

THE JEWISH CALENDAR: A SCIENTIFIC PERSPECTIVE

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The purpose of this succinct introduction to the Jewish calendar is to provide the essential scientific knowledge that was, to varying degrees, available and likely used in the calendar's establishment. Despite Rambam's assertion that this topic can be taught to minors in a few days, the dearth of commentary on these sections of his writings would seem to belie that claim. This summary is intended to help fill that lacunae.

The Metonic Cycle

Following the period during which the sanctification of a new month was based on the testimony of two witnesses who observed a "new" moon, a fixed calendar was introduced. The calendar was established with two major goals in mind. First, given that the Torah mandates that Pesah occur during the springtime, Pesah had to begin after the spring equinox. Second, the Jewish month had to begin, in perpetuity, approximately when the new moon could first be seen.

To accomplish the first goal, the Rabbis used what is known as the Metonic cycle, named for Meton, a 5th-century BCE Greek astronomer. The Metonic cycle equated 19 solar years with

235 lunar months. Were each of the 19 solar years to have only 12 lunar months, a 19-year period would be missing 7 months ($19 \times 12 = 228$ months.) Thus, during every 19-year cycle, 7 additional months had to be added, or "intercalated." The calendar continued an earlier tradition that had added an extra month of Adar, among other reasons, to ensure that Pesah occurred in the springtime. The additional month added during those 7 years was also a second month of Adar, delaying the start of the month of Nissan by an additional month in those years.

The Lunar Month

Before resuming our discussion of the Metonic cycle, we must first discuss the length of a lunar month, a number that would enable the Rabbis to accomplish their second goal of beginning each month at the approximate time when the new moon could first be seen. Even the ancients knew that while solar years were equal in length, lunar months were not. The precise astronomical beginning of each month is called a "conjunction" and occurs when the moon moves between the sun and earth. The midpoint of the month, when the earth moves between the sun and the moon and when the moon is at its fullest, is called an "opposition." If we measure the length of a month as the period between conjunctions (or oppositions), the maximum variation between the lengths of different months (from a little more than 29 days to slightly less than 30) amounts to about 18 hours. Fortunately, the ancients also knew that only at a "perfect" conjunction can we witness a solar eclipse and only at a "perfect" opposition can we witness a (more frequent) lunar eclipse.

By carefully measuring the length of time between such "perfect" events, the ancient Babylonians, well before the Greeks and Romans, were already estimating the average length of a month. The Rabbis used this average to determine the "*molad*"; that is, even though the term "*molad*" ostensibly refers to the actual astronomical conjunction, in practice, the *molad* used and announced in synagogues is set by adding the length of an average month to the previous *molad*. Despite variation in the length of a lunar month, the difference in time between the *molad* and that month's actual conjunction, summed over any substantial number of consecutive months, remains close to zero. Goal two was now accomplished.

The Rabbis determined that the average length of a lunar month from which *moladot* were calculated is 29 days, 12 hours, and $793/1080$ ths of an hour. Expressed as a decimal, that determination is accurate to the 6th decimal place.

Employing the Metonic relationship as a precise equation, the Rabbis used that average length of a lunar month to determine the duration of a solar year. This is the basis for what is known as *tekufot de-Rabbi Ada*, as opposed to the less accurate *tekufot de-Shmuel*, which align with the Julian calendar then in use, utilized in other, less critical, halakhic contexts (such as determining the recitation of “*ve-ten tal u-matar li-vrakhah*” outside of Eretz Yisrael, as well as determining the recitation of *Birkhat ha-Hamah*). More precisely, *tekufot* refer to the spring and fall equinoxes and the summer and winter solstices, the four quarter-points of the solar year.

Additional Considerations

Before describing the accuracy of the fixed calendar and providing an assessment of what minor refinements might have been made given current scientific knowledge, we need to better understand the events surrounding a new month, as well as some additional details that were introduced before the final emergence of the calendar in use.

First, around an actual conjunction, when the moon passes between the sun and the earth, the “old” moon disappears before a “new” moon appears at some later point. The moon is not visible for around 60 hours, with an approximate variation of 24 hours in both directions. (The period without a visible moon is not exactly equal before and after a conjunction.) Since a “new” moon is only visible for a brief period after sunset, yet another day may pass before a “new” moon can be observed. Second, as implied earlier, the *molad* or “average” conjunction can differ from the actual conjunction by as many as 9 hours in either direction. Third, a new moon is not necessarily visible everywhere on earth at the same time. If the moon is on a particularly southerly track, its visibility around the latitude of Jerusalem may be further delayed.

Taken *in toto*, these three factors explain why the *molad* can precede the visibility of a new moon by up to several days. Note that neither this mode of division into exactly these three factors, nor the various lengths of time involved, is to be assumed when reading the Rabbinic literature. Various Talmudic passages do not reflect current scientific knowledge.

Regardless, the *molad* as defined is indirectly critical to establishing the first day of any given month; the relationship is indirect since only the *molad* of Tishrei matters in deciding on Rosh Hodesh for the remaining months of that year. The *molad* announced every Shabbat when *Birkhat ha-Hodesh* is recited has nothing whatever to do with the day or days when Rosh Hodesh will occur.

Finalizing the Calendar

We are now prepared to explain some additional details that played a role in finalizing the calendar.

Based on the Metonic cycle, 7 additional lunar months were added during every 19-year cycle in the 3rd, 6th, 8th, 11th, 14th, 17th, and 19th years. Months normally alternated between 29 and 30 days; those with 30 days celebrated both the last day of that month in addition to the first day of the next month as Rosh Hodesh. The month of Tishrei always had thirty days; as opposed to all other 30-day months, it had two days of Rosh Hodesh (also Rosh Hashanah) on the first and second days of the month. *Except for the postponements described below, the first day of Tishrei coincided with the molad.* Once Tishrei was set, all the remaining months normally alternate between 29 and 30 days, Tishrei always being 30 days.

To this system a few additional rules, each postponing Rosh Hashanah from the day of the *molad*, were added. The most famous rule, referred to as "*lo aleph/daled/vav* (pronounced *ADU rosh*)," postpones Rosh Hashanah if it were to fall on the first, fourth, or sixth day of the week. The Talmud explains that the basis for this rule is two-fold. First, there was a desire to avoid a lengthy period during which a dead body would remain unburied, as would happen if Yom Kippur occurred the day before or after Shabbat; this is prevented by disallowing Rosh Hashanah to begin on Wednesday or Friday. Second, there was a desire to avoid Hoshanah Rabbah occurring on Shabbat, which would result in the omission of the willows ceremony, which would give support to Sadducee claims about the nature of that ceremony. The Rabbis prevented this by not allowing Rosh Hashanah to begin on Sunday.

A second rule, a *molad zaken*, a so-called "old *molad*," required that the *molad* occur before noon. When it occurred after noon, the start of Tishrei would be postponed by one day. Many diverse reasons were given for this postponement, nominally explaining the one given in the Talmud. Attempts to explain the logic behind this postponement has itself generated a large body of literature, which lies beyond the scope of our discussion.

Two other rules were highly technical, resulting from a restriction of the length of a thirteen-month year to 383, 384, or 385 days, and a twelve-month year to 353, 354, or 355 days. These technical restrictions caused two complex rules for the postponement of the first day of Tishrei and affected the usual lengths of the months of Heshvan and Kislev as well.

At most two of the postponements can occur in a given year, delaying the start of Rosh Hashanah by two days. Historical documents indicate that the four rules governing postponements to the first day of Rosh Hashanah were finalized over a lengthy period. Their order of finalization is unclear, though the order in which they have been described above is plausibly the historical order of their finalization.

In the intervening years, our scientific knowledge has advanced. The length of the average month is now known more precisely, to 8 decimal places; the number the Rabbis used is less than $\frac{1}{2}$ a second too long each month. At that rate, the time of the *molad* moves ahead by almost six seconds a year, one minute every ten years, and one hour every 600+ years. In a few thousand years this may become consequential. For purists, the sum, over an extended period, of the differences between the *molad* and the actual conjunction no longer averages to zero. While that arithmetic result is a tad inelegant, it is not troubling, and could be easily corrected if needed.

The length of the year suffers from two issues. Given a very slightly longer assumed length of the month, the resulting inaccuracy in the length of the year would be entirely inconsequential. More consequential is the imprecision that results from the slight inaccuracy in the Metonic equation. (The length of 19 years equals slightly **less** than the length of 235 average months.) That inaccuracy results in the solar year being approximately six minutes short on average over the course of a Metonic cycle. That adds up much more rapidly: one hour every ten years and just under one full day every 240 years. Instead of occurring towards the beginning of the spring, in about 10,000 years Pesah will be celebrated towards the middle of the spring. (Note that something similar happened even when the calendar was set by a *beit din* when they added an additional month in successive years.) Well before that, in some 5,000 years, the Rabbis will have to convene and agree to drop the 13th month of some designated year.

If we were willing to choose a longer than 19-year cycle, we could do better. Computer scientists have created a near-perfect cycle, over 6,000 years in length. However, while our method is not absolutely precise, for the time being, we are doing just fine.

Rav Soloveitchik *zt"l* delivered many *shiurim* describing the halakhic basis for the calendar now in use. In various contexts, he implied that precise alignment with astronomical reality takes a second seat to acceptance by Jewish practice. He further stressed that the courts and rabbinic leaders were acting not in their own right, but as representatives of the Jewish people (“*Keviat Moadim al pi Reyiah Ve-heshbon*” in *Kovetz Hidushei Torah; Shiurim Le-*

zekher Aba Mari z"l, "*Keriat ha-Torah Ba-moadim*"). Our adherence to this remarkable Rabbinic calendar, not absolute cosmological precision, is its ultimate basis for legitimacy.



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