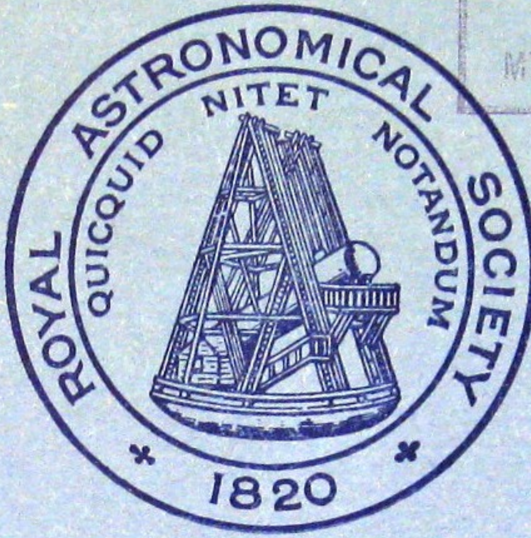
OCCASIONAL NOTES



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EPHEMERIS TIME

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1. Introduction. – At the eighth General Assembly of the International Astronomical Union, held in Rome in 1952 September, the following resolution was adopted:

“It is recommended that, in all cases where the mean solar second is unsatisfactory as a unit of time by reason of its variability, the unit adopted should be the sidereal year at 1900.0; that the time reckoned in these units be designated “Ephemeris Time”; that the change of mean solar time to ephemeris time be accomplished by the following correction:

$$\Delta T = +24^{s}.349 + 72^{s}.318T + 29^{s}.950T^{2} + 1.82144 \cdot B$$

where T is reckoned in Julian centuries from 1900 January 0 Greenwich Mean Noon and B has the meaning given by Spencer Jones in *Monthly Notices* R.A.S., Vol. **99**, 541, 1939; and that the above formula define also the second.

No change is contemplated or recommended in the measure of Universal Time, nor in its definition.”

The ultimate purpose of this article is to explain, in simple terms, the effect that the adoption of this resolution will have on spherical and dynamical astronomy and, in particular, on the ephemerides in the *Nautical Almanac*. It should be noted that, in accordance with another I.A.U. resolution, Ephemeris Time (E.T.) will not be introduced into the national ephemerides until 1960.

Universal Time (U.T.), previously termed Greenwich Mean Time (G.M.T.), depends both on the rotation of the Earth on its axis and on the revolution of the Earth in its orbit round the Sun. There is now no doubt as to the variability, both short-term and long-term, of the rate of rotation of the Earth; U.T. does not therefore increase uniformly and can no longer be regarded as a measure of uniform time. But a uniform time is implicitly assumed as the independent argument in dynamical astronomy; this time must accordingly be defined so as to be independent of the Earth's rotation. It is therefore of interest first to say something about the variation in the rate of rotation of the Earth, and to explain the basis of the form of ΔT.

2. *Rotation of the Earth.* – There are three types of variation in the rate of rotation of the Earth.

Firstly, there is the extremely complex secular change due to the interaction of the Sun, Earth and Moon. Until comparatively recently the observed slow secular increase of about $0^{s}.001$ in a century in the length of the day was attributed solely to the effect of tidal friction, mainly in shallow seas. An undetected change in the rate of the Earth's rotation, without change in angular momentum, will be interpreted as changes in the mean longitudes of the Sun and Moon proportional to their mean motions; it is, in fact, a change in the time-scale. However, the total energy of the Sun-Earth-Moon system must remain constant, so that a decrease in the rate of rotation of the Earth due to tidal friction caused by the Moon is reflected in an acceleration of the Moon in its orbit; similarly in the case of the Sun, for which the effect is so much smaller as to be inappreciable. The ratio of the secular accelerations of the Sun and Moon, calculated on the above basis, is not in accord with that derived from a discussion of the observations.

It has now been shown that the phase of the atmospheric tidal oscillation is such that the Sun's gravitational couple may accelerate the fate of the Earth’s rotation; moreover, it is suggested that the energy so required is extracted from the solar heat falling on the Earth's surface through a heat-engine effect. This added factor gives rise to the possibility of bringing the theoretical ratio into accordance with that observed. The determinations of both the theoretical and observational ratios are exceedingly complex, and subject to considerable uncertainty; moreover, it is not possible to make a unique separation between these secular changes and the irregular changes discussed below.

Secondly, there are seasonal changes due to a variety of causes which give rise to periodic changes in the rate of rotation of the Earth and thus in the accumulated measure of time. When these changes were first established by comparison with high-precision quartz-crystal clocks, there appeared to be a pronounced annual term, resulting in the Earth rotating more slowly than the average rate in the first half of the year and more quickly in the second half; during the course of the year, the variation in the length of the day was about $\pm 0^s.001$, leading to a maximum accumulation in the measure of time of about $\pm 0^s.05$. More recent observations, although confirming the existence of seasonal changes, have suggested that their nature is highly variable from year to year. Many suggestions have been put forward to explain these seasonal changes; perhaps the most reasonable, which gives rise to changes of angular momentum of the right order, is the seasonal movements of air masses in the Earth's atmosphere. Although such periodic changes are of the foremost importance for precise time-keeping, and the associated determination of frequency standards, they are of little interest as regards the determination of ephemeris time, which is essentially a long-term problem.

Thirdly, there are irregular changes which follow no pattern and to which no particular cause can be assigned. It is, however, tacitly assumed that the are reflections of changes in the moment of inertia of the Earth (or at least leave the angular momentum unchanged), so that they will cause no direct change in the orbits of the Sun and Moon; thus, they correspond to changes in the mean longitudes of the Sun, Moon and planets which are proportional to their mean motions. These are, in fact, the changes which give rise to the fluctuations (*B* of the resolution) in the Moon's mean longitude. It is now pretty well established that these fluctuations are due to the accumulated effect of small, random, abrupt accelerations or decelerations producing rather more gradual changes in the rate of rotation of the Earth; certainly the observed values are consistent with this hypothesis. The observed values are difficult to separate from the secular changes.

3. *Derivation of the formula for ΔT.*–With these types of variation in mind, it is now possible to analyse the resolution and to understand why ephemeris time has been defined in this particular way.

First of all, a standard unit should possess two indispensable qualities: it must be invariable, and it must be accessible. To the best of our knowledge the revolution of the Earth round the Sun provides the most suitable basis for the unit of time; there is there is no evidence of any variation, or any cause of variation for which full allowance cannot adequately be made, and it can be made accessible. There is some choice as regards the precise definition; the more rigid and fundamental it is, the less accessible and subject to error it is. The unit of time is actually defined in the resolution as the sidereal year at 1900.0; that is a unique entity, and is thus clearly invariable. (Actually it would have been slightly more fundamental to have used the tropical year at 1900.0 which could have been deduced from observation without an assumed knowledge of precession.) Accessibility is not, however, straightforward.

Celestial mechanics is capable of specifying the motions of bodies in the solar system, on gravitational theory with a uniform time-scale, to ample accuracy for the connection of observations over long periods of time; in particular the motion of the Sun (i.e. the reflected motion of the Earth in its orbit round the Sun) may be regarded as specified by Newcomb's tables. Observations of the Sun's position in its orbit may thus be interpreted as direct measures of ephemeris time. The observations, necessarily made in universal time, will show a progressive discordance from the tables, owing to the influence on the time-scale of the variations in the rate of rotation of the Earth. All such discordances can be identified with corrections to the mean longitude. The difference, ΔT, between U.T. and E.T. is thus simply the time-equivalent of the observed correction, in terms of U.T., to the Sun's mean longitude.

Unfortunately the Sun moves only 1° in a day, or $0''.04$ in one second of time; direct observation is thus an insensitive method of finding ΔT, and so of measuring ephemeris time. The Moon's motion in its orbit is by far the fastest available ($0''.55$ in one second) and the Moon is clearly the most sensitive object to use to determine variations in the rate of rotation of the Earth, and thus ΔT. Is it possible to connect observations of the Moon with those of the Sun, so that corrections to the Sun's mean longitude may be deduced from observations of the Moon?

The regular and irregular changes in the rate of rotation of the Earth will, as explained in the previous section, correspond to different forms of correction; on the one hand, the *regular* (secular) changes will not be proportional to the mean motions (the actual ratio being theoretically very complicated), but the *irregular* changes (or fluctuations, B) will be so proportional. The corrections to the Sun's mean longitude may thus be represented by an expression

$$\alpha + \beta T + cT^2 + 0.074\,804 \cdot B$$

in which the last term corresponds to the fluctuation, B, in a similar expression for the correction to the Moon's mean longitude.

The numerical values of the coefficients in these expressions are determined by analysis of the discordances between observation and theory, over the whole period of recorded observation; such an analysis was made by Spencer Jones in the paper referred to in the resolution. The linear term $\alpha + \beta T$ may be fitted, arbitrarily, to achieve a particular origin and rate for ephemeris time; it is chosen to make the Sun agree with observation as closely as possible during the period covering the observations discussed by Newcomb. Whereas the average value of ΔT will be zero over some such period, the actual value at 1900.0 is not zero.

The other terms are more difficult to deal with, since the secular accelerations are not well separated from the fluctuations; the precise attribution of the observed corrections between terms in T^2 and terms in B is, moreover, of direct relevance to the derivation of ΔT from observations of the Moon. The values of the secular accelerations, given by Spencer Jones in 1939, are $+1''.23T^2$ and $+5''.22T^2$ for the Sun and Moon respectively; B is merely the observed residual correction to the Moon's mean longitude. More recent investigations suggest a reduction of the coefficients to $+1''.01$ and $+2''.2$, with the very large mean errors of $\pm 0''.70$ and $\pm 9''.5$, the changes ($0''.22$ and $3''.0$) being in the ratio of the mean motions; ΔT will be unaltered by such a change since the difference is incorporated directly into B. The new values may be easier to reconcile with theory than the old.

The form of the correction ΔT is now seen in its true perspective; the correction to the Sun's mean longitude is expressed, by means of the formula

$$1''.00 + 2''.97T + 1''.23T^2 + 0.074\,804 \cdot B,$$

in terms of the observed corrections to the Moon's mean longitude. The Sun moves $1''$ in $24^s.349$, and the expression for ΔT follows.

Since ephemeris time is defined by the Sun alone, but in practice determined from observations of the Moon, inconsistencies may arise if the connection between the two motions is not precisely that used; but no serious departure from uniformity is likely to arise for several centuries, and the practical advantages of a uniform time seem adequate to justify its adoption.

The coefficients in the expression for ΔT have been slightly modified, here and in the formal I.A.U. resolution, to make them strictly consistent with the adopted correction to the Sun's tabular mean longitude; they therefore differ from those previously used. The differences are of no practical significance, but for consistency the expression now given should always be used in future.

4. *Relationship between Ephemeris, Universal and Sidereal Time.*—It is most important that the relationship between Ephemeris Time (E.T.) on the one hand, and Universal Time (U.T.) and Sidereal Time (S.T.) on the other, should be clear. E.T., which is the independent argument of the fundamental ephemerides of the Sun, Moon and planets, is independent of the rotation of the Earth; S.T. is essentially a measure of that rotation, partaking in all the departures from uniformity; U.T., which is the practical measure of solar time, is rigidly connected to S.T. by a formula which incorporates the mean motion of the Sun. It is clear that U.T., so determined from S.T. by observations of the stars, cannot refer to the actual Sun whose motion is known only in terms of E.T. The standard definition of universal time, as 12^h + the Greenwich Hour Angle of the mean sun, can clearly no longer apply; it has, in fact, never been rigorously true owing to the discrepancy between the actual Sun and Newcomb's tables. A more general definition is given in the next section.

E.T. is *defined* to be the time referred to which Newcomb's tables of the Sun will agree with observation. It is determined from U.T. by applying to it the observationally determined correction ΔT; although E.T. is thus in practice determined from U.T., it is in fact completely independent of it and there is no reason, other than convenience, for measuring it in conventional units.

S.T. continues to be the hour angle of the first point of Aries (♈) and is, of course, unchanged by the introduction of E.T.

In order that there should be no discontinuity in U.T., the present numerical relationship between S.T. and U.T. must therefore also be retained unchanged in the form:

$$\text{S.T.} = 12^{\text{h}} + \text{U.T.} + 18^{\text{h}}\,38^{\text{m}}\,45^{\text{s}}.836 + 8\,640\,184^{\text{s}}.542T + 0^{\text{s}}.0929T^2,$$

where T is measured in Julian centuries of 36 525 mean solar days from 1900 January 0.0. The last three terms of the above formula are precisely Newcomb's expression for the right ascension of the mean sun (R.A.M.S.); but T must be measured *in terms of U.T.*, whereas E.T. has been specifically introduced to bring Newcomb's tables, and thus his expression for R.A.M.S., in accordance with observation *in terms of E.T.* Although there is thus no discontinuity in the measure of U.T., there is an implicit discontinuity in the ephemeris of the Sun, equal to the difference in R.A.M.S. caused by measuring T in E.T. instead of in U.T. A little thought will show that (as stated above) it is impossible for U.T. to refer to the true mean sun, while being connected with S.T. by a definite relationship.

The conclusion is inescapable: U.T. can no longer be regarded as a fundamental measure of time or as a fundamental concept; it is an artificial measure of the Earth's rotation, chosen to be a very close approximation to mean solar time of the meridian of Greenwich. An even closer approximation is possible by introducing into U.T., and also with opposite sign into ΔT, a discontinuity of the instantaneous value of

$$8\,640\,185^{\text{s}}\ (\Delta T \text{ in centuries}) = 0.002\,737\,9 \cdot \Delta T$$

and modifying the relationship between S.T. and U.T. accordingly; neither S.T. nor E.T. would be affected.

There is an apparent inconsistency in the interpretation of the term “mean solar time” in the resolution as universal time. This is inconsistent, however, only if mean solar time is regarded as related rigorously to the actual true Sun; in practice mean solar time has always been defined by a formula and the true mean sun has not transited at noon U.T. since some time between 1900 and 1905. The latter view of mean solar time preserves the definition of U.T. as “mean solar time measured from midnight at Greenwich”, makes the resolution self-consistent and describes what has actually been done.

5. *The concept of the Ephemeris Meridian.*—The understanding of the relationship between E.T., S.T. and U.T., and the practical application of E.T., are much simplified by the introduction of an auxiliary reference meridian on the Earth. This reference meridian is here termed the “Ephemeris Meridian”, but the whole terminology of this section must be regarded as provisional; if, as seems likely, the related concepts are generally adopted, a wide agreement on terminology is desirable.

The ephemeris meridian is $1.002\,73 \cdot \Delta T$ east of Greenwich*; it represents the position in which the Greenwich meridian would be if it had rotated, independently of the Earth, at the uniform rate implicit in the definition of E.T. The position of the ephemeris meridian reflects the accumulation of all changes in the rate of rotation of the Earth; it could conveniently be used as a measure of these changes to avoid the ambiguities that occasionally arise in the use of the terms “fast” and “slow”.

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* It is of interest to speculate in what year, if ever, it will pass through Herstmonceux, longitude E. 20′.3!

Associated with the ephemeris meridian will be ephemeris longitude (λ^*) and ephemeris hour angle (E.H.A.); it is suggested that, where necessary to avoid confusion, the standard symbols for such quantities be distinguished by an asterisk. All calculations in which the Earth's rotation enters may now be carried out in terms of E.T., referred to the ephemeris meridian, in precisely the same way as with U.T., referred to the Greenwich meridian. For instance, “ephemeris transit”, or transit over the ephemeris meridian, will occur when the right ascension is equal to the “ephemeris sidereal time”, obtained with argument E.T. (instead of U.T.) from the numerical relationship between S.T. and U.T.

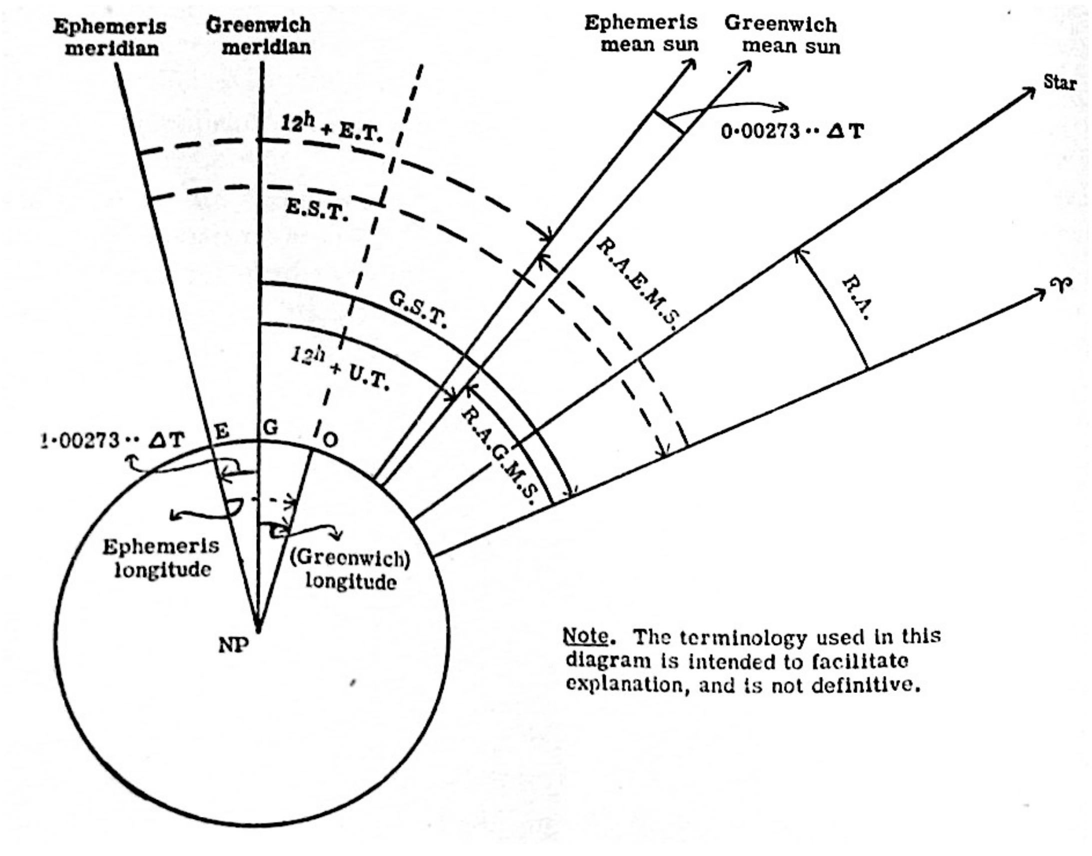
When this concept is applied to the mean sun it leads to the definitions:

(*a*) ephemeris time is the ephemeris hour angle of the “ephemeris mean sun” + 12^h;

(*b*) universal time (i.e. Greenwich mean time) is the Greenwich hour angle of the “Greenwich mean sun” + 12^h;

(*c*) ephemeris sidereal time is the ephemeris hour angle of the first point of Aries;

(*d*) sidereal time (or, to complete the parallel, Greenwich sidereal time) is the Greenwich hour angle of the first point of Aries.



Note. The terminology used in this diagram is intended to facilitate explanation, and is not definitive.

Diagrammatic representation of the relationship between the two systems: the “ephemeris” system using E.T., and the “Greenwich” system using U.T.

“Ephemeris mean sun” is used in (*a*) to emphasize the fact that it is the true mean sun as derived from Newcomb's tables with argument E.T.; the difference between the right ascensions of the Sun and the ephemeris mean sun is the equation of time. It transits the ephemeris meridian at noon E.T. “Greenwich mean sun” is used in (*b*) to indicate the fictitious body (Newcomb's fictitious mean sun) whose right ascension is given by:

$$\alpha(T) = 18^{\mathrm{h}}38^{\mathrm{m}}45^{\mathrm{s}}.836 + 8\,640\,184^{\mathrm{s}}.542T + 0^{\mathrm{s}}.0929T^2$$

when T is measured in U.T. in Julian centuries from 1900 January 0.0. This definition is precisely that used at present, and the mean sun, so defined, transits the Greenwich meridian at noon U.T. It should be noted, however, that the application of the equation of time to the right ascension of the Greenwich mean sun will not give the right ascension of the Sun.

The figure represents an equatorial section of the Earth and its relationship to the “ephemeris” and “Greenwich” mean suns. The relative positions are shown for the instant of time for which U.T. = T and E.T. = $T + \Delta T$. E, G, O are respectively points on the ephemeris meridian, the Greenwich meridian and the observer's meridian. The abbreviations used in the diagrams are self-evident; $\alpha(T)$ is the quadratic expression in T defined above and $\theta(T) \equiv 12^{\mathrm{h}} + T + \alpha(T)$. It can readily be seen that the following relations hold:

U.T. = T	E.T. = $T + \Delta T$
G.S.T.= θ(arg. U.T.)	E.S.T. = θ(arg. E.T.)
= $\theta(T)$	= $\theta(T + \Delta T)$
=12h + $T + \alpha(T)$	= 12h + $(T + \Delta T) + \alpha(T + \Delta T)$

$$\alpha(\text{E.T.}) = \alpha(\text{U.T.}) + 0.002\,73 \cdot \Delta T$$

$$\text{E.S.T.} = \text{G.S.T.} + 1.002\,73 \cdot \Delta T$$

12h + U.T. = G.H.A. of G.M.S.	12h + E.T. = E.H.A. of E.M.S.
= G.S.T. - R.A.G.M.S.	= E.S.T. - R.A.E.M.S.
R.A.G.M.S. = α(U.T.)	R.S.E.M.S. = α(E.T.)
= $\alpha(T)$	= $\alpha(T) + 0.002\,73 \cdot \Delta T$
G.H.A.* = G.S.T. - R.A.*	E.H.A.* = E.S.T. - R.A.*
L.H.A.* = G.S.T. - R.A.* - λ	L.H.A.* = E.S.T. - R.A.* - λ^*
= G.H.A.* - λ	= E.H.A.* - λ^*
Greenwich transit when	Ephemeris transit when
G.H.A.* = 0	E.H.A.* = 0
or G.S.T. = R.A.*	or E.S.T. = R.A.*
Local transit when	Local transit when
G.H.A.* = λ	E.H.A.* = λ^*
or G.S.T. - λ = R.A.*	or E.S.T. - λ^* = R.A.*

$$\lambda^* = \lambda + 1.002\,73 \cdot \Delta T$$

There are thus the two independent self-consistent systems in U.T. and in E.T. For a fixed star they give, as they should, identical values for the local hour angle at any time. For a moving body, its right ascension will generally only be known theoretically in terms of E.T. and, as might be expected, it is not possible to calculate its L.H.A. without assuming *either* a value of ΔT *or* (what is precisely equivalent) the longitude of the ephemeris meridian. It is, however, possible to calculate the ephemeris longitude corresponding to a given L.H.A. (as for eclipses) entirely in terms of ephemeris time.

6. *Effect on the national ephemerides and dynamical astronomy.*—Ephemeris time will be introduced into the national ephemerides from 1960 January 0.

At the same time many other changes will be made (see the resolutions of Commission 4 in *Trans. I.A.U.*, Vol. VIII); the effect of these, where relevant, is included below.

The fundamental ephemerides of the Sun, Moon and planets will be tabulated with argument E.T. and will be strictly in accord with gravitational theory. For the Sun and inner planets the actual figures, tabulated with argument E.T., will be continuous with those at present given with argument U.T.; the corresponding discontinuities in the positions, as explained in detail in respect of the Sun, serve to bring the ephemerides into agreement with observation. For the five outer planets new ephemerides will be given; these are based on the numerical integration of the fundamental equations of motion recently completed in U.S.A. and will be gravitationally consistent to of $0^{s}.001$ and $0''.01$. In the case of the Moon a corrected ephemeris, calculated rigorously from Brown's theory of the motion of the Moon (and not from the tables based on that theory), will also be given to the extra precision $0^{s}.001$ and $0''.01$; this will be discontinuous with the present ephemeris.

The lunar ephemeris is of special importance, since it is by comparison with observation that the difference between ephemeris time and universal time is found in practice; the new ephemeris will enable the E.T. corresponding to an observation made in U.T., and thus ΔT, to be found immediately by inverse interpolation. For this reason the lunar ephemeris has been calculated on the new basis from 1952 onwards and is being published for the years 1952-1959 in a “Joint Supplement to the *American Ephemeris* and the (British) *Nautical Almanac*”.

There will be a tabulation, both direct and inverse, of sidereal time with argument U.T., i.e. $\theta(T)$ with argument T; the identical figures can also a regarded as a tabulation of ephemeris sidereal time with argument E.T. Ephemerides at transit over the ephemeris meridian can therefore be calculated, if required; interpolation to a particular observatory would be made by using its ephemeris longitude as interpolating factor. It is probable, however, that, to sufficient accuracy for the Sun and planets, a value of ΔT can be assumed in advance; for the Moon a partial ephemeris, giving semi-diameters and horizontal parallax at transit, is desirable for the reduction of observations, even though the comparison is made with the hourly ephemeris.

The apparent places of stars are, of course, unaffected by the change. The ephemerides of the satellites and the physical ephemerides, which are given to facilitate observations, will continue to be given with U.T. as argument.

At the request of I.A.U. Commission 13 (Eclipses of the Sun), the circumstances of eclipses are calculated, by the U.S. Nautical Almanac Office, about ten years in advance, and published in the U.S. Naval Observatory *Circulars*; it will now be possible to make these calculations with reference to the ephemeris meridian, without any assumption as to the value of ΔT (except to very low precision for the eclipse maps). Nearer the date of the eclipse, when a more reliable value for ΔT is available, it will be easy for a user to make the simple corrections to time and longitude. For local circumstances, it may well prove simpler to use the ephemeris longitude and to work entirely in the ephemeris system. A value for ΔT is essential for local predictions, so that prediction of occultations cannot be made on the same basis as for eclipses; the lower accuracy, and the shorter time-interval, make extrapolation of ΔT a matter of little difficulty.

A separate ephemeris of the Moon, in terms of U.T., is essential for navigational purposes; the accuracy required, 0′.1, is such that it can be calculated, with reasonable certainty, several years in advance. Times of moonrise and moonset (in U.T.) will doubtless be based on this ephemeris, though the precision required required is not so high. The phases of the Moon, although strictly in E.T., can be regarded as in U.T. Other practical requirements for navigation and surveying, for example the ephemerides of the Sun and planets, are less sensitive and no difficulties arise in providing for them in terms of U.T.
The times of observation will be recorded in U.T., or the corresponding S.T.; comparison with theory will have to be made in relation to ephemerides in E.T.; ΔT will therefore strictly be an unknown in the comparison. In practice, ΔT is determined from observations of the Moon so much more accurately than in any other way that, for most comparisons, ΔT may be regarded as known. Modern observational techniques allow the timing (in U.T.) of the contacts in eclipses and occultations to be made with high accuracy; in the reduction of these observations ΔT will probably be the major unknown, so that the present forms of reduction will be changed slightly from those at present used.

All phases of dynamical astronomy will in future be carried out in terms of ephemeris time as the independent, uniformly increasing time-variable. This will bring to an end the difficulties with which practical and theoretical work celestial mechanics has long been handicapped, through the use of a non-uniform time-scale. Before being used, the times of observations will first have to be converted to E.T.; and the resulting ephemerides, of comets and minor planets, will be in terms of E.T. At present it is necessary to apply corrections to the solar coordinates before using them in the conversion of topocentric observations (of, say, comets) to heliocentric observations; these corrections will no longer be required.

7. *Values of* ΔT.—Values of ΔT will in future be available, to sufficient accuracy for most purposes, not more than one year in arrear; these will be based upon the observations of the Moon's position with the special dual-rate Moon cameras at the U.S. Naval Observatory and elsewhere. It is not possible to collect, reduce and discuss the occultation observations within less than two years; but these observations will still be of value.

Extrapolation must be made with caution, since abrupt changes in the rate of increase of ΔT are by no means unknown.

The table on page 112, which is based mainly on data given by Brouwer, gives values of ΔT, and of the corresponding longitude of the ephemeris meridian, $\Delta\lambda$, for a selection of dates; there are also included the smoothed values, ΔP, of the excess (+), or defect (-), of the period of the Earth's rotation over the uniform period implicit in the definition of ephemeris time. These values may be regarded as the difference between the lengths of the mean solar day and the ephemeris mean day.

8. *The second.*—In this article the emphasis has deliberately been placed on the effect of the introduction of ephemeris time on astronomical practice; the, perhaps more interesting, aspect of the physical causes of the variations of the Earth's rotation has only been lightly touched upon. It is, however, of importance to recall that the unit of time, the second, is defined by means of E.T. The greatest care is taken over the precise legal definitions of fundamental units of length and mass. But, perhaps because of its intangible nature, the unit of time has been previously defined in a very casual way; it is now given

a precise definition, though there is no readily accessible standard with which an interval of time may be immediately compared.

Values of ΔT, the longitude ($\Delta\lambda$) of the ephemeris meridian, and the variation (ΔP) in the period of the Earth's rotation

Year	ΔT [s]	$\Delta\lambda$ [′]	ΔP [s/d]	Year	ΔT [s]	$\Delta\lambda$ [′]	ΔP [s/d]
1681	−13.5	W 3.38		1925.5	+22.68	E 5.69	+0.0006
1710	−12.0	W 3.01		1926.5	+22.94	E 5.75	+0.0003
1747	−0.4	W 0.10		1927.5	+22.93	E 5.75	+0.0003
1761	+2.1	E 0.53		1928.5	+22.69	E 5.69	+0.0003
1774	+6.6	E 1.65		1929.5	+22.94	E 5.75	+0.0004
1785	+8.3	E 2.08		1930.5	+23.20	E 5.82	+0.0004
1793	+7.4	E 1.86		1931.5	+23.31	E 5.84	+0.0004
1802	+5.7	E 1.43		1932.5	+23.63	E 5.92	+0.0004
1812	+4.7	E 1.18		1933.5	+23.47	E 5.88	+0.0002
1820.5	+5.15	E 1.29	−0.0015	1934.5	+23.68	E 5.94	0.0000
1825.5	+2.45	E 0.61	−0.0009	1935.5	+23.62	E 5.92	−0.0001
1830.5	+2.42	E 0.61	−0.0006	1936.5	+23.53	E 5.90	0.0000
1835.5	+0.03	E 0.01	−0.0012	1937.5	+23.59	E 5.91	+0.0002
1840.5	−0.47	W 0.12	+0.0009	1938.5	+23.99	E 6.01	+0.0005
1845.5	+0.37	E 0.09	+0.0007	1939.5	+23.80	E 5.97	+0.0007
1850.5	+2.67	E 0.67	+0.0005	1940.5	+24.20	E 6.07	+0.0010
1855.5	+3.31	E 0.83	+0.0004	1941.5	+24.99	E 6.26	+0.0012
1860.5	+4.27	E 1.07	−0.0004	1942.5	+24.97	E 6.26	+0.0012
1865.6	+1.39	E 0.35	−0.0012	1943.5	+25.72	E 6.45	+0.0013
1870.5	−1.88	W 0.47	−0.0033	1944.5	+26.21	E 6.57	+0.0013
1875.5	−7.36	W 1.85	−0.0015	1945.5	+26.37	E 6.61	+0.0014
1880.5	−8.35	W 2.09	−0.0001	1946.5	+26.89	E 6.74	+0.0014
1885.5	−7.88	W 1.98	+0.0003	1947.5	+27.68	E 6.94	+0.0015
1890.5	−7.17	W 1.80	−0.0004	1948.5	+28.13	E 7.05	+0.0015
1895.5	−6.94	W 1.74	+0.0010	1949.5	+28.80	E 7.22	+0.0015
1900.5	−3.90	W 0.98	+0.0032	1950.5	+29.31	E 7.35	+0.0016
1905.5	+3.08	E 0.77	+0.0039	1951.5	+29.7	E 7.45	+0.0016*
1910.5	+10.50	E 2.63	+0.0037	1952.5	+30.2	E 7.57	+0.0016*
1915.5	+15.81	E 3.96	+0.0028	1953.5	+30.8*	E 7.72*	+0.0016*
1920.5	+20.36	E 5.10	+0.0017	1954.5	+31.4*	E 7.87*	+0.0016*

* Very provisional values.

The second may now be defined as the 86 400th part of the ephemeris mean day, which is $1/365.25636042$ of the sidereal year at epoch 1900.0, or $1/365.24219878$ of the tropical year at epoch 1900.0. As can be seen from the table, it is possible, in arrear, to connect the ephemeris mean day directly with the mean solar day, and thus to connect the ephemeris second with the mean solar second (corrected for short-period variations). This standard may be used to increase the absolute precision of physical measurements; the period of the Earth's rotation can vary by nearly one part in 10^7, while frequencies may be compared to about 100 times this precision. Standards of frequency of great precision are being developed, but it is unlikely that they can compete with the long-term permanence of the standard set by ephemeris time.

The Astronomer Royal and Dr G. M. Clemence have been kind enough to read and criticize the above article; I have gladly accepted their suggested improvements and gratefully acknowledge their help.

Bibliography

References have been deliberately omitted from the main text. Readers who wish to pursue the subject further may refer to:

(1) H. Jeffreys, *The Earth* (3rd edition, 1952), p. 222, for a discussion on the relationship between the secular accelerations of the Sun and Moon.

(2) H. Spencer Jones, *M.N.*, **99**, 541, 1939, for the original derivation of the correction to the solar ephemeris.

(3) G. M. Clemence, *A.J.*, **53**, 169, 1948, for the original proposal for the introduction of E.T.

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(8) J. Jackson, *The Observatory*, **72**, 233, 1952. A discussion on the accuracy of the determination of the secular acceleration of the Sun, and its effect on E.T.

(9) D. Brouwer, *A.J.*, **57**, 125, 1952, for a comprehensive study of the changes in the rate of rotation of the Earth, and the hypothesis of cumulative random changes.

(10) A. J. J. van Woerkom, *A.J.*, **58**, 10, 1953. In this paper the author is mainly concerned with the statistical properties of cumulative sums of random numbers; he applies this analysis to the fluctuations in the Moon's mean longitude, and gives a determination of the secular acceleration.

(11) Report of Commission 4 of the International Astronomical Union, *Trans. I.A.U.*, VIII, 80, 1954. In the Appendix to the “Joint Supplementary Report”, the relationship between U.T., E.T. and S.T. is explained.

(12) *Sky and Telescope*, **13**, 1953 November, p. 5. A brief description of the Markowitz dual-rate Moon camera.

On the speed of rotation of the Earth

(13) E. R. R. Holmberg, *M.N., Geophys. Suppl.*, **6**, 325, 1952. A suggested explanation of the present value of the speed of rotation of the Earth, on the basis of the gravitational couple on the atmospheric tides.

Very many papers have been written on the seasonal variations of the rate of the Earth's rotation. It is hoped that it may be possible to devote a future “Occasional Note” to the whole subject of the Earth's rotation.