SOME ASTRONOMICAL AND PHYSICAL DATA

Many of the numbers listed below are determined by measurement. Exceptions include defined quantities (indicated by three lines in the equal sign ≡), quantities calculated from defined quantities (e.g. m/ly, AU/pc), and numbers of mathematical origin such as π and conversion factors in angular measure. Of the measured quantities, some are known to only approximate precision. For these the equal sign is reduced to ≈. Many others are known to quite high precision. In these cases all digits shown are significant, with the uncertainties occurring after the last digit. The units, symbols, and nomenclature are based on recommendations of the *International Astronomical Union*, the *International Union of Pure and Applied Physics*, and the *Metric Commission Canada*. A concise review of physical measurement standards appears in *Physics in Canada 44*, p. 3, 1988. (RLB)

LENGTH

1 astronomical unit (AU) = $1.495\,978\,70 \times 10^{11}$ m = 499.004 782 light-seconds
1 light-year (ly) = $9.460\,536 \times 10^{15}$ m (based on average Gregorian year)
= 63 239.8 AU
1 parsec (pc) = $3.085\,678 \times 10^{16}$ m
= 206 264.8 AU = 3.261 631 light-years
1 mile* ≡ 1.609 344 km
1 micron* ≡ 1 μm
1 Angstrom* ≡ 0.1 nm

Astronomical
Almanac
2008

TIME

Day: Mean sidereal (equinox to equinox) = 86 164.092 s
Mean rotation (fixed star to fixed star) = 86 164.100 s
Day (d) ≡ 86 400. s
Mean solar = 86 400.001 s
Month: Draconic (node to node) = 27.212 22 d
Tropical (equinox to equinox) = 27.321 58 d
Sidereal (fixed star to fixed star) = 27.321 66 d
Anomalistic (perigee to perigee) = 27.554 55 d
Synodic (New Moon to New Moon) 29.530 589 = 29.530 59 d
Year: Eclipse (lunar node to lunar node) = 346.6201 d
Tropical (equinox to equinox) (a) 365.242 190 = 365.2422 d
Average Gregorian ≡ 365.2425 d
Average Julian ≡ 365.2500 d
Sidereal (fixed star to fixed star) = 365.2564 d
Anomalistic (perihelion to perihelion) = 365.2596 d

EARTH

Mass = 5.974×10^{24} kg
Radius: Equatorial, a = 6378.140 km; Polar, b = 6356.755 km;
Mean, $\sqrt[3]{a^2b}$ = 6371.004 km
1° of latitude = 111.133 − 0.559 cos 2ϕ km (at latitude ϕ)
1° of longitude = 111.413 cos ϕ − 0.094 cos 3ϕ km
Distance of sea horizon for eye h metres above sea-level ≈3.9 $\sqrt{h}$ km (refraction inc.)
Standard atmospheric pressure ≡ 101.325 kPa (≈1 kg above 1 cm^2)
Speed of sound in standard atmosphere = 331 m s^{-1}
Magnetic field at surface ≈5 × 10^{-5} T
Magnetic poles: 76°N, 101°W; 66°S, 140°E
Standard acceleration of gravity ≡ 9.806 65 m s^{-2}
Age ≈4.6 Ga
Meteoric flux ≈1 × 10^{-15} kg m^{-2} s^{-1}
Escape speed from Earth = 11.2 km s^{-1}
Solar parallax = 8″.794 148 (Earth equatorial radius ÷ 1 AU)
Constant of aberration = 20″.495 52

*Deprecated unit. Unit on right is preferred.

TIME

Time has been said to be nature's way of keeping everything from happening at once. For astronomical and physical purposes, time is defined by the means of measuring it (As Hermann Bondi has put it: "Time is that which is manufactured by clocks."). Thus, to deal with time, units and scales must be established and clocks devised.

There are three obvious, natural, periodic time intervals on Earth: the seasonal cycle (year); the cycle of lunar phases (month); and the day-night cycle (day). The problem of accurately subdividing these natural intervals to make time locally available at any moment was satisfactorily solved in 1657 by Christiaan Huygens who invented the first practical pendulum clock. Through successive refinements the pendulum clock reigned supreme for nearly three centuries, until it was surpassed in precision by the quartz oscillator in the 1940's. Within another 20 years the quartz clock was, in turn, superseded by the cesium atomic clock which today has a precision near one part in 10^{13} (one second in 300 000 years). The recent technique of "laser cooling" of atomic beams promises further improvements in the precision of atomic clocks.

The cycle of the seasons is called the *tropical year* and contains 365.2422 days. The cycle of lunar phases is known as the *synodic month* and equals 29.53059 days. The average day-night (diurnal) cycle is the *mean solar day* and contains approximately 86 400.001 s. Other types of year, month and day have been defined and are listed along with brief definitions and durations on p. 15.

Today the second is the basic unit of time. For many years a second meant 1/86400 of the mean solar day. However, Earth's rotation on its axis is not perfectly uniform: there are (i) long, (ii) medium, and (iii) short-term accelerations. (i) Over many centuries there is a *secular* slowing due to tidal friction of about 5 parts in 10^{13} per day (i.e. the day becomes one second longer about every 60 000 years). (ii) Over a few decades there are *random* accelerations (positive and negative), apparently due to core-mantle interactions. These are about ten times larger than the tidal acceleration and thus completely obscure the latter effect over time intervals of less than a century or so. (iii) The largest accelerations in Earth's rotation rate are short-term ones: they are *periodic* and are associated mainly with lunar-induced tides (over two-week and monthly intervals), and seasonal meteorological factors (over semiannual and annual intervals). They are typically one or two orders of magnitude larger again than the random, decade fluctuations on which they are superimposed. Also, although not actually a variation in Earth's rotation rate, shifts of Earth's crust relative to the axis of rotation (*polar wobble*) also affect astronomical time determinations through the resulting east-west shift in the meridian at latitudes away from the equator. Like the seasonal accelerations, these are short-term and periodic, but of smaller amplitude. (For more information, see the article by John Wahr in the June 1986 issue of *Sky and Telescope*, p. 545.)

Atoms display a permanence and stability that planets cannot, thus, since 1967, the second has had an atomic definition: 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom. This is known as the SI (for Système International) second (abbreviation s).

Although Earth's axial rotation is not sufficiently predictable to serve as a precise clock, the orbital motions of the planets and of our Moon are predictable to high accuracy. Through the dynamical equations describing these motions, a uniform time scale can be derived. This scale, known as *Ephemeris Time* (ET), was for many years the basis of astronomical ephemerides. Also, the definition of the SI second, mentioned above, was chosen so that it was identical to the ephemeris second to within the precision of measurement. Because atomic clocks are readily available and because of their proven precision, at the beginning of 1984 Ephemeris Time was abandoned in favor of *Terrestrial Dynamical Time* (TDT). The unit of TDT is the SI second and its scale was chosen to agree with the 1984 ET scale.

Other time scales are in use. *International Atomic Time* (TAI), like TDT, runs at the SI rate but, for historical reasons, lags TDT by exactly 32.184 seconds. Another is *Universal Time* (UT1, or often simply UT) which is mean solar time at the Greenwich (England) meridian, corrected for polar wobble. In practice UT1 is defined in terms of *Greenwich Mean Sidereal Time* (GMST), the latter being defined in terms of Earth's rotation relative to the mean vernal equinox of date (see p. 9). The adjective *mean* is used here to denote that small, periodic variations due to the nutation of Earth's axis have been averaged out, the mean equinox being affected only by the precession of the axis. GMST is the hour angle of this equinox, i.e. GMST equals the right ascension of a star (corrected for nutation) at the Greenwich meridian. In short, UT1 follows Earth's rotation relative to the mean Sun, and includes the associated short-term (periodic), decade (random), and secular (tidal slowing) accelerations.

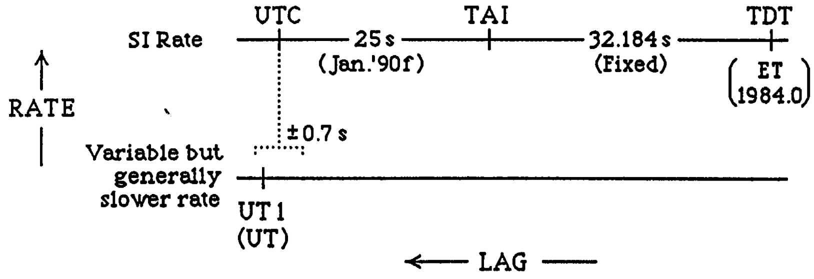
Early in the 20th century the UT1 and ET scales coincided, but since Earth's rotation rate has been generally slower than the SI (ET) rate, by 1970 UT1 was 40 seconds behind ET and was losing more than one second per year. During the next 15 years, Earth's rotation rate increased (part of the random decade fluctuations) so that UT1 now loses only about half a second per year relative to TDT.

Closely related to UT1 is *Coordinated Universal Time* (UTC). UTC runs at the SI rate and is offset an integral number of seconds from TAI so that it approximates UT1. When required (at the end of June 30 or December 31), "leap seconds" are inserted into (or, if necessary, deleted from) UTC so that the difference $\text{UT1} - \text{UTC} \equiv \Delta\text{UT1}$ does not exceed ± 0.7 s. UTC now lags TAI, and as of January 1, 1988 (when a leap second was last inserted) $\text{TAI} - \text{UTC} \equiv \Delta\text{AT} = 24$ s. Thus as this edition of the *Observer's Handbook* goes to press (August, 1989), $\text{TDT} - \text{UTC} = 24\text{ s} + 32.184\text{ s} = 56.184$ s exactly). At the average rotational angular speed Earth has had over the past few years, an additional leap second will be needed at the end of 1989. (Note the diagram at the top of the next page).

The world system of civil time is based on UTC. To keep clocks at various longitudes reasonably in phase with the day-night cycle and yet to avoid the inconvenience to travellers of a local time that varies continuously with longitude, a century ago Earth was divided into about 24 *standard time* zones, adjacent zones generally differing by one hour and each ideally 15 degrees wide (see the map on page 27). The zero zone is centred on the Greenwich meridian. All clocks within the same time zone read the same time. Some countries observe "daylight saving time" during the summer months. In Canada and the United States, clocks are generally set one hour ahead of standard time on the first Sunday in April and return to standard time on the last Sunday in October ("spring ahead, fall back").

A sundial indicates *apparent solar time* at the observer's meridian. Not only is this, in general, different from standard time, but it is far from uniform because of Earth's elliptical orbit and the inclination of the ecliptic to the celestial equator. If the Sun is replaced by a fictitious mean sun moving uniformly along the equator, this defines *Local Mean (Solar) Time* (LMT). Apparent solar time can differ by up to 16 minutes from LMT depending upon the time of year (see p. 58). Also, depending upon the observer's location within his standard time zone, his standard time may differ by up to an hour or so from LMT (see p. 63).

In the same manner that GMST is defined, a *Local Mean Sidereal Time* (LMST) is defined for each observer's meridian. Because Earth makes one more rotation with respect to the other stars than it does with respect to the Sun during a year, sidereal time gains relative to standard time, LMT, UT1, TAI or TDT by about $3^{m}56^{s}$ per day or 2^{h} per month. Also, because of precession, the mean sidereal day is about 8 ms shorter than Earth's period of rotation (see p. 15). LMST may be used to set a telescope on an object of known right ascension. The hour angle of the object equals the sidereal time less the right ascension. LMST may be available from a sidereal clock, or it can be calculated as explained on p. 28. (RLB)



This diagram displays the rate and scale relations between time scales which run at or near the SI rate and which are not longitude dependent.

WORLD MAP OF STANDARD TIME ZONES

The map on the next page shows the world system of standard time zones. It is reproduced from the booklet Astronomical Phenomena for the Year 1989 (Washington: U.S. Government Printing Office, and London: Her Majesty's Stationery Office, 1987). Over the open oceans the time zones are uniformly spaced and are bounded by lines of longitude 15 degrees apart. In populated regions, political and other considerations have considerably modified the ideal geometry.

As Earth rotates with sunlight shining from one side, at some line of longitude the day of the week must jump discontinuously ahead by one day (otherwise, Monday would be followed by Monday)! The line chosen for this jump is in the relatively-unpopulated central part of the Pacific Ocean and approximates longitude 180 degrees. It is called the International Date Line. A person travelling westward across this line has to advance the calendar date by one day, while an eastward-bound traveller moves back one day on the calendar.

The standard time zones are generally designated by letters of the alphabet. Z denotes the "zero" zone, centred on the longitude zero meridian passing through the Airy Transit Circle at the Old Royal Observatory in Greenwich, England. Standard time within this zone is the same as Coordinated Universal Time (UTC). Zones A, B, C, . . . M (J excluded), run eastward at one-hour intervals to the International Date Line, while zones N, O, P, . . . Y run westward to the same boundary. Zones M and Y are only one-half hour wide. Also, as indicated on the map, there are several partial zones that are one-half hour different from the adjacent main zones.

In North America there are seven standard time zones. In terms of their name (and letter designation, hours behind the Greenwich zone, and the west longitude of the reference meridian), these are: Newfoundland (P*, 3h30m, 52.5 degrees), Atlantic (Q, 4h, 60 degrees), Eastern (R, 5h, 75 degrees), Central (S, 6h, 90 degrees), Mountain (T, 7h, 105 degrees), Pacific (U, 8h, 120 degrees), Alaska (V, 9h, 135 degrees). (RLB)