86	+0.1
12*	+0.1	37	0.0	62	0.0	87	−0.1
13	−0.2	38	−0.2	63	−0.2	88*	+0.7
14	−0.4	39	−0.4	64*	+0.5	89	+0.4
15	−0.6	40*	+0.3	65	+0.2	90	+0.2
16*	+0.1	41	+0.1	66	0.0	91	0.0
17	−0.1	42	−0.2	67	−0.2	92*	+0.7
18	−0.4	43	−0.4	68*	+0.5	93	+0.5
19	−0.6	44*	+0.3	69	+0.2	94	+0.2
20*	+0.1	45	+0.1	70	0.0	95	0.0
21	−0.1	46	−0.1	71	−0.2	96*	+0.7
22	−0.3	47	−0.4	72*	+0.6	97	+0.5
23	−0.6	48*	+0.4	73	+0.3	98	+0.3
24*	+0.2	49	+0.1	74	+0.1	99	0.0

R

$⊙ = ⊙_1 + ⊙_2$

⊙	year −1000	−500	0	+500
0°	516	515	514	513
10	517	516	516	515
20	518	517	517	516
30	519	518	518	517
40	519	518	518	517
50	520	519	519	518
60	520	519	519	519
70	519	519	519	519
80	518	518	519	519
90	518	518	519	519
100	517	517	518	518
110	516	517	518	518
120	515	516	517	517
130	514	515	516	516
140	512	513	514	515
150	511	512	513	514
160	510	511	512	513
170	508	509	510	511
180	507	508	509	510
190	506	507	508	509

⊙	year −1000	−500	0	+500
200°	505	506	507	508
210	505	506	506	507
220	504	505	505	506
230	504	505	505	505
240	504	504	504	504
250	505	504	504	504
260	505	505	505	505
270	506	505	505	505
280	507	506	506	506
290	508	507	507	507
300	509	508	507	507
310	510	509	508	508
320	512	511	510	509
330	513	512	511	510
340	514	513	512	511
350	515	514	513	512
360	516	515	514	513

centuries a_1 m_1

year	Mercury a_1	Mercury m_1	Venus a_1	Venus m_1	Mars a_1	Mars m_1	Jupiter a_1	Jupiter m_1	Saturn a_1	Saturn m_1
−1000	107.6	52.3	124.0	161	691.1	58	270.5	72	215.6	9
− 900	15.3	70.0	445.9	60	559.1	173	98.1	258	65.7	51
− 800	38.8	87.7	183.8	183	427.1	287	324.7	11	293.8	94
− 700	62.4	17.4	505.6	82	295.1	401	152.3	197	143.9	28
− 600	86.0	35.1	243.6	205	163.0	515	378.8	384	372.1	71
− 500	109.6	52.8	565.4	104	31.0	629	206.5	137	222.1	5
− 400	17.3	70.5	303.4	3	679.0	57	34.2	323	72.2	48
− 300	40.8	0.2	41.3	126	546.9	171	260.7	76	300.4	90
− 200	64.4	17.9	363.2	25	414.9	285	88.3	262	150.4	25
− 100	88.0	35.6	101.1	148	282.9	399	314.9	15	0.5	67
0	111.6	53.3	423.0	47	150.9	514	142.5	201	228.6	2
+ 100	19.3	71.0	160.9	171	18.9	628	369.0	388	78.7	44
+ 200	42.8	0.8	482.8	69	666.8	55	196.7	140	306.9	86
+ 300	66.4	18.5	220.7	193	534.8	169	24.4	327	157.0	21
+ 400	90.0	36.2	542.6	92	402.8	283	250.9	80	7.1	64

years a_2 m_2

* leap year

year	Mercury a_2	Mercury m_2	Venus a_2	Venus m_2	Mars a_2	Mars m_2	Jupiter a_2	Jupiter m_2	Saturn a_2	Saturn m_2
0*	0.0	0.0	0.0	0	0.0	0	0.0	0	0.0	0
1	17.4	13.1	365.0	140	365.0	365	365.0	36	365.0	4
2	34.7	26.2	146.1	56	730.0	43	331.1	73	351.9	7
3	52.1	39.4	511.1	196	315.1	408	297.2	109	338.8	11
4*	70.5	53.5	293.2	113	681.1	87	264.4	146	326.7	15
5	87.8	66.6	74.2	28	266.1	452	230.5	183	313.6	18
6	105.2	79.7	439.2	169	631.1	130	196.6	219	300.5	22
7	6.7	4.9	220.3	84	216.2	495	162.7	256	287.4	26
8*	25.1	19.0	2.4	1	582.2	174	129.8	292	275.4	29
9	42.4	32.1	367.4	141	167.2	539	95.9	329	262.3	33
10	59.8	45.2	148.5	57	532.2	217	62.0	365	249.2	37
11	77.2	58.4	513.5	197	117.3	582	28.2	402	236.1	40
12*	95.5	72.5	295.6	114	483.3	261	394.2	5	224.0	44
13	112.9	85.6	76.6	29	68.4	626	360.3	41	210.9	47
14	14.4	10.8	441.6	170	433.4	304	326.4	78	197.8	51
15	31.8	23.9	222.7	85	18.4	669	292.5	114	184.7	55
16*	50.1	38.0	4.8	2	384.4	348	259.6	151	172.6	58
17	67.5	51.1	369.8	142	749.4	26	225.7	188	159.5	62
18	84.9	64.3	150.9	58	334.5	391	191.9	224	146.4	66
19	102.2	77.4	515.9	198	699.5	69	158.0	261	133.3	69
20*	4.7	3.5	298.0	115	285.6	435	125.1	297	121.2	73
21	22.1	16.7	79.0	30	650.6	113	91.2	334	108.2	77
22	39.5	29.8	444.0	170	235.6	478	57.3	370	95.1	80
23	56.8	42.9	225.1	86	600.6	156	23.4	407	82.0	84
24*	75.2	57.0	7.2	3	186.7	522	389.4	10	69.9	88
25	92.6	70.2	372.2	143	551.7	200	355.6	46	56.8	91
26	109.9	83.3	153.3	59	136.8	565	321.7	83	43.7	95
27	11.4	8.4	518.3	199	501.8	243	287.8	119	30.6	99
28*	29.8	22.6	300.4	116	87.8	609	254.9	156	18.5	102
29	47.2	35.7	81.4	31	452.8	287	221.0	193	5.4	106
30	64.5	48.8	446.4	171	37.9	652	187.1	229	370.4	2
31	81.9	61.9	227.5	87	402.9	330	153.3	266	357.3	6
32*	100.3	76.0	9.6	4	768.9	9	120.4	302	345.2	9
33	1.8	1.2	374.6	144	354.0	374	86.5	339	332.2	13
34	19.1	14.3	155.7	60	719.0	52	52.6	375	319.1	17
35	36.5	27.4	520.7	200	304.0	417	18.7	412	306.0	20
36*	54.8	41.6	302.8	116	670.0	96	384.7	15	293.9	24
37	72.2	54.7	83.8	32	255.1	461	350.8	51	280.8	27
38	89.6	67.8	448.8	172	620.1	139	316.9	88	267.7	31
39	107.0	80.9	229.9	88	205.1	504	283.1	124	254.6	35
40*	9.4	7.1	12.0	4	571.2	183	250.2	161	242.5	38
41	26.8	20.2	377.0	145	156.2	548	216.3	198	229.4	42
42	44.2	33.3	158.1	60	521.2	226	182.4	234	216.3	46
43	61.6	46.4	523.1	201	106.3	591	148.5	271	203.2	49
44*	79.9	60.6	305.1	117	472.3	270	115.6	307	191.1	53
45	97.3	73.7	86.2	33	57.3	635	81.8	344	178.0	57
46	114.7	86.8	451.2	173	422.3	313	47.9	380	165.0	60
47	16.2	12.0	232.3	89	7.4	678	14.0	417	151.9	64
48*	34.5	26.1	14.4	5	373.4	357	380.0	20	139.8	68
49	51.9	39.2	379.4	146	738.4	38	346.1	56	126.7	71

year	Mercury a_2	Mercury m_2	Venus a_2	Venus m_2	Mars a_2	Mars m_2	Jupiter a_2	Jupiter m_2	Saturn a_2	Saturn m_2
50	69.2	52.3	160.5	61	323.5	400	312.2	93	113.6	75
51	86.6	65.4	525.5	202	688.5	78	278.3	130	100.5	79
52*	105.0	79.6	307.5	118	274.5	444	245.4	166	88.4	82
53	6.5	4.7	88.6	34	639.5	122	211.6	203	75.3	86
54	23.8	17.8	453.6	174	224.6	487	177.7	239	62.2	90
55	41.2	31.0	234.7	90	589.6	165	143.8	276	49.1	93
56*	59.6	45.1	16.8	6	175.7	531	110.9	312	37.0	97
57	76.9	58.2	381.8	147	540.7	209	77.0	349	23.9	101
58	94.3	71.3	162.9	62	125.7	574	43.1	385	10.8	104
59	111.7	84.5	527.9	202	490.7	252	9.2	422	375.8	0
60*	14.2	10.6	309.9	119	76.8	618	375.2	25	363.8	4
61	31.5	23.7	91.0	35	441.8	296	341.4	62	350.7	8
62	48.9	36.9	456.0	175	26.8	661	307.5	98	337.6	11
63	66.3	50.0	237.1	91	391.8	339	273.6	135	324.5	15
64*	84.6	64.1	19.2	7	757.9	18	240.7	171	312.4	18
65	102.0	77.2	384.2	148	342.9	383	206.8	208	299.3	22
66	3.5	2.4	165.3	63	707.9	61	173.0	244	286.2	26
67	20.9	15.5	530.3	203	293.0	426	139.1	281	273.1	29
68*	39.2	29.6	312.3	120	659.0	105	106.2	317	261.0	33
69	56.6	42.8	93.4	36	244.0	470	72.3	354	247.9	37
70	74.0	55.9	458.4	176	609.0	148	38.4	390	234.8	40
71	91.3	69.0	239.5	92	194.1	513	4.5	427	221.8	44
72*	109.7	83.1	21.6	8	560.1	192	370.5	30	209.7	48
73	11.2	8.3	386.6	148	145.2	557	336.6	67	196.6	51
74	28.6	21.4	167.7	64	510.2	235	302.8	103	183.5	55
75	45.9	34.5	532.7	204	95.2	600	268.9	140	170.4	59
76*	64.3	48.6	314.7	121	461.2	279	236.0	176	158.3	62
77	81.7	61.8	95.8	36	46.3	644	202.1	213	145.2	66
78	99.0	74.9	460.8	177	411.3	322	168.2	249	132.1	70
79	0.5	0.0	241.9	92	776.3	0	134.4	286	119.0	73
80*	18.9	14.2	24.0	9	362.4	366	101.5	322	106.9	77
81	36.3	27.3	389.0	149	727.4	44	67.6	359	93.8	81
82	53.6	40.4	170.0	65	312.4	409	33.7	395	80.7	84
83	71.0	53.5	535.0	205	677.4	87	398.7	432	67.6	88
84*	89.4	67.6	317.1	122	263.5	453	365.8	35	55.5	92
85	106.7	80.8	98.2	37	628.5	131	331.9	72	42.5	95
86	8.2	5.9	463.2	178	213.6	496	298.0	108	29.4	99
87	25.6	19.0	244.3	93	578.6	174	264.2	145	16.3	102
88*	44.0	33.2	26.4	10	164.6	540	231.3	181	4.2	106
89	61.3	46.3	391.4	150	529.6	218	197.4	218	369.2	2
90	78.8	59.4	172.4	66	114.7	583	163.5	254	356.1	6
91	96.1	72.5	537.4	206	479.7	261	129.6	291	343.0	9
92*	114.4	86.7	319.5	123	65.8	627	96.7	327	330.9	13
93	15.9	11.8	[illegible]	38	430.8	305	[illegible]	364	317.8	17
94	[illegible]	24.9	465.6	179	15.8	670	29.0	400	304.7	20
95	50.6	38.0	246.7	94	[illegible]	[illegible]	[illegible]	3	[illegible]	24
96*	69.0	52.2	28.8	11	746.8	27	361.1	40	279.5	28
97	86.4	65.3	393.8	151	331.9	392	[illegible]	77	[illegible]	31
98	103.8	78.4	174.8	67	696.9	70	293.3	113	253.4	35
99	5.2	3.6	539.8	207	281.9	435	259.4	150	240.3	39

days a_3 m_3

day: ordin. year	day: leap year	Mercury Venus Mars a_3	Mercury Venus Mars m_3	Jupiter a_3	Jupiter m_3	Saturn a_3	Saturn m_3
I 0	1	$0^d.0$	0^d	$0^d.0$	0^d	$0^d.0$	0^d
10	11	10.0	10	10.0	1	10.0	0
20	21	20.0	20	20.0	2	20.0	0
30	31	30.0	30	30.0	3	30.0	0
II 9	10	40.0	40	40.0	4	40.0	0
19	20	50.0	50	50.0	5	50.0	1
III 1		60.0	60	60.0	6	60.0	1
11		70.0	70	70.0	7	70.0	1
21		80.0	80	80.0	8	80.0	1
31		90.0	90	90.0	9	90.0	1
IV 10		100.0	100	100.0	10	100.0	1
20		110.0	110	110.0	11	110.0	1
30		120.0	120	120.0	12	120.0	1
V 10		130.0	130	130.0	13	130.0	1
20		140.0	140	140.0	14	140.0	1
30		150.0	150	150.0	15	150.0	2
VI 9		160.0	160	160.0	16	160.0	2
19		170.0	170	170.0	17	170.0	2
29		180.0	180	180.0	18	180.0	2
VII 9		190.0	190	190.0	19	190.0	2
19		200.0	200	200.0	20	200.0	2
29		210.0	210	210.0	21	210.0	2
VIII 8		220.0	220	220.0	22	220.0	2
18		230.0	230	230.0	23	230.0	2
28		240.0	240	240.0	24	240.0	2
IX 7		250.0	250	250.0	25	250.0	3
17		260.0	260	260.0	26	260.0	3
27		270.0	270	270.0	27	270.0	3
X 7		280.0	280	280.0	28	280.0	3
17		290.0	290	290.0	29	290.0	3
27		300.0	300	300.0	30	300.0	3
XI 6		310.0	310	310.0	31	310.0	3
16		320.0	320	320.0	32	320.0	3
26		330.0	330	330.0	33	330.0	3
XII 6		340.0	340	340.0	34	340.0	3
16		350.0	350	350.0	35	350.0	4
26		360.0	360	360.0	36	360.0	4
36		370.0	370	370.0	37	370.0	4

a_4 r

Mercury m	Mercury a_4	Mercury r	Mercury m	Mercury a_4	Mercury r	Venus m	Venus a_4	Venus r
0^d	$0^d.0$	0	44^d	$0^d.0$	181	0^d	$0^d.0$	367
1	+0.7	1	45	−0.5	180	5	+0.2	367
2	+1.4	2	46	−0.9	180	10	+0.4	368
3	+2.1	4	47	−1.3	179	15	+0.6	368
4	+2.7	7	48	−1.7	178	20	+0.8	368
5	+3.4	11	49	−2.1	177	25	+1.0	368
6	+4.0	15	50	−2.5	176	30	+1.1	369
7	+4.6	20	51	−2.9	174	35	+1.2	369
8	+5.1	26	52	−3.3	172	40	+1.3	370
9	+5.6	32	53	−3.7	170	45	+1.4	370
10	+6.0	38	54	−4.1	168	50	+1.5	371
11	+6.4	45	55	−4.5	165	55	+1.5	371
12	+6.7	52	56	−4.8	162	60	+1.4	372
13	+6.9	59	57	−5.2	159	65	+1.4	372
14	+7.1	65	58	−5.5	155	70	+1.3	373
15	+7.3	72	59	−5.8	151	75	+1.3	374
16	+7.4	79	60	−6.1	147	80	+1.1	374
17	+7.5	86	61	−6.4	143	85	+1.0	374
18	+7.5	92	62	−6.6	138	90	+0.8	374
19	+7.5	99	63	−6.8	133	95	+0.7	375
20	+7.5	105	64	−7.0	128	100	+0.5	375
21	+7.4	111	65	−7.2	123	105	+0.3	375
22	+7.3	117	66	−7.3	117	110	+0.1	375
23	+7.2	123	67	−7.4	112	115	−0.1	375
24	+7.0	128	68	−7.5	106	120	−0.3	375
25	+6.8	133	69	−7.5	100	125	−0.5	375
26	+6.6	138	70	−7.5	93	130	−0.7	375
27	+6.4	143	71	−7.5	86	135	−0.8	374
28	+6.1	147	72	−7.4	79	140	−1.0	374
29	+5.8	151	73	−7.3	72	145	−1.1	374
30	+5.5	155	74	−7.1	65	150	−1.2	373
31	+5.2	159	75	−6.9	58	155	−1.3	373
32	+4.8	162	76	−6.7	52	160	−1.4	372
33	+4.5	165	77	−6.4	45	165	−1.5	372
34	+4.1	168	78	−6.0	38	170	−1.5	371
35	+3.7	170	79	−5.6	32	175	−1.4	371
36	+3.3	172	80	−5.1	26	180	−1.4	370
37	+2.9	174	81	−4.6	20	185	−1.3	370
38	+2.5	176	82	−4.0	15	190	−1.2	369
39	+2.1	177	83	−3.4	11	195	−1.1	369
40	+1.7	178	84	−2.7	7	200	−1.0	368
41	+1.3	179	85	−2.1	4	205	−0.8	368
42	+0.9	180	86	−1.4	2	210	−0.6	368
43	+0.5	180	87	−0.7	1	215	−0.4	368
44	+0.0	181	88	−0.0	0	220	−0.2	367
						225	0.0	367

Periods

Mercury a_0	Mercury m_0	Venus a_0	Venus m_0	Mars a_0	Mars m_0	Jupiter a_0	Jupiter m_0	Saturn a_0	Saturn m_0
$115^d.9$	$88^d.0$	$583^d.9$	225^d	$779^d.9$	687^d	$398^d.9$	433^d	$378^d.1$	108^d
231.7	175.9	1167.8	449	1559.9	1374	797.8	866	756.2	215
347.6	263.9	1751.8	674						
463.5	351.9								

a_4 r

Mars

m	a_4 −1000	a_4 0	r
0ᵈ	0.0	0.0	653
5	−1.2	−1.2	653
10	−2.3	−2.3	653
15	−3.4	−3.5	653
20	−4.5	−4.6	654
25	−5.7	−5.8	654
30	−6.8	−6.9	655
35	−7.9	−8.0	655
40	−8.9	−9.0	656
45	−9.9	−10.1	657
50	−10.9	−11.1	658
55	−11.9	−12.1	659
60	−12.9	−13.0	661
65	−13.7	−13.9	662
70	−14.6	−14.8	664
75	−15.5	−15.7	665
80	−16.3	−16.5	667
85	−17.1	−17.3	668
90	−17.8	−18.0	670
95	−18.5	−18.7	671
100	−19.1	−19.3	673
105	−19.6	−19.8	674
110	−20.1	−20.3	676
115	−20.5	−20.8	677
120	−20.9	−21.2	679
125	−21.2	−21.5	681
130	−21.5	−21.8	683
135	−21.8	−22.1	685
140	−22.0	−22.3	687
145	−22.2	−22.5	689
150	−22.3	−22.6	691
155	−22.3	−22.6	693
160	−22.3	−22.6	695
165	−22.3	−22.6	697
170	−22.3	−22.6	698
175	−22.2	−22.5	700
180	−22.1	−22.4	702
185	−21.9	−22.2	704
190	−21.6	−21.9	705
195	−21.3	−21.6	707
200	−21.0	−21.2	708
205	−20.6	−20.8	710
210	−20.2	−20.4	711
215	−19.8	−20.0	712
220	−19.3	−19.5	714
225	−18.8	−19.0	715
230	−18.2	−18.4	716

m	a_4 −2000	a_4 0	r
230ᵈ	−18.2	−18.4	716
235	−17.6	−17.8	718
240	−17.0	−17.2	719
245	−16.4	−16.6	720
250	−15.7	−15.9	721
255	−15.0	−15.2	723
260	−14.3	−14.4	724
265	−13.6	−13.7	725
270	−12.8	−12.9	726
275	−12.0	−12.1	727
280	−11.2	−11.3	728
285	−10.4	−10.5	729
290	−9.5	−9.6	729
295	−8.7	−8.8	730
300	−7.8	−7.9	730
305	−6.9	−7.0	730
310	−6.0	−6.1	731
315	−5.2	−5.3	731
320	−4.3	−4.4	732
325	−3.4	−3.5	732
330	−2.5	−2.5	732
335	−1.6	−1.6	732
340	−0.7	−0.7	732
345	+0.3	+0.3	732
350	+1.2	+1.2	732
355	+2.1	+2.1	732
360	+3.0	+3.0	732
365	+3.9	+4.0	732
370	+4.8	+4.9	731
375	+5.7	+5.8	731
380	+6.6	+6.7	731
385	+7.5	+7.6	731
390	+8.3	+8.4	730
395	+9.2	+9.3	730
400	+10.1	+10.2	729
405	+10.9	+11.0	728
410	+11.7	+11.8	727
415	+12.5	+12.6	726
420	+13.2	+13.4	725
425	+13.8	+14.1	724
430	+14.6	+14.8	723
435	+15.3	+15.5	722
440	+16.0	+16.2	721
445	+16.7	+16.9	720
450	+17.3	+17.5	719
455	+17.9	+18.1	718
460	+18.5	+18.7	716

m	a_4 −1000	a_4 0	r
460ᵈ	+18.6	+18.7	716
465	+19.0	+19.2	715
470	+19.6	+19.7	713
475	+20.0	+20.2	712
480	+20.4	+20.7	710
485	+20.8	+21.1	709
490	+21.2	+21.4	707
495	+21.4	+21.7	705
500	+21.7	+22.0	703
505	+21.9	+22.2	702
510	+22.1	+22.4	700
515	+22.2	+22.5	699
520	+22.3	+22.6	697
525	+22.3	+22.6	695
530	+22.3	+22.6	693
535	+22.3	+22.5	691
540	+22.3	+22.5	689
545	+22.2	+22.4	688
550	+22.0	+22.2	686
555	+21.7	+21.9	684
560	+21.4	+21.6	682
565	+21.1	+21.3	680
570	+20.7	+20.9	678
575	+20.3	+20.5	677
580	+19.8	+20.0	675
585	+19.2	+19.4	674
590	+18.6	+18.8	672
595	+17.9	+18.1	671
600	+17.1	+17.4	669
605	+16.5	+16.7	668
610	+15.7	+15.9	666
615	+14.9	+15.1	665
620	+14.1	+14.3	663
625	+13.2	+13.4	662
630	+12.3	+12.5	660
635	+11.4	+11.5	659
640	+10.4	+10.5	658
645	+9.4	+9.5	657
650	+8.4	+8.5	656
655	+7.3	+7.4	656
660	+6.1	+6.2	655
665	+5.0	+5.1	655
670	+3.9	+4.0	654
675	+2.8	+2.8	654
680	+1.6	+1.6	653
685	+0.4	+0.4	653
690	−0.7	−0.7	653

a_4 r

Jupiter

m	a_4 −1000	a_4 0	r
0ᵈ	0.0	0.0	1208
10	−0.8	−0.9	1208
20	−1.6	−1.7	1209
30	−2.4	−2.5	1210
40	−3.1	−3.2	1212
50	−3.7	−3.9	1214
60	−4.3	−4.5	1216
70	−4.8	−5.0	1218
80	−5.1	−5.3	1220
90	−5.3	−5.5	1223
100	−5.4	−5.6	1226
110	−5.4	−5.6	1229
120	−5.3	−5.6	1232
130	−5.1	−5.4	1235
140	−4.8	−5.0	1237
150	−4.3	−4.5	1240
160	−3.8	−4.0	1242
170	−3.3	−3.4	1244
180	−2.7	−2.8	1245
190	−2.0	−2.1	1245
200	−1.2	−1.3	1246
210	−0.5	−0.6	1246
220	+0.2	+0.2	1247
230	+1.0	+1.0	1246
240	+1.7	+1.8	1246
250	+2.4	+2.5	1245
260	+3.1	+3.2	1244
270	+3.6	+3.8	1242
280	+4.1	+4.3	1240
290	+4.6	+4.8	1238
300	+5.0	+5.2	1235
310	+5.3	+5.5	1233
320	+5.4	+5.6	1230
330	+5.4	+5.6	1228
340	+5.4	+5.6	1225
350	+5.2	+5.5	1223
360	+4.9	+5.1	1220
370	+4.4	+4.6	1218
380	+3.9	+4.1	1215
390	+3.3	+3.5	1213
400	+2.7	+2.8	1211
410	+1.9	+2.0	1210
420	+1.1	+1.1	1209
430	+0.3	+0.3	1209
440	−0.5	−0.5	1209

a_4 r

Saturn

m	a_4 −1000	a_4 0	r
0ᵈ	0.0	0.0	1464
2	−1.1	−1.0	1464
4	−2.1	−2.0	1465
6	−3.0	−2.9	1466
8	−4.0	−3.8	1467
10	−4.8	−4.6	1469
12	−5.7	−5.4	1472
14	−6.4	−6.1	1474
16	−6.9	−6.6	1476
18	−7.4	−7.1	1479
20	−7.8	−7.5	1483
22	−8.1	−7.8	1486
24	−8.2	−7.9	1489
26	−8.2	−7.9	1492
28	−8.2	−7.8	1495
30	−8.0	−7.6	1498
32	−7.6	−7.3	1501
34	−7.2	−6.9	1504
36	−6.8	−6.5	1507
38	−6.2	−6.0	1509
40	−5.6	−5.4	1511
42	−5.0	−4.8	1513
44	−4.2	−4.0	1515
46	−3.4	−3.3	1516
48	−2.6	−2.5	1517
50	−1.7	−1.7	1517
52	−0.8	−0.8	1518
54	+0.0	0.0	1518
56	+0.9	+0.9	1518
58	+1.8	+1.8	1517
60	+2.7	+2.6	1517
62	+3.5	+3.4	1516
64	+4.3	+4.2	1514
66	+5.1	+4.9	1513
68	+5.7	+5.5	1511
70	+6.3	+6.1	1509
72	+6.9	+6.6	1507
74	+7.3	+7.0	1504
76	+7.7	+7.4	1501
78	+8.0	+7.7	1498
80	+8.2	+7.8	1495
82	+8.2	+7.8	1491
84	+8.2	+7.8	1488
86	+8.0	+7.7	1485
88	+7.7	+7.4	1482
90	+7.3	+7.0	1479
92	+6.9	+6.6	1476
94	+6.3	+6.0	147
96	+5.6	+5.3	147
98	+4.7	+4.5	146
100	+3.8	+3.7	146
102	+2.9	+2.8	146
104	+1.9	+1.8	146
106	+0.9	+0.9	146
108	−0.1	−0.1	146

a_5

day: ordin. years	day: leap years	Mercury a_5 −500	Mercury 0	Mercury +500	Venus a_5 −500	Venus 0	Venus +500	Mars a_5 −500	Mars 0	Mars +500	Jupiter a_5 −500	Jupiter 0	Jupiter +500	Saturn a_5 −500	Saturn 0	Saturn +500
I 0	I 1*	$-0^{d}.4$	$-0^{d}.3$	$-0^{d}.2$	$-1^{d}.8$	$-1^{d}.6$	$-1^{d}.3$	$+2^{d}.4$	$+2^{d}.1$	$+1^{d}.8$	$+1^{d}.2$	$+1^{d}.1$	$+0^{d}.9$	$+1^{d}.3$	$+1^{d}.1$	$+0^{d}.9$
10	11*	−0.5	−0.4	−0.3	−2.3	−2.1	−1.8	+3.0	+2.7	+2.4	+1.6	+1.4	+1.2	+1.5	+1.4	+1.2
20	21*	−0.6	−0.5	−0.4	−2.7	−2.5	−2.3	+3.5	+3.3	+3.0	+1.8	+1.7	+1.5	+1.7	+1.6	+1.5
30	31*	−0.6	−0.6	−0.5	−3.0	−2.8	−2.6	+4.0	+3.8	+3.5	+2.0	+1.9	+1.7	+1.9	+1.8	+1.7
II 9	II 10*	−0.6	−0.6	−0.6	−3.1	−3.0	−2.8	+4.2	+4.1	+3.8	+2.1	+2.1	+1.9	+2.0	+2.0	+1.8
19	20*	−0.7	−0.6	−0.6	−3.3	−3.2	−3.1	+4.4	+4.3	+4.1	+2.2	+2.2	+2.1	+2.1	+2.1	+2.0
III 1		−0.6	−0.6	−0.6	−3.2	−3.2	−3.1	+4.3	+4.3	+4.2	+2.2	+2.2	+2.1	+2.1	+2.1	+2.0
11		−0.6	−0.6	−0.6	−3.2	−3.2	−3.2	+4.2	+4.3	+4.2	+2.2	+2.2	+2.2	+2.1	+2.1	+2.1
21		−0.6	−0.6	−0.6	−3.0	−3.1	−3.1	+4.1	+4.2	+4.1	+2.1	+2.1	+2.1	+2.0	+2.0	+2.0
31		−0.5	−0.6	−0.6	−2.7	−2.8	−2.9	+3.7	+3.8	+3.9	+1.9	+1.9	+2.0	+1.8	+1.8	+1.9
IV 10		−0.4	−0.5	−0.6	−2.4	−2.5	−2.6	+3.2	+3.4	+3.6	+1.6	+1.7	+1.7	+1.6	+1.7	+1.8
20		−0.4	−0.4	−0.5	−2.0	−2.2	−2.3	+2.6	+2.9	+3.0	+1.4	+1.5	+1.5	+1.4	+1.5	+1.6
30		−0.3	−0.3	−0.4	−1.5	−1.7	−1.9	+2.0	+2.3	+2.5	+1.1	+1.2	+1.3	+1.1	+1.2	+1.3
V 10		−0.2	−0.2	−0.3	−1.0	−1.2	−1.4	+1.3	+1.6	+1.9	+0.7	+0.8	+0.9	+0.7	+0.8	+1.0
20		0.0	−0.1	−0.2	−0.4	−0.7	−0.9	+0.6	+0.9	+1.2	+0.3	+0.5	+0.6	+0.3	+0.5	+0.7
30		+0.1	0.0	−0.1	+0.1	−0.2	−0.4	−0.1	+0.2	+0.5	−0.1	+0.1	+0.3	−0.1	+0.1	+0.3
VI 9		+0.2	+0.1	0.0	+0.6	+0.4	+0.2	−0.8	−0.5	−0.2	−0.4	−0.3	−0.1	−0.4	−0.3	−0.1
19		+0.3	+0.2	+0.1	+1.1	+0.9	+0.6	−1.5	−1.2	−0.8	−0.8	−0.6	−0.4	−0.8	−0.6	−0.4
29		+0.4	+0.3	+0.2	+1.6	+1.4	+1.1	−2.2	−1.9	−1.5	−1.1	−1.0	−0.8	−1.1	−1.0	−0.8
VII 9		+0.5	+0.4	+0.3	+2.1	+1.9	+1.6	−2.8	−2.5	−2.2	−1.4	−1.3	−1.1	−1.4	−1.3	−1.1
19		+0.5	+0.5	+0.4	+2.5	+2.3	+2.1	−3.3	−3.1	−2.8	−1.7	−1.6	−1.4	−1.6	−1.5	−1.4
29		+0.6	+0.5	+0.5	+2.8	+2.7	+2.5	−3.8	−3.6	−3.3	−1.9	−1.8	−1.7	−1.8	−1.7	−1.6
VIII 8		+0.6	+0.6	+0.5	+3.0	+2.9	+2.7	−4.1	−3.9	−3.7	−2.0	−2.0	−1.9	−2.0	−1.9	−1.8
18		+0.7	+0.6	+0.6	+3.2	+3.1	+3.0	−4.3	−4.2	−4.0	−2.1	−2.1	−2.0	−2.0	−2.0	−1.9
28		+0.7	+0.6	+0.6	+3.2	+3.2	+3.1	−4.4	−4.3	−4.2	−2.2	−2.2	−2.1	−2.1	−2.1	−2.0
IX 7		+0.6	+0.6	+0.6	+3.2	+3.2	+3.2	−4.3	−4.3	−4.3	−2.2	−2.2	−2.2	−2.1	−2.1	−2.1
17		+0.6	+0.6	+0.6	+3.0	+3.1	+3.2	−4.1	−4.2	−4.3	−2.1	−2.1	−2.2	−2.0	−2.0	−2.1
27		+0.5	+0.6	+0.6	+2.8	+2.9	+3.0	−3.8	−3.9	−4.0	−1.9	−2.0	−2.1	−1.9	−1.9	−2.0
X 7		+0.5	+0.5	+0.6	+2.5	+2.7	+2.8	−3.4	−3.6	−3.7	−1.7	−1.8	−1.9	−1.7	−1.8	−1.9
17		+0.4	+0.5	+0.5	+2.1	+2.3	+2.4	−2.9	−3.1	−3.3	−1.5	−1.6	−1.7	−1.5	−1.6	−1.7
27		+0.3	+0.4	+0.5	+1.6	+1.9	+2.1	−2.2	−2.5	−2.7	−1.2	−1.3	−1.5	−1.2	−1.3	−1.4
XI 6		+0.2	+0.3	+0.4	+1.1	+1.4	+1.6	−1.5	−1.9	−2.3	−0.8	−1.0	−1.1	−0.8	−1.0	−1.1
16		+0.1	+0.2	+0.3	+0.6	+0.9	+1.1	−0.8	−1.2	−1.5	−0.4	−0.6	−0.8	−0.4	−0.6	−0.8
26		0.0	+0.1	+0.2	0.0	+0.3	+0.5	0.0	−0.4	−0.7	0.0	−0.2	−0.4	0.0	−0.2	−0.3
XII 6		−0.2	−0.1	+0.1	−0.5	−0.3	0.0	+0.7	+0.4	0.0	+0.3	+0.2	0.0	+0.3	+0.2	−0.0
16		−0.3	−0.2	−0.1	−1.1	−0.8	−0.5	+1.4	+1.1	+0.7	+0.7	+0.5	+0.3	+0.8	+0.6	+0.4
26		−0.4	−0.3	−0.2	−1.6	−1.3	−1.0	+2.1	+1.8	+1.5	+1.1	+0.9	+0.7	+1.1	+0.9	+0.7
36		−0.5	−0.4	−0.3	−2.0	−1.8	−1.5	+2.7	+2.4	+2.0	+1.4	+1.2	+1.0	+1.3	+1.2	+1.0

Mercury $\lambda - \odot$

a	$R-r$ 320	360	400	440	480	520
0^d	0°	0°	0°	0°	0°	0°
2	2	2	2	2	1	1
4	4	4	4	3	3	3
6	6	6	5	5	5	4
8	8	8	7	7	6	6
10	10	9	9	8	8	7
12	12	11	10	10	9	8
14	14	13	12	11	10	10
16	16	15	14	13	12	11
18	17	16	15	14	13	12
20	19	18	17	15	14	13
22	21	19	18	17	15	14
24	22	21	19	18	16	15
26	24	22	20	19	17	16
28	25	23	21	20	18	16
30	26	24	22	20	19	17
32	27	25	23	21	19	17
34	28	26	23	21	19	18
36	28	26	23	21	19	18
38	29	26	23	21	19	17
40	28	26	23	21	19	17
42	28	25	22	20	18	16
44	27	24	21	19	17	15
46	25	22	19	17	15	14
48	23	20	17	15	13	12
50	20	17	15	13	11	10
52	15	13	11	10	9	8
54	10	9	8	7	6	5
56	5	5	4	3	3	3
58	0	0	0	0	0	0
60	355	355	356	357	357	357
62	349	350	352	353	354	355
64	344	346	348	350	351	352
66	340	343	345	347	348	350
68	337	340	342	345	347	348
70	335	338	340	343	345	346
72	333	336	339	341	343	345
74	332	335	338	340	342	344
76	332	334	337	339	341	343
78	332	334	337	339	341	343
80	332	334	337	339	341	342
82	332	335	337	339	341	342
84	333	335	337	339	341	343
86	334	336	338	340	341	343
88	335	337	339	340	342	344
90	336	338	340	342	343	344
92	338	339	341	343	344	345
94	339	341	342	344	345	346
96	341	342	344	345	346	347
98	343	344	345	346	347	348
100	345	346	347	347	348	349
102	346	347	348	349	350	350
104	348	349	350	350	351	352
106	350	351	351	352	352	353
108	352	353	353	353	354	354
110	354	355	355	355	356	356
112	356	356	357	357	357	357
114	358	358	358	358	359	[illegible]
116	360	360	360	360	360	360

Venus $\lambda - \odot$

a	$R-r$ 130	145	160	a	$R-r$ 130	145	160
0^d	0°	0°	0°	295^d	355°	355°	356°
5	1	1	1	300	346	347	349
10	3	3	3	305	339	340	342
15	4	4	4	310	333	334	336
20	5	5	5	315	327	329	331
25	7	7	6	320	323	325	327
30	8	8	8	325	320	322	324
35	9	9	9	330	317	319	321
40	10	10	10	335	315	317	319
45	12	12	12	340	314	316	318
50	13	13	13	345	313	315	317
55	14	14	14	350	313	314	316
60	16	16	15	355	312	314	315
65	17	17	17	360	312	314	315
70	18	18	18	365	312	314	315
75	19	19	19	370	312	314	315
80	21	21	20	375	313	314	315
85	22	22	22	380	313	314	316
90	23	23	23	385	313	314	316
95	25	24	24	390	314	315	317
100	26	26	26	395	315	316	317
105	27	27	27	400	316	317	318
110	28	28	28	405	317	318	319
115	29	29	29	410	318	319	319
120	31	30	30	415	319	320	320
125	32	31	31	420	320	320	321
130	33	32	32	425	321	321	322
135	34	34	33	430	322	322	323
140	35	35	34	435	323	323	324
145	36	36	35	440	324	324	325
150	37	37	36	445	325	326	326
155	38	38	37	450	326	327	327
160	39	39	38	455	327	328	328
165	40	40	39	460	328	329	329
170	41	41	40	465	330	330	331
175	42	41	41	470	331	331	332
180	43	42	42	475	332	332	333
185	44	43	42	480	333	334	334
190	45	44	43	485	334	335	335
195	46	45	44	490	336	336	336
200	46	45	44	495	337	337	338
205	47	46	45	500	338	338	339
210	47	46	45	505	339	340	340
215	48	46	45	510	341	341	341
220	48	46	45	515	342	342	342
225	48	46	45	520	343	343	344
230	48	46	45	525	345	345	345
235	47	45	44	530	346	346	346
240	47	45	43	535	347	347	348
245	46	44	42	540	349	349	349
250	44	42	41	545	350	350	350
255	42	40	39	550	351	351	351
260	39	37	36	555	352	352	352
265	36	34	32	560	354	354	354
270	32	30	28	565	355	355	355
275	26	25	23	570	356	356	356
280	20	18	17	575	357	357	357
285	12	11	10	580	359	359	359
290	4	3	3	585	361	361	361
295	355	355	356				

Mars $\lambda - \odot$.

a	r−R 120	140	160	180	200	220	240
0^d	360°	360°	360°	360°	360°	360°	360°
10	357	357	357	357	357	357	357
20	355	355	355	354	354	354	354
30	352	352	352	352	352	351	351
40	350	349	349	349	349	348	348
50	347	346	346	346	346	346	345
60	344	344	344	343	343	343	342
70	341	341	341	340	340	340	339
80	339	338	338	338	337	337	337
90	336	336	335	335	334	334	334
100	334	333	332	332	331	331	330
110	331	330	330	329	329	328	327
120	328	327	327	326	325	325	324
130	325	325	324	323	322	322	321
140	323	322	321	320	320	319	318
150	320	319	318	318	317	316	315
160	317	316	315	315	314	313	312
170	314	313	312	311	310	309	308
180	312	310	309	308	307	306	305
190	309	308	306	305	304	303	302
200	306	304	303	302	301	299	298
210	303	301	300	299	297	296	295
220	299	298	297	295	294	292	291
230	296	295	293	292	290	289	287
240	293	292	290	288	287	285	283
250	290	288	286	284	283	281	279
260	286	284	282	280	279	277	275
270	283	281	279	276	274	272	270
280	279	277	274	272	270	268	266
290	275	272	270	267	265	263	261
300	271	268	265	262	260	258	255
305	269	266	263	260	257	255	252
310	266	263	260	257	254	252	249
315	264	260	257	254	251	249	246
320	261	257	254	251	248	246	243
325	258	254	251	248	245	242	240
330	255	251	248	244	241	239	236
335	252	248	244	241	238	235	233
340	248	244	240	237	234	231	229
345	244	240	236	233	230	227	225
350	239	235	231	228	225	222	220
355	234	230	226	223	220	218	216
360	228	224	220	218	215	213	211
365	222	218	215	212	210	208	206
370	215	211	208	206	204	202	201
375	207	204	202	200	198	197	196
380	199	197	195	193	192	191	191
385	190	189	188	187	186	186	186
390	180	180	180	180	180	180	180

a	r−R 120	140	160	180	200	220	240
390^d	180°	180°	180°	180°	180°	180°	180°
395	170	171	172	173	174	174	174
400	161	163	165	167	168	169	169
405	153	156	158	160	162	163	164
410	145	149	152	154	156	157	159
415	138	142	[illegible]	148	150	152	154
420	132	136	139	142	145	147	149
425	126	130	133	137	140	142	144
430	121	125	129	132	135	138	140
435	116	120	124	127	130	133	135
440	112	116	120	123	126	129	131
445	108	112	116	119	122	125	127
450	105	109	112	116	119	121	124
455	102	106	109	112	115	117	120
460	99	103	106	109	112	114	117
465	96	100	103	106	109	111	114
470	94	97	100	103	106	108	110
475	91	94	97	100	103	105	108
480	89	92	95	98	100	102	105
485	87	90	92	95	97	99	102
490	85	88	90	93	95	97	99
500	81	83	86	88	90	92	94
510	77	79	81	84	86	88	90
520	74	76	78	80	81	83	85
530	70	72	74	76	77	79	81
540	67	68	70	72	73	75	77
550	64	65	67	68	70	71	73
560	61	62	63	65	66	68	69
570	57	59	60	61	63	64	65
580	54	56	57	58	59	61	62
590	51	53	54	55	56	57	58
600	48	50	51	52	53	54	55
610	46	47	48	49	50	51	52
620	43	44	45	45	46	47	48
630	40	41	42	42	43	44	45
640	37	38	39	40	40	41	42
650	35	35	36	37	38	38	39
660	32	33	33	34	35	35	36
670	29	30	30	31	31	32	33
680	26	27	28	28	29	29	30
690	24	24	25	25	26	26	26
700	21	22	22	22	23	23	23
710	19	19	19	20	20	20	21
720	16	16	16	17	17	17	18
730	13	14	14	14	14	14	15
740	10	11	11	11	11	12	12
750	8	8	8	8	8	9	9
760	5	5	5	6	6	6	6
770	3	3	3	3	3	3	3
780	0	0	0	0	0	0	0

Jupiter $\lambda - \odot$.

a	r−R 670	710	750
0^d	360°	360°	360°
10	353	352	352
20	345	345	345
30	338	337	337
40	330	330	329
50	322	322	321
60	315	314	313
70	307	306	305
80	299	298	297
90	290	290	289
100	282	281	280
110	273	272	271
120	264	263	262
130	255	254	253
140	245	244	243
150	235	234	233
160	224	224	223
170	213	213	212
180	202	202	201
190	191	191	191
200	180	180	180
210	169	169	169
220	158	158	159
230	147	147	148
240	136	136	137
250	125	126	127
260	115	116	117
270	105	106	107
280	96	97	98
290	87	88	89
300	78	79	80
310	70	70	71
320	61	62	63
330	53	54	55
340	45	46	47
350	38	38	39
360	30	30	31
370	22	23	23
380	15	15	15
390	7	8	8
400	0	0	0

Saturn $\lambda - \odot$.

a	r−R 930	970	1010
0^d	360°	360°	360°
10	352	352	351
20	343	343	343
30	334	334	334
40	326	325	325
50	317	317	316
60	308	308	307
70	299	299	298
80	290	290	289
90	281	280	280
100	271	271	270
110	262	261	261
120	252	252	251
130	242	242	241
140	232	232	231
150	222	221	221
160	211	211	211
170	201	200	200
180	190	190	190
190	179	179	179
200	169	169	169
210	158	158	158
220	147	147	148
230	136	137	137
240	126	127	127
250	116	117	117
260	106	107	107
270	96	97	97
280	87	87	88
290	77	78	78
300	68	69	69
310	59	60	60
320	50	51	51
330	41	42	42
340	33	33	33
350	24	24	24
360	16	16	16
370	7	7	7
380	358	358	358