

Rambam on Calendar

📖 jewish

📖 calendar

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Colophon

Published by the [Open Torah Project](#).

Corrections, additions and suggestions are welcome at dub@opentorah.org.

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Acknowledgements

I want to acknowledge people who contributed to the content of this work - and to the fact of its existence ;) If your name should be on this list but isn't, please forgive me: the omission is not intentional.

- Mordechai Goldin - for providing office space and computer equipment when I, as a Yeshiva student, had neither;
- Ilia Pomansky - for encouraging this work from its beginning in 1991 and on;
- my wife Nina - for listening to my wild ideas, for her patience, and for help with math;
- my daughter Menucha Rochel - for assistance with the translation;
- Rabbi Michael Koretz - for stimulating discussions during our visit to Israel in 2005, encouragement, and extensive research into customs of Torah/Haftarah reading;
- Dr. Michael Partensky - for encouragement and advise;
- Dr. Peter Ofman - for asking questions that prodded me to revive this project in 2011, after years of hiatus;
- Aron Matskin - for a discussion during his visit on Rosh Chodesh Mar Cheshvan 2012;
- Rabbi Chaim Prus - for causing me to investigate which number does the year of Creation has - 0, 1 or 2;

Introduction

In the "Laws of Sanctification of the Moon", Rambam gives algorithmic description of two calendars: fixed ("arithmetic") and observational ("astronomical"). Both calendars are described in a form ready to be implemented, but the reasons for the calculation steps - especially for the astronomical calendar - are not always given: what are the models - and the formulae resulting from them - that reproduce the numbers? Sometimes Rambam describes the models, so only the formulae need to be reconstructed; sometimes the models are not described, so both the models and the formulae need to be reconstructed.

Goals of this paper are:

- reconstruct models that Rambam uses from the Rambam's text
- describe the models with diagrams and formulae
- reconstruct parameters of the models from the numbers given by Rambam
- identify misprints in the traditional editions
- analyze correspondence with the fixed calendar
- verify Rambam's tables and rounding decisions against his models
- analyze impact of various misprints on the sighting calculations
- verify consistency of Rambam's numbers
- see how Rambam's calculations of the moon visibility compare to the current models
- translate relevant chapters of Rambam into English The translation does not have to be literal; literal translations are already available ([\[Yale\]](#), [\[Moznaim\]](#)). The goal of our translation is to make the text complete and accessible for collaboration by people not proficient enough in Hebrew.

Approximate timeline of the project:

- In 1984, The Rebbe instructed Jews to learn Rambam every day. As a result, in 1991 I encountered calendar chapters of Rambam, decided to reconstruct the models behind the calculations described in them, and discovered mistakes in the text of one of the laws (15:6). The results were published in "Notices of Temimim and Anash", a weekly of the central Lubavicher Yeshiva 770. Some of the readers were appalled that someone dares to correct the text of Rambam! My point was that the text as published contains mistakes that need to be corrected. Indeed, Frenkel edition [\[Frenkel\]](#), that was already published at the time, corrects all of the mistakes I did. In fact, they were already corrected by Hazon Ish in his commentary on Rambam [\[HazonIsh\]](#) - but I did not know it then.
- 2008: I acquired a pile of books on the subject and started looking into it; I also experimented with various ways of publishing the work on the web.

- 2009: coded some of the algorithms to look into the rumors the dates of [Birkhat HaHamah](#) that were circulating then.
- 2013: code converted to Scala.
- 2017-2018: split-file encoding of the family polymorphism and current representation of the dates and angles were implemented in the supporting code.
- 2018-2019: generation of reading and learning schedules was added to the code.

Some Remarks

Solar Theory

Mean movement

In his "Laws of the Sanctification of the Moon", [Chapter 12](#), [Law 1](#), Rambam states:

“*The mean rate of movement of the sun in one day (that is, twenty-four hours) is fifty-nine minutes and eight seconds, in symbols - 59'8". It follows that its movement in ten days is nine degrees fifty-one minutes and twenty-three seconds, in symbols - 9°51'23". It also follows that its movement in a hundred days is ninety-eight degrees thirty-three minutes and fifty-three seconds, in symbols - 98°33'53". It also follows that remainder of its movement in a thousand days, after you subtract all multiples of 360° (as was explained) is two hundred sixty-five degrees thirty-eight minutes and fifty seconds, in symbols - 265°38'50". It also follows that the remainder of its movement in ten thousand days is one hundred thirty-six degrees twenty-eight minutes and twenty seconds, in symbols - 136°28'20".*

And in this way you can multiply and calculate its movement for any number of days that you want. Similarly, if you want to make known to you values of its movement for two days, three, four and so on to ten - do it. Similarly, if you want for to have known and ready values of its movement for twenty days, thirty, forty and so on to a hundred - do it. This is clear and known once you know its movement in one day.

And you should have ready and known to you mean movement of the Sun for twenty-nine days and for three hundred and fifty-four (which is the number of days in the lunar year when its months are "regular", and it is called "regular year"). The reason is: if you have those movement values ready, these calculations of the visibility of the moon will be easy, because there are twenty-nine complete days from the night of observation to the night of observation of the following month, and so it is every month: no less than twenty-nine days and no more. Since our sole desire in all those calculations is exclusively to determine visibility of the moon. And between the night of sighting of this month and night of sighting of the same month next year there is either a regular year or a year and one day; and the same every year. Mean movement of the Sun in twenty-nine days is twenty-eight degrees thirty-five minutes and one second, in symbols - $28^{\circ}35'1''$. Its movement in a regular year is three hundred forty-eight degrees, fifty-five minutes and fifteen seconds, in symbols - $348^{\circ}55'15''$.

Simple reading of the text:

“*movement in one day is ... it follows that movement in 10, 100, 1000, 10000 days is ...you can multiply and calculate movement for any number of days that you want ... movement for twenty-nine days and for three hundred and fifty-four ...*

suggests the assumption:

Values given by Rambam can be calculated by multiplying the value for one day that he gives by the number of days and discarding full circles as appropriate.

If this assumption was true, it would present a difficulty for those that read literally Rambam's statement in the introduction to "Mishne Torah" that he only includes laws in the text: values that can be calculated are redundant and should not be included!

As it turns out, the values Rambam gives can *not* be calculated from the value for one day, as is clear from the following table, where the values given by Rambam are listed alongside the values calculated from the value for one day and the difference between them:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-printedAndCalculated.adoc[]

As we see, calculated values are smaller than the values Rambam gives, so the values that Rambam included in the text are not redundant - if, of course, they are used in the calculations; we'll look into that when reading [Chapter 12, Law 2](#) in the [Aphelion](#) section below. TODO wrong section

This prompts the change of assumption to:

*Values given by Rambam, including the value for one day, can be calculated by multiplying the **exact** value for one day that he does not give by the number of days, discarding full circles as appropriate and rounding the remainder up to the seconds.*

The reading of the text then changes to:

“movement in one day if rounded is ... it follows that movement in 10, 100, 1000, 10000 days calculated using the exact value and then rounded is ... you can multiply the exact value and calculate movement for any number of days that you want ... movement for twenty-nine days and for three hundred and fifty-four can also be calculated the same way ...

Our goal is to extract as much information about the exact value Rambam used as possible *from the text itself*. Of course, it is impossible to determine the exact value from the rounded results of multiplying it: the best we can do is to find the *interval* of possible values for a given precision.

To find the interval of possible exact values for a given precision we:

- look for one value that reconstructs the values given by Rambam using step at the precision we want;
- if none is found, increase the precision (and thus decrease the step);
- construct an interval that contains just the value found;
- expand it at its precision using the appropriate step;
- expand it to the precision desired.

The code for this procedure, which is probably easier to understand than its description in words, is in [org.opentorah.astronomy.Days2Rotation](#).

Here are the intervals for the possible exact value that Rambam used extracted from the values he gives - with the least precision possible for each:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-exactMin.adoc[]

Precision sufficient for all of the values Rambam gives turns out to be up to the fourths; here are the intervals at that precision:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-exact.adoc[]

Contemplation of this table reveals a surprising fact: some pairs of the values are *incompatible* in the sense that they can not be reconstructed from the same exact value by multiplication and rounding, and even though increasing the precision widens the intervals of the possible exact values, intervals for the incompatible values will never intersect, because there is a separating value for the pair such that the intervals of possible exact values are strictly on different sides of the separating value. Here is a table that gives those separating values:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-compatibility.adoc[]

We can see that 29 is incompatible with 354, 1000 and 10000, and 354 is incompatible with 29, 100, 1000 and 10000; so, we have the following options:

option	reconstructed	exceptions
1	1, 10, 100, 1000, 10000	29, 354
2	1, 10, 100, 29	1000, 10000, 354
3	1, 10, 354	100, 1000, 10000, 29

Since we are looking for a reading with the most of the values reconstructed from the exact one and the fewest exceptions, we choose the first option; our assumption now becomes:

Values given by Rambam, including the value for one day, can be calculated by multiplying the exact value for one day that he does not give by the number of days, discarding full circles as appropriate and rounding the remainder up to the seconds - except for the values for the month and the year, which can not be calculated this way.

Accordingly, our reading of the text changes to:

“movement in one day if rounded is ... it follows that movement in 10, 100, 1000, 10000 days calculated using the exact value and then rounded is ... you can multiply the exact value and calculate movement for any number of days that you want ... movement for twenty-nine days and for three hundred and fifty-four can not be calculated this way ...

Values for 29 and 354 are separated from the rest of the values in the text itself, and that is another argument (besides minimizing the number of exceptions) for choosing the reading where the exceptions are just 29 and 354: any other choice makes the reading even *more* unnatural...

Intervals for 1, 10, 100, 1000 and 10000 days nest within one another, so any number in the interval for 10000 days reconstructs all of them.

For precision of four digits, that interval contains just one number: $0^{\circ}59'8''19'''48'''$, so if the exact value Rambam used was of this precision (and not more precise; it could not have been less precise), it is this number. In a sense, this number "falls out of the text". Here are the values reconstructed from it, and how they compare with Rambam's values:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/tables/slm-printedAndCalculatedRambam.adoc[]

As expected, values for 29 and 354 are off.

It seems that ancient and medieval authors liked the precision of six sexagesimal digits (minutes, seconds, thirds, fourths, fifths, sixths), although it is not clear how meaningful is precision of less than 1/46 billionth of a degree in this context. Here are the intervals for the exact values at precision of six digits:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/tables/slm-exact6.adoc[]

For our chosen interpretation, at this precision the exact value is in the interval from $0^{\circ}59'8''19'''47'''49'''2'''$ to $0^{\circ}59'8''19'''48'''10'''37'''$.

Now that we saw what the text itself tells us, let's see what classic and modern authors have to say about it; in the following, [\[HaMevuar\]](#) refers to the "in-depth analysis" in [\[HaMevuar\]](#) pp. 115-118. TODO remove this and add page references to all HaMevuar citations

The earliest remark that I am aware of belongs to [\[Pirush\]](#):

“Movement in one day of $0^{\circ}59'8''$ is according to al-Battani, who in his book gives the value close to $0^{\circ}59'8''20'''35''''$; but according to Btolemeus = Ptolemy, it is $0^{\circ}59'8''17'''13''''12'''''31'''''$. For every opinion it corresponds with the length of the solar year on that opinion (which for Ptolemy is 365 and $1/4$ days minus $1/300$ of a day, and for al-Battani 365 and $1/4$ days minus $3^{\circ}40'$ - where a day is 360°): movement in one day is obtained by dividing 360° (full circle) by the length of the solar year.

Proof that Rambam follows al-Battani and not someone else is: the value for 10 days that he gives - $9^{\circ}51'23''$ - is $3''$ bigger than what it would have been - $9^{\circ}51'20''$ - if it was obtained as he suggests previously by multiplying the value for 1 day that he gives by 10; but since movement in one day is bigger than $0^{\circ}59'8''$ by $20'''$, and multiplied by 10 they come to $200'''$, he took out $180'''$ of them as $3''$ and added them to $20''$, obtaining $23''$; remaining $20'''$ he multiplied by 10 and took out of them $3''$ and added them to the value for 100 days, which he gives as $98^{\circ}33'53''$ $3''$ more than the value he gives for 10 days ($9^{\circ}51'23''$) multiplied by 10 ($98^{\circ}33'50''$). The same applies to the movement over a year and a month. (The way to multiply is clear once the rules explained in chapter 11 are understood.)

If we calculate movement in one day from the length of the solar year that [\[Pirush\]](#) attributes to Ptolemy, we get the value that [\[Pirush\]](#) gives; for al-Battani, we get $0^{\circ}59'8''21'''12''''50'''''39'''''$, which is *not* the value [\[Pirush\]](#) gives - there seems to be a mistake in [\[Pirush\]](#)'s calculation, as [\[HaMevuar\]](#) quotes Sefer HaZichronos noting.

Here is the comparison of the values reconstructed from the exact value that [\[Pirush\]](#) suggests with the values given by Rambam:

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-printedAndCalculatedAlBattaniPirush.adoc[]

We see that the only values that are explained by the [\[Pirush\]](#)'s suggestion are the values for 1 and 10 days; everything else is off.

[\[IbnHabib\]](#) writes on [\[Pirush\]](#):

■ ■ [\[Pirush\]](#)'s statement that Rambam follows al-Battani's calculations and that is the reason he adds 3" to the value for 10 days seems to me to be true, correct and unassailable. I have a difficulty, though: why didn't Rambam do the same with the value for 1000 days, where he should have also added 3" resulting from multiplying by 10 20" remaining from the value for 100 days. The same applies to the value for 10000 days: in current time, which is more than 126000 days after Rambam's epoch, resulting discrepancy in the position of the sun is 7'... I need to look into this. I also have a difficulty with Rambam stating that movement of the sun during a regular year is 348°55'15": it looks like Rambam added 7" (TODO 2?) more than he should have based on the rate of movement mentioned. I need to look into this; although some thoughts that provide partial explanation of the Rambam's text did occur to me, they are not yet complete in my mind - and that is why I did not write them down.

In the standard editions, in "3" resulting from 20"", 20"" is misprinted as 2"", which is hard to explain - unless it used to be written as a number instead of being spelled out, and somebody mistook chof for a bet. It is not clear to me how did IbnHabib arrive at the value 7' for the discrepancy.

We see that [\[IbnHabib\]](#):

- ignores the apparent mistake in the exact value suggested by [\[Pirush\]](#)
- questions the values for 1000, 10000, which [\[Pirush\]](#) doesn't claim as explained by his suggestion
- questions the value for 354, which [\[Pirush\]](#) does claim as explained
- affirms the value for 10 days
- does not mention the values for 100 and 29 days
- discrepancies that he quotes are not always the same as in the table above

We also see that [\[Pirush\]](#) and [\[IbnHabib\]](#) insist that Rambam must have copied his numbers from al-Battani (if he did not copy them from Ptolemy); some later authors (including [\[LaAm\]](#)) follow this opinion; [\[HaMevuar\]](#) quotes some of the increasingly convoluted "explanations" of Rambams calculations that those authors produced while trying to preserve [\[Pirush\]](#)'s statements.

TODO why it is ok to disagree with Pirush.

[\[HaMevuar\]](#) credits [\[Ajdlar\]](#) with quoting an alternative approach attributed to some unnamed "later sages"; as far as I can tell, it is actually from cite:

[Neu83(398-399)], (p. 338-339 in the original publication) (recapitulated in shorter and less aggressive form in [\[Yale\]](#), p. 129):

“These values are not consistent with one another in the sense that they are not exact multiples of $0^{\circ}59'8''$. The obvious explanation is, of course, that we are dealing here with rounded off multiples of a more exact initial value. Indeed, we can show even more. The values for 1, 10 and 29 days and for 354 days (erroneously assumed to be an error by [\[Baneth\]](#) p. 43 note 5) are identical with the corresponding values in Al-Battani's tables, which, in turn are rounded off from multiples of $0^{\circ}59'8''20'''46''''56'''''14''''''$. The values for 100, 1,000 and 10,000 are not included in Al-Battani's tables but can be derived directly from them as follows. We multiply the value for 30 days, given by Al-Battani as $29^{\circ}34'10''$, by 3 and add the value for 10 days, which is $9^{\circ}51'23''$. Then we obtain exactly Maimonides's value $98^{\circ}33'53''$. From this the values for 1,000 and for 10,000 days are obtained by multiplication by 10 and 100.

The insight into this procedure of Maimonides is historically not without interest. In order to obtain the value for 100 days he simply took the rounded-off values for 30 and for 10 days, thus committing an error $3\varepsilon_1 + \varepsilon_2$ if ε_1 and ε_2 are the errors of rounding off committed by Al-Battani. This total error appears multiplied by 100 in the value for 10,000 days. It is an amusing accident that the result agrees much better with modern values than any other value from Ptolemy to Copernicus. [\[Baneth\]](#), who did not realize how Maimonides's tables were constructed, praised this result "als ein glänzendes Ergebnis" = a brilliant result and conjectured that Maimonides compared observations of Al-Battani with results of Hipparchus. We see now that Maimonides not only did not have the slightest intention to deviate from Al-Battani but that he showed the same disregard for the cumulative effect of errors which can be recognized in almost all ancient and mediaeval astronomers.

The following table compares the values Rambam gives with the calculations based on the al-Battani's exact value as given by [\[Neugebauer\]](#):

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-printedAndCalculatedAlBattaniNeugebauer.adoc[]

We see that the values for 100, 1000 and 10000 days can not be obtained by multiplying and then rounding the exact value derived from al-Battani, just as [Neugebauer] says - but neither is the value for 29 days what it should be, while [Neugebauer] lists it among those "rounded off from multiples" of the exact value for one day.

TODO 29 and 354 incompatible in al-Battani also?

[Neugebauer] p. 336 (396) says:

“Off hand, it is to be expected that Maimonides followed Arabic astronomers, even if he had Arabic translations of the Almagest at his disposal. Indeed, we shall show that there exist very close relations between Maimonides and Al-Battani. ... We shall confirm this result for the whole theory of the solar and lunar movement. The theory of visibility, however, deviates from Al-Battani ... I do not know the source of this special section.

It seems that [Neugebauer] was so set in his preconception that Rambam must have copied his numbers from al-Battani, that all the proof he needed is the numbers in al-Battani being the same as the ones given by Rambam, even though, as we already know, Rambam's numbers (except for the 29 and 353 days) can be reconstructed from an exact value for one day that is **different** from al-Battani's! So, [Neugebauer]'s statements that Rambam:

- showed disregard for the cumulative effect of errors
- did not have the slightest intention to deviate from al-Battani
- obtained his value for 10000 days through an "amusing accident"

are incorrect unless Rambam indeed copied all the numbers from al-Battani and calculated the missing value for 100, 1000, and 10000 days the way [Neugebauer] describes - an assumption that is not supported by the text itself.

We focus on the Rambam's text itself, and feel no duty to satisfy any preconceived notions about the "history of ideas" and the "historical context"; we choose the reading that minimizes the number of values Rambam gives that can not be reproduced from an exact value for one day - and as we already saw, there is an interval of values that result in just two exceptions: 29 and 354 days.

We are not the first to choose this approach:

- [HaMevuar] ascribes it to Shvilei HaRakia, Nove Kodosh, Moer Hodosh, Shekel Hakodesh etc.

- [\[Baneth\]](#) seems to favor it.
- [\[Moznaim\]](#) also follows it: in 12:1 note 1, it quotes the value for one day as $0^{\circ}59'8''19.8'''$, which is $0^{\circ}59'8''19'''48''''$; no references are given.
- [\[Tzikuni\]](#), p. 44 also comes up with this value - if read charitably: the value he gives, $0^{\circ}59'8.33''$, which is $0^{\circ}59'8''20'''$, is not precise enough, but the floating point number he gives is; again, no references are given.
- [\[Glitzenshtein\]](#) also gives this number, and also without references.

On our approach, values for 29 and 354 days are exceptions not explained by multiplication and rounding; disturbingly, nobody writes that the value for 29 is an exception, not on the Rambam and not - lehavdil - on al-Battani. This needs attention ;)

[\[HaMevuar\]](#) quotes Moer Hodosh's suggestion that the value $348^{\circ}55'15''$ for 354 days got garbled during the transmission of the text, and should be corrected (restored) to $348^{\circ}55'9''$; [\[Glitzenshtein\]](#) gives an explanation of how such garbling happened.

[\[HaMevuar\]](#) quotes [\[Ajdler\]](#) questioning possibility of such corruption for the value for 354 days in all five angular velocity tables Rambam writes about - two for the sun and three for the moon. This question becomes even stronger since 354 is not the only exception - 29 is another one. Also, it is hard to explain even one occurrence of such corruption, since Rambam gives each number in both word and numeric forms. At the same time, I do not think 354 is an exception in the second angular velocity table - the one we discuss in the following section, [Aphelion](#).

TODO move into a section after the aphelion movement is introduced

TODO quote opinions about the second movement being included in the table from the first!

[\[Pirush\]](#) describes the correspondence between the length of the solar year and the movement of the sun in one day; since observable (true) movement of the sun is different from the mean one, it is not obvious to me that the correspondence described by [\[Pirush\]](#) is correct; nevertheless, let's bring together various opinions on the length of the solar year (and hence, angular velocity of the sun) that we encountered so far.

In the following table, the value that is primary according to the opinion (year length or velocity) is highlighted - TODO!. We also list the values of the movement of the sun that Rambam gives that each opinion reconstructs correctly

(by multiplication and rounding). Opinion "al-Battani - Pirush (year)" uses the value for the length of the year that Pirush mentions (the one that does *not* correspond the value for the velocity that he gives).

TODO describe and give sources for the opinions of Shmuel and Rav Ada

TODO quote the discourse about their opinions being incompatible with the text here but used by the court for intercalation (that - from Sinai, this - reality)

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-opinions.adoc[]

TODO move into the "Epoch" section

And one more thing: in the description of the arithmetic calendrical calculations (TODO where), Rambam brings two opinions on the months when the world was created; assuming that the sun was created at the start of the fourth day of creation, and that it was at an equinox at the moment of its creation, we can calculate the interval of possible exact values for the velocity of the sun which will position it correctly at the Rambam's epoch (TODO reference):

Unresolved directive in remarks/solar-theory.adoc -
include:::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/slm-at-creation.adoc[]

Aphelion

In his [Chapter 12](#), [Law 2](#), Rambam continues:

“*There is a point on the Sun's orbit (and on orbits of the other seven planets) such that when the planet is there it is the highest above Earth. This point of the Sun's orbit (and so for other planets, except for the moon) rotates with constant speed. Its movement every seventy years is approximately one degree. This point is called [solar apogee](#). Its movement in ten days is one and a half seconds, half a second being thirty thirds. It follows that its movement in a hundred days is fifteen seconds. Its movement in a thousand days is two minutes and thirty seconds. Its movement in ten thousand days is twenty-five minutes. It also follows that its movement in twenty-nine days is a bit more (TODO!) than four seconds; and its movement in a regular year is fifty-three seconds.*

Here it is even more obvious that Rambam uses an exact value to calculate the values he gives: he does not give the value for the movement in one day at all, so there is no way to calculate the values that he does give.

Value for 10 days, if multiplied by 10, gives the value for 100 days; values for 1000 and 10000 days can be obtained similarly.

Unresolved directive in remarks/solar-theory.adoc -
include::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/sa-printedAndCalculated.adoc[]

Rambam does not give the value for one day, presumably because it is too small to matter for our purposes, and he wants to simplify the calculations.

Straightforward criterion of being too small is: rounded up to a specific precision, the value becomes zero. Usually, everything in Rambam's text is rounded up to the seconds; here Rambam gives the value for ten days up to the *thirds*, so it would be natural to assume that his exact value for one day becomes zero when rounded up to the thirds - but any such value would then be too small to be usable to reconstruct the other values, so we are forced to say that the exact value becomes zero only when rounded up to the seconds.

We can use the same procedure as before to obtain the intervals for the possible exact value that Rambam used from the values he gives; here they are - with the least precision possible for each:

Unresolved directive in remarks/solar-theory.adoc -
include::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/sa-exactMin.adoc[]

One number "jumps out of the text" (again): we can reproduce all the values Rambam gives assuming that the exact value for one day that he used is $0^{\circ}0'0''9'''$.

Unresolved directive in remarks/solar-theory.adoc -
include::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/sa-printedAndCalculatedRambam.adoc[]

Calculations show that it takes a bit less than 66 years for the aphelion to move one degree, not 70 years.

When we round the results of the calculations up to the thirds, the highest precision Rambam uses (in the value for ten days), we see some discrepancies:

Unresolved directive in remarks/solar-theory.adoc -
include::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/sa-printedAndCalculatedRambam3.adoc[]

TODO need to see the effects of the rounding; compare with the explanations of
Pirush above; analyze the alternative presentation possibilities

TODO no answer for the redundancy question here

Here are the intervals for the exact values at precision of six digits:

Unresolved directive in remarks/solar-theory.adoc -
include::/home/runner/work/opentorah/opentorah/docs/paper/calendar/../../build/t
ables/sa-exact6.adoc[]

The interval for ten thousand days is nested within every other interval, so all the
values can be reconstructed based on any value from the interval from
0°0'0"8"59"49"2" to 0°0'0"9"0"10"37".

Translation of the original text

Laws of the Sanctification of the new Moon

There is one positive commandment: to calculate, to know, and to establish on
which day each month of the year begins. Explanation of this commandment is in
these chapters.

Chapter 1

Law 1

The months of the year are lunar months, as it is said: "... the burnt offering of
the month in its month" and it is said: "This month shall be for you the head of
the months". This is what the sages said: "The Holy One, blessed be He, showed
to Moshe, in a prophetic vision, the image of the Moon, and said to him: 'When
you see the Moon like this - sanctify it.'"

But the years that we reckon are solar years, as it is said: "Keep the month of
aviv spring".

Law 2

By how much is the solar year longer than the lunar year? By approximately 11 days. Therefore, when this excess accumulates to around 30 days, or a little less, or a little more, a month is added and the year is made to have 13 months - which is called a "pregnant" year. This is done because it is impossible to have a year of 12 months and some days, as it is said: "for the months of the year" - you count the months of the year, but not the days of the year.

Law 3

Each month, the moon becomes hidden for about two days, or a little less or more: about one day before its conjunction with the sun at the end of the month, and about one day after its conjunction with the sun, and in the evening it is sighted in the west. The night when it is sighted in the west after being hidden is the beginning of the month. We count 29 days from that day; if the moon is sighted on the 30th night, the 30th day is the first day of the next month. If it is not sighted, first day of the next month is the 31st day, and the 30th day belongs to the previous month. On the 31st night, we do not depend on the moon, regardless if it is visible or not, since lunar month is never longer than 30 days.

Law 4

Month of 29 days, when the moon was sighted on the 30th night, is called "lacking". If the moon was not sighted, and the previous month has 30 days, it is called "pregnant" month, or "full" month. The moon sighted on the 30th night is called "moon sighted on time". If it is sighted on the 31st night, but not on the 30th night, it is called "moon sighted on the night of pregnancy".

Law 5

Sighting of the moon is not up to an individual, unlike determination of the Shabbos, where one counts 6 days and observes Shabbos on the 7th, but is given to the court. Only when the court sanctifies and establishes the day as the beginning of the new month does it become the beginning of the new month. As it is said: "this month shall be for you" - this testimony is entrusted to you.

Law 6

The court calculates, like the astronomers who know positions of the planets and their movements, and look into it until they know if it is possible for the moon to be sighted on time - that is, on the 30th night - or not. If they determined that it is possible for it to be sighted, they sit and wait for witnesses all day - that is, the 30th day. If the witnesses did come and were examined in accordance with the law, and their words were accepted - they sanctify it. If the moon was not sighted and the witnesses did not come, they complete the 30 days and the month will be "pregnant". If they found out from calculations that it is impossible to sight the moon, they do not sit during the 30th day and do not await the witnesses. And if the witnesses did come, it is certain that they are false witnesses or that they saw a likeness of the moon in the clouds and not the real moon.

Law 7

It is a positive commandment of the Torah for the court to calculate and to know whether the moon can be sighted or not, and to examine the witnesses before the month is sanctified, and to send messengers to notify the rest of the people which day is the beginning of the month, so that they know on which day are the festivals. As it is said: "which you will call the holy convocations" and as it is said : "keep this statute in its time".

Law 8

Calculation and establishment of the months and declaration of "pregnant" years is done only in the Land of Israel, as it is said: "For out of Zion will come forth Torah, and the word of G-d - from Jerusalem". But, if there was a man great in wisdom, and ordained in the Land of Israel, who came out of the Land, and there remains no one equal to him in the Land of Israel, he can calculate and establish month, and declares "pregnant" years outside of the Land. If he becomes aware that in the Land of Israel there appeared a man as great as him - or, needless to say, greater than him - he is prohibited to establish and to proclaim outside of the Land, and if he transgressed and did establish or did proclaim, it is as if he didn't do a thing.

Chapter 9

Law 1

In regard the length of the solar year: there are Jewish sages that say that it is three hundred sixty five days and a quarter of a day, which is six hours. There are among them that say that it is less than a quarter of a day. Likewise, among the scholars of Greece and Persia there is a disagreement about this matter.

Law 2

Those that say that it is 365 days and a quarter of a day, remainder of each nineteen-year cycle is one hour and four hundred eighty five parts, as we said. Then, from season to season there is ninety one day and seven and a half hours. And once you know one season - in which day and in which hour it is - start counting to the second season that is after it, and from the second to the third - until the end of the world.

Law 3

Season of Nisan is the hour and the part when the sun enters into the beginning of the constellation of Aries. And season of Tammuz is when the sun is at the start of the constellation of Cancer. And the season of Tishrei is when the sun is at the start of the constellation of Libra. And the season of Tevet is when the sun is at the start of the constellation of Capricorn. And the season of Nisan in the first year of Creation - according to this calculation = opinion - preceded the new moon of Nisan by seven days nine hours and six hundred and forty two part, in symbols - 7 9 642.

Law 4

This is the way to calculate the season. First, figure out how many complete cycles are there from the year of the Creation till the cycle that you want. And take, for each of those cycles, one hour and 485 parts. Gather all the parts into hours, and all the hours into days, and subtract from the total seven days nine hours and six hundred and forty two parts, and what remains - add it to the new moon of Nisan of the first year of the cycle. You get in which hour and in which day of the month will be the season of Nisan of that first year of that cycle. And from it, start counting ninety one day and seven and a half hours for each subsequent season.

And if you'd want to know the season of Nisan of the a year that is year number so-and-so of the cycle you are in, take for all the full cycles an hour and 485 for

each cycle, and for all complete years that passed in the cycle, ten days and twenty one hours and two hundred and four parts for each year, and add everything up, and subtract from it seven days and nine hours and six hundred and forty two parts. And what remains, remove from it lunar months of twenty nine days and twelve hours and seven hundred ninety-three parts. And remainder less than a lunar month - add it to the new moon of Nisan of that year, and you'll know the time of the season of Nisan of that year, what day of the month is it and at what hour.

TODO

Law 5

TODO

Law 6

TODO

Law 7

TODO

Law 8

TODO

Chapter 12

Law 1

The mean rate of movement of the sun in one day (that is, twenty-four hours) is fifty-nine minutes and eight seconds, in symbols - $59'8''$. It follows that its movement in ten days is nine degrees fifty-one minutes and twenty-three seconds, in symbols - $9^{\circ}51'23''$. It also follows that its movement in a hundred days is ninety-eight degrees thirty-three minutes and fifty-three seconds, in symbols - $98^{\circ}33'53''$. It also follows that remainder of its movement in a thousand days, after you subtract all multiples of 360° (as was explained) is two hundred

sixty-five degrees thirty-eight minutes and fifty seconds, in symbols - $265^{\circ}38'50''$. It also follows that the remainder of its movement in ten thousand days is one hundred thirty-six degrees twenty-eight minutes and twenty seconds, in symbols - $136^{\circ}28'20''$.

And in this way you can multiply and calculate its movement for any number of days that you want. Similarly, if you want to make known to you values of its movement for two days, three, four and so on to ten - do it. Similarly, if you want for to have known and ready values of its movement for twenty days, thirty, forty and so on to a hundred - do it. This is clear and known once you know its movement in one day.

And you should have ready and known to you mean movement of the Sun for twenty-nine days and for three hundred and fifty-four (which is the number of days in the lunar year when its months are "regular", and it is called "regular year"). The reason is: if you have those movement values ready, these calculations of the visibility of the moon will be easy, because there are twenty-nine complete days from the night of observation to the night of observation of the following month, and so it is every month: no less than twenty-nine days and no more. Since our sole desire in all those calculations is exclusively to determine visibility of the moon. And between the night of sighting of this month and night of sighting of the same month next year there is either a regular year or a year and one day; and the same every year. Mean movement of the Sun in twenty-nine days is twenty-eight degrees thirty-five minutes and one second, in symbols - $28^{\circ}35'1''$. Its movement in a regular year is three hundred forty-eight degrees, fifty-five minutes and fifteen seconds, in symbols - $348^{\circ}55'15''$.

Law 2

There is a point on the Sun's orbit (and on orbits of the other seven planets) such that when the planet is there it is the highest above Earth. This point of the Sun's orbit (and so for other planets, except for the moon) rotates with constant speed. Its movement every seventy years is approximately one degree. This point is called [solar apogee](#). Its movement in ten days is one and a half seconds, half a second being thirty thirds. It follows that its movement in a hundred days is fifteen seconds. Its movement in a thousand days is two minutes and thirty seconds. Its movement in ten thousand days is twenty-five minutes. It also follows that its movement in twenty-nine days is a bit more (TODO!) than four seconds; and its movement in a regular year is fifty-three seconds.

We already said that the epoch that our calculations start from is beginning of the night of the fifth day that is 3rd of Nisan of the year four thousand nine hundred thirty-eight from the Creation. Position of the Sun in its mean movement at the epoch was seven degrees three minutes and thirty-two seconds in the constellation of Ram, in symbols - $7^{\circ}3'32''$. Position of the Sun's apogee at the epoch was twenty-six degrees forty-five minutes and eight seconds in the constellation of Twins, in symbols - $26^{\circ}45'8''$.

When you want to know position of the Sun in its mean movement at any time you want, take the number of days from the epoch to the day that you want, and find out its mean movement during those days from the values we mentioned, add all of it to the epoch, adding each kind of unit with its kind, and the result is the position of the Sun in its mean movement on that day.

For example, if we wanted to know Sun's mean position at the beginning of the night of Shabbat whose day is the fourteenth of Tammuz of this year, which is the year of the epoch - we find the number of days from the day of the epoch to the beginning of the day that we want to find Sun's position on to be a hundred days. We take its mean movement over a hundred days - which is $98^{\circ}33'53''$ - and add it to the epoch - which is $7^{\circ}3'32''$. Result of this calculation: one hundred and five degrees thirty seven minutes and twenty-five seconds. In symbols - $105^{\circ}37'25''$. So its position in its mean movement at the beginning of this night is in the constellation of Cancer, at fifteen degrees in it, and thirty-seven minutes of the sixteenth degree.

Mean position thus calculated is sometimes exactly at the beginning of the night, sometimes an hour before sunset, and sometimes - an hour after sunset. This fact is not important for the Sun in the calculations of the observation of the new moon since we compensate for this approximation when calculating mean Moon.

Do it the same way for whatever time you want whatsoever, even after a thousand years: when you add up all the reminders and add to the epoch, result you get is the mean position. And the same you do for the mean Moon and mean of every planet: once you know what is the movement in one day and what is the epoch that we start from, and you sum up its movement in the years and days that you want, and add it to the epoch - you get its position in mean movement.

Do the same for the Sun's apogee: add its movement in those days or years to the epoch, and you get position of the Sun's apogee for the day that you want.

Also, if you want to make a different epoch from which to start, other than the epoch that we start from (which is this year), so that epoch is at the beginning of

the year of a known cycle or at the beginning of a hundred-year period - you can do it. And if you want the epoch from which you start to be in the years that already passed before this epoch or many years after it - the way is known.

What is this way? You already know movement of the Sun in a regular year, and its movement in twenty-nine days, and its movement in one day. And it is known that year whose months are full is longer than the regular year by one day, and the year whose months are lacking is shorter than the regular year by one day. And the leap year: if its months are regular, it will be longer than the regular year by thirty days, and if its months are full, it will be longer than the regular one by thirty-one day, and if its months are lacking, it will be longer than the regular one by twenty-nine days. Once you know all those facts, calculate Sun's mean movement for the years and days that you want, and add to the epoch that we made, and you'll get its mean position for the day that you want from the coming years - and that you make into an epoch. Or subtract mean movement that you calculated from the epoch that we made, and you get an epoch for the day that you want from the years that passed, and make that mean position an epoch. And the same you shall do for the mean Moon and the rest of the planets if their movements will be known to you. And it should be clear to you from the idea of our words that the same way you can find out mean Sun for any day you want from the coming days, you can calculate its mean for any day you want from the days that passed.

Chapter 13

Law 1

If you want to find out true position of the Sun for any day that you want, first calculate its mean position for that day the way we explained, and calculate position of the Sun's apogee. Subtract position of the Sun's apogee from the Sun's mean position; what is left is called [solar portion](#).

Law 2

See how many degrees is the maslul of the Sun; if maslul was less than one hundred and eighty degrees, subtract parallax correction from the position of the mean Sun; if maslul was more than one hundred and eighty degrees up to three hundred and sixty, add parallax correction to the position of the mean Sun; that what it is after you add to it or subtract from it is the true position.

Law 3

Know that if maslul is exactly one hundred and eighty or exactly three hundred and sixty, it doesn't have parallax correction; rather, the mean position is the true position

Law 4

And what is the value of the parallax correction? If maslul will be ten degrees, its parallax correction will be twenty seconds; and if it will be twenty degrees, its parallax correction will be forty minutes; and if it will be thirty degrees, its parallax correction will be fifty eight minutes; and if it will be forty degrees, its parallax correction will be one degree and fifteen minutes; and if it will be fifty degrees, its parallax correction will be one degree and twenty nine minutes; and if it will be sixty degrees, its parallax correction will be one degree and forty one minutes; and if it will be seventy degrees, its parallax correction will be one degree and fifty one minutes; and if it will be eighty degrees, its parallax correction will be one degree and fifty seven minutes; and if it will be ninety degrees, its parallax correction will be one degree and fifty nine minutes; and if it will be one hundred degrees, its parallax correction will be one degree and fifty eight minutes; and if it will be one hundred and ten degrees, its parallax correction will be one degree and fifty three minutes; and if it will be one hundred and twenty degrees, its parallax correction will be one degree and forty five minutes; and if it will be one hundred and thirty degrees, its parallax correction will be one degree and thirty three minutes; and if it will be one hundred and forty degrees, its parallax correction will be one degree and nineteen minutes; and if it will be one hundred and fifty degrees, its parallax correction will be one degree and one minute; and if it will be one hundred and sixty degrees, its parallax correction will be forty two minutes; and if it will be one hundred and seventy degrees, its parallax correction will be twenty one minutes; and if it will be one hundred and eighty degrees exactly, it doesn't have parallax correction, as we explained, rather Sun's mean position is its true position.

Law 5

If maslul was more than one hundred and eighty degrees, subtract it from three hundred and sixty degrees and find out its parallax correction. For example, if maslul was two hundred degrees, subtract it from three hundred and sixty, and one hundred and sixty degrees will be left. And we already made known that

parallax correction for one hundred and sixty degrees is forty two minutes, and so is the parallax correction for two hundred - forty two minutes.

Law 6

Also, if the maslul was three hundred degrees, subtract it from three hundred and sixty - and sixty will remain. And you already know that parallax correction for sixty degrees is one degree and forty one minutes, and so is the parallax correction for three hundred degrees. And the same way - for every number.

Law 7

TODO

Law 8

TODO

Law 9

TODO

Law 10

TODO

Law 11

TODO

Chapter 14

Law 1

The moon has two mean movements. The moon itself rotates on a small circle that does not surround all of the Earth. Moon's movement on that small circle is called [mean lunar anomaly](#). The small circle (epicycle [TODO link to Wikipedia](#)) itself rotates on a big circle (deferent [TODO link to Wikipedia](#)) that encircles the

Earth. The mean movement of the small circle on the big circle that encircles the Earth is called movement of the [mean lunar longitude](#).

Law 2

Movement in mean lunar longitude in one day is $13^{\circ}10'35''$.

For longer periods, (remainder) of the movement in mean lunar longitude is:

And in this way you can calculate it for any number of days and years that you want.

Law 3

Movement in mean lunar anomaly in one day is $13^{\circ}3'54''$.

For longer periods, (remainder) of the movement in mean lunar anomaly is:

Law 4

In the beginning of the night to Thursday that is the epoch (TODO measured from what? Chapter 11?) [TODO: link to definition] for these calculations, mean lunar longitude was $1^{\circ}14'43''$ into the constellation of Ram. And mean lunar anomaly on the epoch was $84^{\circ}28'42''$. Now that you know rate of movement in the mean lunar longitude and its value on the epoch to which you add, you'll calculate mean lunar longitude on any day that you want the same way as you did for the mean solar longitude. TODO: reference

Law 5

After you calculate mean lunar longitude at the beginning of the night that you want, contemplate the sun (TODO: longitude?) and figure out which constellation (zodiac) is it in. [TODO is this in the text? This is the correction of the mean lunar longitude depending on the mean solar longitude:]

Law 6

Solar Longitude on the Zodiac	from	to, not including	Lunar longitude correction
middle of Pisces-middle of Taurus	315°	15°	0°
middle of Taurus-beginning of Gemini	15°	30°	0°15′
beginning of Gemini-beginning of Leo	30°	90°	0°15′
beginning of Leo-middle of Virgo	90°	135°	0°15′
middle of Virgo-middle of Libra	135°	165°	0°
middle of Libra-beginning of Sagittarius	165°	210°	-0°15′
beginning of Sagittarius-beginning of Aquarius	210°	270°	-0°30′
beginning of Aquarius-middle of Pisces	270°	315°	-0°15′

The value of mean lunar longitude after you add to it or subtract from it or leave it as it is - that is mean lunar longitude approximately a third of an hour after sunset on the date you are calculating it for. And this is what is called [mean lunar longitude at observation time](#).

Chapter 15

Law 1

To find [true lunar longitude](#) on a specific day: First, calculate mean lunar longitude during observation time of the desired night. Also, calculate mean lunar anomaly and mean solar longitude for the same time. Then, subtract mean solar longitude from the mean lunar longitude and double the result. This value is called [doubled distance](#).

Law 2

We already stipulated that all the calculations in these chapters are for one purpose only: to know if the moon is visible. And it is not possible for this double distance during the night of observation when the moon is indeed visible to be outside the interval from 5° to 62° . It cannot be more - nor less.

Law 3

A correction that depends on the doubled distance is added to the mean lunar anomaly, giving [corrected lunar anomaly](#):

doubled distance	correction of the mean anomaly
$\sim 5^\circ$	0°
6° - 11°	1°
12° - 18°	2°
19° - 24°	3°
25° - 31°	4°
32° - 38°	5°
39° - 45°	6°
46° - 51°	7°
52° - 59°	8°
60° - 63°	9°

Law 4

Then, see how many degrees is corrected lunar anomaly. If it is less than 180° , subtract visible anomaly of this corrected anomaly from the mean lunar longitude the observation time. And if corrected lunar anomaly is more than 180° but less than 360° , add visible anomaly of this corrected anomaly to the mean lunar longitude the observation time. And mean lunar longitude after you add to it or subtract from it is the [true lunar longitude at the observation time](#).

Law 5

If the corrected anomaly is 180° or 360° , there is no visible anomaly, so mean lunar longitude at observation time is also true longitude.

Law 6

What is the value of the visible anomaly for a given value of the corrected anomaly?

Law 7

TODO

Law 8

TODO

Law 9

TODO

Glossary

Astronomical Terms

solar apogee

Point on the orbit of the Sun where it is highest above the Earth. -
aphelion/perihelion

solar portion

???

mean lunar anomaly

in the original: אמצע המסלול

Mean angular coordinate of the Moon on its epicycle.

corrected lunar anomaly

in the original: מסלול הנכון

mean lunar longitude

in the original: אמצע הירח

mean lunar longitude at observation time

???

true lunar longitude

in the original: הירח האמיתי

true lunar longitude at the observation time

???

doubled distance

in the original: מרחק הכפול

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1 Bamidbar 28:14 2 Shemos 12:2 3 Rosh Hashanah 20b; Menachot 29a 4 Dvarim 16 5 Megilla 5a; Nazir 7a 6 This is part of Law 1. 7 This is part of Law 4. 8 My understanding of the word usage in the original. 9 See Chapter 11, Law 7 on the start of Jewish Zodiac. (TODO reference) 10 This is Law 5.

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