BABYLONIAN ASTRONOMY*

By W.M. O'Neil

Though the modern western world had heard of the Chaldaeans in the Old Testament as soothsayers and astrologers and students of Hellenistic astronomy knew of references to Babylonian observations of eclipses and the like, it is only during the last three quarters of a century but especially during the last half century that modern scholars, following the decipherment of the cuneiform writing on clay tablets, have begun to reveal the richness of Babylonian astronomy. They have, however, a long way yet to go. First, only a fraction of the materials scattered throughout the western world have been studied and interpreted. Fragments of the one tablet are sometimes in different museums; this adds to the difficulty. Second, the materials are usually fragmentary: a few pages torn from a book as it were or even only a few parts of pages (See Plate 1). Otto Neugebauer, perhaps the greatest scholar recently working on Babylonian astronomy, says that it is impossible yet to write an adequate history of Babylonian astronomy and suggests that it may never be possible. How many of the needed basic texts have crumbled into dust after acquisition by small museums unable to give them the needed care?, how many are lying unstudied in the multitudinous collections in the Middle East, in Europe and in North America? or are still lying in the ground?, are questions to which the answers are unknown.

Nevertheless, through the work of Neugebauer, his predecessors and younger scholars taking over from him, some outlines of the history and the methods of Babylonian astronomy are becoming clearer. What I wish to do is to give you some hint of these outlines. I am, of course, not a scholar in the field, but just a persistent parasite living symbiotically on the work of scholars.

An interest in the heavens occurred very early in Mesopotamia, the land between the rivers. The brighter stars, I use the term loosely to cover what we call the Sun, the Moon, the planets other than the Earth, and the brighter so-called fixed stars, were named and constellations recognised and named. Some of this interest and activity was Sumerian, that is pre-Babylonian. It was as early as at least the 3rd and probably was as early as the 4th millennium BC. It seems to have had practical purposes, first to aid in time-reckoning and second for the reading of omens. I should like to make a few brief comments on

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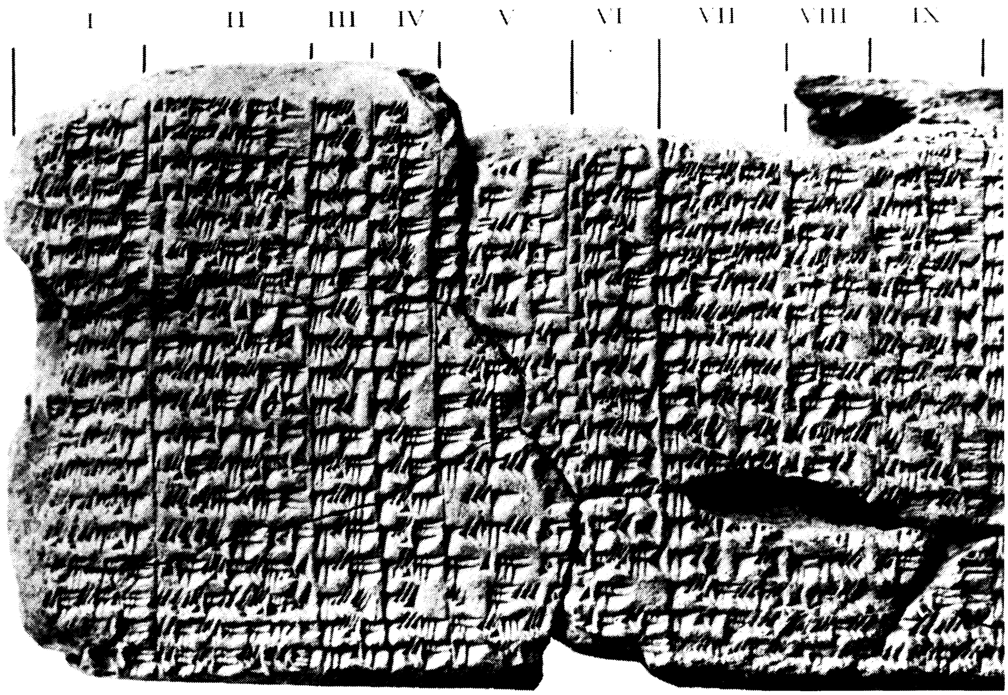

Plate 1. **Part of an unusually well preserved tablet giving astronomical data for three years in the 2nd** century BC. The tablet is approximately 34 cm. by 11 cm.

astrology and then subsequently ignore that pseudo-science. First, the horoscope cast for an individual on the basis of his birth-date is a Hellenistic invention, probably in Ptolemaic Egypt. Mesopotamian astrology in pre-Hellenistic times was judicial, that is it provided omens relevant for the King or for the whole community. Let me quote an entry from the Venus Tablets of Ammizaduga, probably 17th century BC.

> If on the 21st day of the month Abu, Nin-si-anna (the mistress of the heavens, Venus) disappeared in the east, remaining absent in the sky for 2 months 11 days, and in the month of Arasamnu on the 2nd day, she was seen in the west, there will be rains in the land, desolation will be wrought.

Second, you will notice that the Chaldaeans who are referred to in the Old Testament and who provided the 10th Babylonian dynasty from *circa* 626 to *circa* 538 BC were the inheritors of at least a millennium of judicial astrology.

The Sumerians, as did the later Babylonians, took as their basic time units (a) the day, sunset to sunset and (b) the month, from one first visible crescent moon after sunset to the next. The intervals between first visible crescents average a little more than 29.53 days. Twelve such months come to a little more than 354.36 days, rounded on two out of three occasions to 354 days and on the third to 355 days. A 'year' of such 12 months is a little more than 10 or 11 days short of the tropical year of about 365.2425 days. Hence in every second or third calendar year an extra or thirteenth month had to be added into the calendar year to keep it in reasonable step with the year of the seasons. Hammurapi, the most notable King of Old Babylonia, *circa* 18th century BC, issued a decree which has been preserved for us. "As the year is ending too soon, let the month following Ululu be called the second Ululu, but let the taxes due in Babylon in Tashritu be paid in the second Ululu". How would he have known that the calendar year was ending too soon? His judgment could have been based on certain terrestrial events, the ripening of the barley and the grapes, the rise of the river, the lambing of the ewes, all affected by meteorologically and biologically variable cycles. His Sumerian predecessors perhaps a millennium or more earlier had discovered a more constant basis for this judgment.

As a result of the Earth's revolution around the Sun, the Sun appears to move eastward in a year among the so-called fixed stars. As some star is approached by the Sun it makes a final appearance after sunset and after it is passed by the Sun it makes its reappearance or heliacal rising before sunrise. The Sumerians noticed the result though they did not understand the cause. They recognised however that Spring was heralded by the heliacal rising of the leading stars, the Pleiades to give them their Greek name or the Bristle or Beard to give them their Mesopotamian name, in a constellation which the Sumerians called *Gu-ud-anna*, the Bull of Heaven, approximately our Taurus. Likewise, they recognised that Summer, Autumn and Winter were heralded by similar heliacal risings of the leading stars in constellations which they named the Great Lion (approximately our Leo) the Scorpion (our Scorpio plus the two brightest stars in Libra which were regarded as the claws of the Scorpion and which were later called *Chelai* by the Greeks) and the Ibex. The Ibex was subsequently broken into two constellations, our Capricornus and Aquarius, and seven other intervening constellations were later added to yield our twelve zodiacal constellations.

Of the Greek zodiacal names, which we preserve, ten were early Mesopotamian in origin, and perhaps the other two were late Babylonian. The early Babylonian twelve were the Bull-of-Heaven, the Great Twins, the Crab, the Lion, the Furrow, the Weighing Scales, the Scorpion, the Arrow-shooter, the Fish-goat, the Water-pourer, the Fish-tails and the Hired Farm-worker. The Furrow later became, possibly in late Babylonian times but possibly in Hellenistic times, Virgo. The Babylonian Furrow was divided into two parts, the ear-of-wheat and the date-palm flower. In the drawings of the winged virgin in Hellenistic, Medieval and early Modern representations she is usually shown as bearing in one hand an ear-of-wheat and in the other a palm-frond. The brightest star in Virgo is still called Spica, Latin for an ear-of-wheat. The winged figure is also Babylonian in origin. The transformation of the Hired Farm-worker, sometimes shown (see Figure 1) as goading the Bull to rise and so open Spring, and with his plough cutting through the soil, into the Ram is a bit of a puzzle. There is a fair case that the transformation was

Figure 1. The Hired Farm-worker with his right hand on his plough and with his left hand goading the Bull-of-Heaven to make his Spring heliacal rising.

Babylonian, but I shall not go into it here as I have discussed it briefly elsewhere (O'Neil 1974).

The Babylonians were interested in the disappearance of the planets as they approached conjunction with the Sun and their reappearance some little time after conjunction. By the 5th or even 6th century BC they had worked out a way of predicting these and other planetary phenomena. It was based on what is called the resonance period of each planet resulting from the eccentricity of the Earth's orbit and that of the planet (a cause the Babylonians did not know). The rule for Venus was "look up the dates of the phenomena eight years before and subtract 4 days", for Mars "look up the dates 47 years before and add 2 days or the dates 79 years before and add 7 days" and so on. These rules are approximately correct.

A tablet written presumably in about 276 BC records lunar eclipses for a period of 95 years. As the tablet is broken off on the left-hand side the period may well have been longer. As it stands it spans the last 14 years of the reign in Babylon of Artaxerxes II, the reigns of Umasu, Arses, Darius III (all Persians), Alexander the Great, Philip, Antigonos, Seleucos I and 3 years of Seleucos II (all Greeks) (see Table 1). The eclipses are arranged in series of 38 with 223 lunar months elapsing between the beginning of one series and that of the next. This is the so-called Saros Cycle, wrongly named by the English astronomer Halley who knew of the cycle through Greek sources. Each series

33A	II	5	III	2	III	6	III	12	IV
	VIII	dir	IX		IX		IX	(dir)	X
34	II	6	II	1Da	III	1An	III	13	III
dir	VIII		VIII	dir	IX		IX		IX
35	I	7	II	2	II	2	III	14	III
	VII		VIII		VIII	dir	IX		IX
36	I	8	II	3	II	3	II	15	III
	VII	VIdir	VII		VIII		VIII	dir	IX
	XII		XII	4	I	4	I	16	I
37	VI	9	VI		VIa		VII		VII
dir	XII		XII		XII	5	I	17	I
38	V	10	VI	5	VI		VIa		VII
	XI	dir	XII		XII		XII	18	I
39	V	11	V	1A	VI	6	VI		VIa
	XI		XI	dir	XII		XII		XII
40	IV	12	IV	2	IV	1Si	V	19	V
dir	X		X		X	dir	XI		XI
41	III	13	IV	3	IV	2	IV	20	V
	IX	dir	X		X		X	dir	XI
42	III	14	III	4	IV	3	IV	21	IV
	IX		IX	dir	X		X		X
43	III	15	III	5	III	4	IV	22	IV
dir	IX		IX		IX	dir	X		X
44	I	16	II	6	II	5	II	23	II
	VII	dir	VIII		VIII		VIII	dir	IX
45	I	17	I	7	II	6	II	24	II
	VII		VII	dir	VIII		VIII		VIII
	XIIa	18	I	1Phi	I	7	II	25	II
46	VI		VII		VII	dir	VIII		VIII
	XII		XIIa	2	I	8	I	26	II
1U	VI	19	VI	dir	VII		VII		VIII
	XI		XI		XII		XII		XIIa
2	V	20	V	3	V	9	VI	27	VI
dir	XI		XI		XI	dir	XII		XII
3	IV	21	V	4	V	10	V	28	VI
	X	dir	XI		XI		XI	dir	XII
4	IV	1Ar	IV	5	V	11	V	29	V
	X		X	dir	XI		XI		XI

Table 1. Dates of lunar eclipses in terms of an early-3rd century BC conception of the Saros Cycle. 33A is the 33rd year of the reign of Artaxerxes II; the following reigns are those of Umasu, Arses, Darius III. Alexander the Great, Philip Arrhidaeus, Antigonus and Seleucus I Nicator. The word 'dir' indicates that there is an intercalary of 13th lunar month before the next specified month; 'VIa' and 'XIIa' indicate such intercalary months.

consists of five sub-series each including 7 or 8 eclipses. Within a sub-series the eclipses are 6 lunar months apart but the interval between the end of one sub-series and the beginning of the next is only 5 months. As this is the pattern in which lunar eclipses occur (with one exception to be mentioned), the tablet appears to be a record of very accurate observations over almost a century or possibly more. It cannot, however, be a record of eclipses observed at Babylon. First, about half the lunar eclipses occur below the horizon at a particular site. Second, lunar eclipses are of three sorts, total umbral eclipses, partial umbral eclipses and penumbral eclipses (see Figure 2). The last when occurring above the horizon are barely detectable by naked eye observation. Each sub-series usually has one or two penumbral eclipses at its beginning and at its end. Further quite often near the beginning or the end of a sub-series there are two penumbral eclipses only a month apart. There is no indication of these additional penumbral eclipses in the Babylonian record. The record to which I refer is not a record of observed eclipses but a record of possible eclipses, an ingenious piece of actuarial calculation.

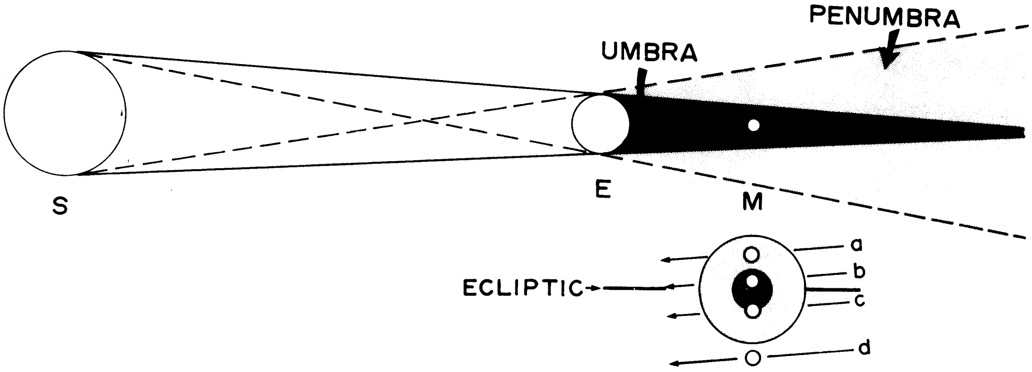

Figure 2. Diagram showing the Earth's umbra and penumbra. A total eclipse occurs when the Moon fully enters the umbra and a partial eclipse when only part of it so enters; if the Moon enters on the penumbra there is a scarcely noticeable penumbral eclipse.

This ingenuity can be seen more clearly in a tablet covering a period from 121 BC (the 190th year of the Seleucid Era, SE) to 103BC (208 SE) (see Table 2). It gives the date (year, month and day in the month) and the longitude within a Sign of the Zodiac (in degrees and seconds) of the second station of Jupiter. For most of the time Jupiter, like the Sun and the Moon, appears to an observer on Earth to move eastward among the fixed stars. However, unlike the Sun and Moon, but like the other planets it pauses from time to time and then enters a retrograde (westward) phase of apparent motion. After a month or so it stops again (the second station) after which it re-enters its phase of eastward apparent motion (see Figure 3). The interval between successive first stations or between successive second stations of Jupiter is 13 lunar months and 10 to 20 days. Column I of the tablet reflects this fact. What is more remarkable is that

I SE Year	II Month, Day	III Long.	IV Implied change of position	V Diff. in implied change
190	XII 11	21°49′ Can.		
			29°41′	
191	XIIa22	21°30′ Leo		- 1°3′
			28°38′	
193*	II 4	20°8′ Vir.		+ 1°48′
			30°26′	
(194)	III 16	20°34′ Lib.		+ 1°48′
			32°14′	
(195)	(IV) 1	22°48′ Sco.		+ 1°48′
			34°2′	
196	V 17	26°50′ Sag.		+ 1°48′
			35°50′	
197	VII 5	2°40′ Aqu.**		+ 1°48′
			37°38′	
198	VII 25	10°18′ Pis.		- 1°0′
			36°38′	
199	IX 13	16°56′ Ari.		- 1°48′
			34°50′	
200	IX 30	21°46′ Tau.		- 1°48′
			33°2′	
201	XI 15	24°48′ Gem.		- 1°48′
			31°14′	
202	XII 28	26°2′ Can.		- 1°48′
			29°26′	
204*	I 10	25°28′ Leo		- 1°33′
			28°53′	
205	II 21	24°21′ Vir.		+ 1°48′
			30°41′	
206	III 4	25°2′ Lib.		+ 1°48′
			32°29′	
207	IV 18	27°31′ Sco.		+ 1°48′
			34°17′	
208	VI 4	1°48′ Cap.**		

Table 2. The dates (the year within the Seleucid Era, the month and the day within the months) and the positions (in degrees and minutes with a Sign of the Zodiac) of the second stations of Jupiter. The values in columns I and II are transcribed from the tablet. The two years marked with an asterisk, indicate occasions when the second station has 'jumped' a year and the two positions marked with a double asterisk indicate occasions when it has 'jumped' a Sign. The values in Columns II and IV are deduced from the values given in the original tablet and reproduced in column II.

longitudes in Column II are given to the accuracy of 1 minute of arc. While the Babylonians would no doubt have been able to estimate a smaller difference between two stars than 1 minute (twice the apparent diameter of the Moon), it is surprising that with whatever sighting devices they may have had they could get a station when the planet was not moving among the fixed stars to a precision of 1 minute of arc. The origin of these values becomes clear when one plots them in a graph (see Figure 4). They were generated by what the scholars call a 'zig-zag' function. We know that a better, but not much superior, function would be sinusoidal. This is almost certainly not a record of

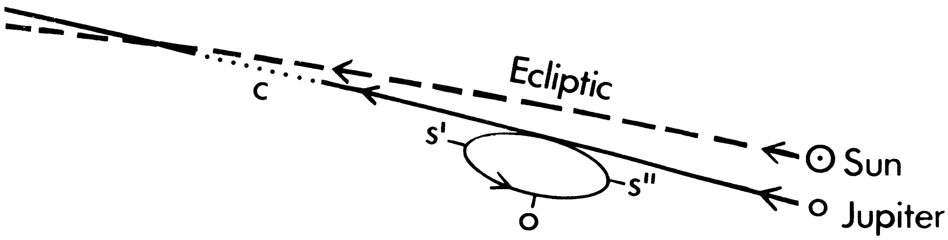

Figure 3. A schematic illustration of the apparent direct and retrograde phases of the motion of Jupiter among the fixed stars. Point *c* marks Jupiter's conjunction with the Sun and *o* its opposition; *s′* and *s″* mark its first and second station respectively.

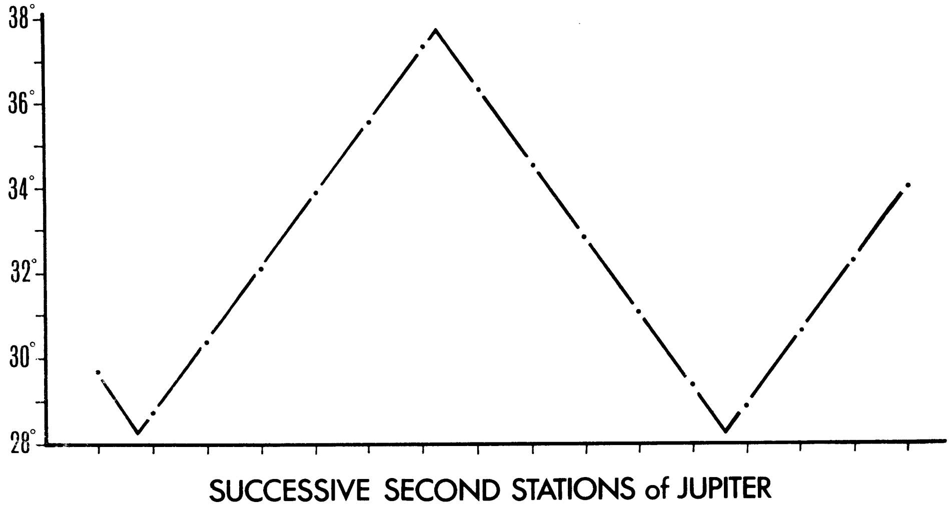

Figure 4. A graph of the positional differences recorded in column III in Table 2 revealing the 'zig-zag' function used to generate the values in column II. It should be noticed that the difference of 1°30′ between the positions of the second stations in the years SE 190 and 191 has according to this graph to have added to it 2 x 22′30″ which brings it to 1°48′ which so frequently appears in column IV of Table 2.

observations; it is almost certainly a record of predictions. Had hours within the day been given, the dates would probably have been seen to have been generated by another 'zig-zag' function much evidenced in other astronomical texts.

I shall examine in part a very complex tablet dealing with a few years later in the 2nd century BC when the Greeks had been displaced from the Babylonian throne by a Parthian dynasty. It is basically a table of possible eclipses and probable dates of the first visible crescent. It is centred on dates and times of conjunction of the Sun and the Moon, their longitudes within Signs of the Zodiac, the length of sunlight and night on these occasions, the latitude of the Moon (on or north or south of the Ecliptic, the Sun's apparent path), the apparent velocities of the Sun and the Moon on these occasions. There are several remarkable features of this table of data. First, positions of conjunction and lunar latitude are given to seconds of arc, well beyond the capacity of the Babylonians to observe, and times of conjunction are given in seconds of time degrees (a time degree is 4 minutes, so a second of time degree is about .0666 of a second by our clocks). The values of arc and of time could not possibly have been measured to this degree of precision by the devices which the Babylonians may have possessed. All these values appear to be predicted by the use of 'zig-zag' functions. Second, the 'zig-zag' functions manifest in this tablet assume remarkably accurate estimates of the synodic, the draconic and anomalistic months; the synodic month is the interval between successive conjunctions of the Moon with the Sun (29.53049 days), the draconic month is the period taken by the Moon to make a double-crossing of the Sun's apparent path (27.21222 days) and the anomalistic month is the interval between successive occasions when the Moon is moving most swiftly through the fixed stars (27.55455 days). The tablet also recognises and gives a good value to the anomalistic year, the interval between successive occasions when the Sun appears to be moving most swiftly through the fixed stars (365.25964 days). These values were adopted by Hipparchos in about 150 BC so it is likely that they were established in Babylonia prior to the date of the tablet I have been discussing. What is still more remarkable is that when we calculate from modern observations what may have been happening in the period covered by this text, its values have a constant error of 1.5 hours and a variable error of 1 hour. The former seems to be a result of minor errors in the basic data whatever they may have been and the latter the result of imprecision in the 'zig-zag' functions used in generating the values in the table.

I have intentionally given the impression that most of the later Babylonian astronomical texts were almanacs giving predictions rather than observations. There is a small group of texts, now called diaries, which give observations on which the numerous almanacs were presumably based. They usually cover half a year reporting dates of eclipses or of expected eclipses which were not observed, of disappearances or reappearances of the Moon and of the five other planets which occurred on the expected date or a few days before or afterwards. These diaries recorded the dates of other celestial phenomena such as haloes around the Sun or the Moon and terrestrial phenomena such as rain requiring or not requiring the removal of sandals, the height of the river, the daily price of staple commodities and some important news of the day such as fire in some part of the city or a theft from a temple. One such diary records the date of the welcome given Alexander the Great upon his entry into the city, overthrowing the earlier Persian tyranny and another the date of his death.

Though Greek astronomy from Eudoxos to Ptolemaeus was greatly dependent on Neo-Babylonian astronomy for its basic values it differed in one important respect. The Babylonian values used by the later Greeks included the eclipse cycles, the periods of the several months (synodic, sidereal, draconic and anomalistic), the variable apparent angular velocity of the Sun and so on. Babylonian astronomy was descriptive and predictive but attempted no explanations in terms of underlying motions in geometric terms. Greek astronomy did attempt to provide a geometric explanation in terms of homocentric spheres (Eudoxos) or in terms of encentrics, deferents and epicycles (Hipparchos and Ptolemaeus). The Greek attempt at explanation was only partially successful, not so much because it usually began with a geocentric orientation (from which Aristarchos and Seleucos were exceptions) but because they were obsessed with Plato's requirement that the explanation be given in terms of basic uniform, circular motions. It was Kepler early in the 17th century AD who broke away from this obsession and let modern planetary theory begin.

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