**TIME**

From the earliest ages, the natural division of time into recurring periods of day and night has provided the practical time-scale for the everyday activities of the human race. Indeed, if any alternative means of time measurement is adopted, it must be capable of adjustment so as to remain in general agreement with the natural time-scale defined by the diurnal rotation of the Earth on its axis. Ideally the rotation should be measured against a fixed frame of reference; in practice it must be measured against the background provided by the celestial bodies. If the Sun is chosen as the reference point, we obtain Apparent Solar Time, which is the time indicated by a sundial. It is not a uniform time but is subject to variations which amount to as much as a quarter of an hour in each direction. Such wide variations cannot be tolerated in a practical time-scale, and this has led to the concept of Mean Solar Time in which all the days are exactly the same length and equal to the average length of the Apparent Solar Day.

The positions of the stars in the sky are specified in relation to a fictitious reference point in the sky known as the First Point of Aries (or the Vernal Equinox). It is therefore convenient to adopt this same reference point when considering the rotation of the Earth against the background of the stars. The time-scale so obtained is known as Apparent Sidereal Time.

**GREENWICH MEAN TIME**

The daily rotation of the Earth on its axis causes the Sun and the other heavenly bodies to appear to cross the sky from east to west. It is convenient to represent this relative motion as if the Sun really performed a daily circuit around a fixed Earth. Noon in Apparent Solar Time may then be defined as the time at which the Sun transits across the observer’s meridian. In Mean Solar Time, noon is similarly defined by the meridian transit of a fictitious Mean Sun moving uniformly in the sky with the same average speed as the true Sun. Mean Solar Time observed on the meridian of the transit circle telescope of the Royal Observatory at Greenwich is called Greenwich Mean Time (GMT). The mean solar day is divided into 24 hours and, for astronomical and other scientific purposes, these are numbered 0 to 23, commencing at midnight. Civil time is usually reckoned in two periods of 12 hours, designated am (ante meridiem, ie before noon) and pm (post meridiem, ie after noon), although the 24 hour clock is increasingly being used.

**UNIVERSAL TIME**

Before 1925 January 1, GMT was reckoned in 24 hours commencing at noon; since that date it has been reckoned from midnight. To avoid confusion in the use of the designation GMT before and after 1925, since 1928 astronomers have tended to use the term Universal Time (UT) or Weltzeit (WZ) to denote GMT measured from Greenwich Mean Midnight.

In precision work it is necessary to take account of small variations in Universal Time. These arise from small irregularities in the rotation of the Earth. Observed astronomical time is designated UT0. Observed time corrected for the effects of the motion of the poles (giving rise to a ‘wandering’ in longitude) is designated UT1. There is also a seasonal fluctuation in the rate of rotation of the Earth arising from meteorological causes, often called the annual fluctuation. UT1 corrected for this effect is designated UT2 and provides a time-scale free from short-period fluctuations. It is still subject to small secular and irregular changes.

**APPARENT SOLAR TIME**

As mentioned above, the time shown by a sundial is called Apparent Solar Time. It differs from Mean Solar Time by an amount known as the Equation of Time, which is the total effect of two causes which make the length of the apparent solar day non-uniform. One cause of variation is that the orbit of the Earth is not a circle but an ellipse, having the Sun at one focus. As a consequence, the angular speed of the Earth in its orbit is not constant; it is greatest at the beginning of January when the Earth is nearest the Sun.

The other cause is due to the obliquity of the ecliptic; the plane of the equator (which is at right angles to the axis of rotation of the Earth) does not coincide with the ecliptic (the plane defined by the apparent annual motion of the Sun around the celestial sphere) but is inclined to it at an angle of 23° 26′. As a result, the apparent solar day is shorter than average at the equinoxes and longer at the solstices. From the combined effects of the components due to obliquity and eccentricity, the equation of time reaches its maximum values in February (−14 minutes) and early November (+16 minutes). It has a zero value on four dates during the year, and it is only on these dates (approximately April 15, June 14, September 1 and December 25) that a sundial shows Mean Solar Time.

**SIDEREAL TIME**

A sidereal day is the duration of a complete rotation of the Earth with reference to the First Point of Aries. The term sidereal (or ‘star’) time is a little misleading since the time-scale so defined is not exactly the same as that which would be defined by successive transits of a selected star, as there is a small progressive motion between the stars and the First Point of Aries due to the precession of the Earth’s axis. This makes the length of the sidereal day shorter than the true period of rotation by 0.008 seconds. Superimposed on this steady precessional motion are small oscillations (nutation), giving rise to fluctuations in apparent sidereal time amounting to as much as 1.2 seconds. It is therefore customary to employ Mean Sidereal Time, from which these fluctuations have been removed. The conversion of GMT to Greenwich sidereal time (GST) may be performed by adding the value of the GST at 0h on the day in question to the GMT converted to sidereal time using the Mean and Sidereal Time table on page XXXX.

**EPHEMERIS TIME**

An analysis of observations of the positions of the Sun, Moon and planets taken over an extended period is used in preparing ephemerides. (An ephemeris is a table giving the apparent position of a heavenly body at regular intervals of time, eg one day or ten days, and may be used to compare current observations with tabulated positions.) Discrepancies between the positions of heavenly bodies observed over a 300-year period and their predicted positions arose because the time-scale to which the observations were related was based on the assumption that the rate of rotation of the Earth is uniform. It is now known that this rate of rotation is variable. A revised time-scale, Ephemeris Time (ET), was devised to bring the ephemerides into agreement with the observations.

The second of ET is defined in terms of the annual motion of the Earth in its orbit around the Sun (1/31556925.9747 of the tropical year for 1900 January 0d 12h ET). The precise determination of ET from astronomical observations is a lengthy process as the requisite standard of accuracy can only be achieved by averaging over a number of years.

In 1976 the International Astronomical Union adopted Terrestrial Dynamical Time (TDT), a new dynamical time-scale for general use whose scale unit is the SI second (see Atomic Time, below). TDT was renamed Terrestrial Time (TT) in 1991. ET is now of little more than historical interest.

**TERRESTRIAL TIME**

The uniform time system used in computing the ephemerides of the solar system is Terrestrial Time (TT), which has replaced ET for this purpose. Except for the most rigorous astronomical calculations, it may be assumed to be the same as ET. In June 2021 the difference TT − UT is estimated to be 69.4 seconds. This is known as Delta T.

**ATOMIC TIME**

The fundamental standards of time and frequency must be defined in terms of a periodic motion adequately uniform, enduring and measurable. Progress has made it possible to use natural standards, such as atomic or molecular oscillations. Continuous oscillations are generated in an electrical circuit, the frequency of which is then compared or brought into coincidence with the frequency characteristic of the absorption or emission by the atoms or molecules when they change between two selected energy levels. Since the 13th General Conference on Weights and Measures in October 1967, the unit of time, the second, has been defined in the International System of units (SI) as ‘the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom’.

In the UK, the national time scale is maintained by the National Physical Laboratory (NPL), using an ensemble of atomic clocks based on either caesium or hydrogen atoms. In addition the NPL (along with several other national laboratories) has constructed and operates caesium fountain primary frequency standards, which utilise the cooling of caesium atoms by laser light to determine the duration of the SI second at the highest attainable level of accuracy. Caesium fountain primary standards typically achieve an accuracy of around 2 parts in 10,000,000,000,000,000, which is equivalent to one second in 158 million years.

Timekeeping worldwide is based on two closely related atomic time scales that are established through international collaboration. International Atomic Time (TAI) is formed by combining the readings of more than 400 atomic clocks located in more than 70 institutes and was set close to the astronomically based Universal Time (UT) near the beginning of 1958. It was formally recognised in 1971 and since 1988 January 1 has been maintained by the International Bureau of Weights and Measures (BIPM). Civil time in almost all countries is now based on Coordinated Universal Time (UTC), which differs from TAI by 37 seconds and was designed to make both atomic time and UT available with accuracy appropriate for most users. On 1 January 1972 UTC was set to be exactly 10 seconds behind TAI, and since then the UTC time-scale has been adjusted by the insertion (or, in principle, omission) of leap seconds in order to keep it within ±0.9s of UT. An average Earth day is about 0.002 seconds longer than 24 hours. The difference grows to one second in about 1.5 years. However, the Earth’s rotation speed fluctuates constantly, so the actual frequency of leap seconds can vary. These leap seconds are introduced, when necessary, at the same instant throughout the world, either at the end of December or at the end of June. The last leap second occurred immediately prior to 0h UTC on 2017 January 1, and was the 27th leap second. All leap seconds so far have been positive, with 61 seconds in the final minute of the UTC month. The time 23h 59m 60s UTC is followed one second later by 0h 0m 00s of the first day of the following month. Notices concerning the insertion of leap seconds are issued by the International Earth Rotation and Reference Systems Service (IERS).

The computation of UTC is carried out monthly by the BIPM and takes place in three stages. First, a weighted average known as Echelle Atomique Libre (EAL) is calculated from all of the contributing atomic clocks. In the second stage, TAI is generated by applying small corrections, derived from the results contributed by primary frequency standards, to the scale interval of EAL to maintain its value close to that of the SI second. Finally, UTC is formed from TAI by the addition of an integer number of seconds. The results are published monthly in the BIPM Circular T in the form of offsets at 5-day intervals between UTC and the time scales of contributing organisations.

**RADIO TIME-SIGNALS**

UTC is made generally available through time-signals and standard frequency broadcasts such as MSF in the UK, CHU in Canada and WWV and WWVH in the USA. These are based on national time-scales that are maintained in close agreement with UTC and provide traceability to the national time-scale and to UTC. The markers of seconds in the UTC scale coincide with those of TAI.

To disseminate the national time-scale in the UK, special signals (call-sign MSF) are broadcast by the National Physical Laboratory. From April 1, 2007 the MSF service, previously broadcast from British Telecom's radio station at Rugby, has been transmitted from Anthorn radio station in Cumbria. The signals are controlled from a caesium beam atomic frequency standard and consist of a precise frequency carrier of 60 kHz which is switched off, after being on for at least half a second, to mark every second. The first second of the minute begins with a period of 500 ms with the carrier switched off, to serve as a minute marker. In the other seconds the carrier is always off for at least one tenth of a second at the start and then it carries an on-off code giving the British clock time and date, together with information identifying the start of the next minute. Changes to and from summer time are made following government announcements. Leap seconds are inserted as announced by the IERS and information provided by them on the difference between UTC and UT is also signalled. Other broadcast signals in the UK include the BBC six pips signal, the BT Timeline (‘speaking clock’), the NPL telephone and internet time services for computers, and a coded time-signal on the BBC 198 kHz transmitters which is used for timing in the electricity supply industry. From 1972 January 1 the six pips on the BBC have consisted of five short pips from second 55 to second 59 (six pips in the case of a leap second) followed by one lengthened pip, the start of which indicates the exact minute. From 1990 February 5 these signals have been controlled by the BBC with seconds markers referenced to the satellite-based US navigation system GPS (Global Positioning System) and time and day referenced to the MSF transmitter. Formerly they were generated by the Royal Greenwich Observatory. The NPL telephone and internet time services are directly connected to the national time scale.

Accurate timing may also be obtained from the signals of international navigation systems such as the ground-based eLORAN, or the satellite-based American GPS or Russian GLONASS systems.

**STANDARD TIME**

Since 1880 the standard time in Britain has been Greenwich Mean Time (GMT); a statute that year enacted that the word ‘time’ when used in any legal document relating to Britain meant, unless otherwise specifically stated, the mean time of the Greenwich meridian. Greenwich was adopted as the universal meridian on 13 October 1884. A system of standard time by zones is used worldwide, standard time in each zone differing from that of the Greenwich meridian by an integral number of hours or, exceptionally, half-hours or quarter-hours, either fast or slow. The large territories of the USA and Canada are divided into zones approximately 7.5° on either side of central meridians.

Variations from the standard time of some countries occur during part of the year; they are decided annually and are usually referred to as Summer Time or Daylight Saving Time.

At the 180th meridian the time can be either 12 hours fast on Greenwich Mean Time or 12 hours slow, and a change of date occurs. The internationally recognised date or calendar line is a modification of the 180th meridian, drawn so as to include islands of any one group on the same side of the line, or for political reasons. The line is indicated by joining up the following coordinates:

|  |  |  |  |
| --- | --- | --- | --- |
| Lat. | Long. | Lat. | Long. |
| 90° S. | 180° | 48° N. | 180° |
| 51° S. | 180° | 53° N. | 170° E. |
| 45° S. | 172.5° W. | 65.5° N. | 169° W. |
| 15° S. | 172.5° W. | 68° N. | 169° W. |
| 5° S. | 180° | 90° N. | 180° |

Changes to the date line would require an international conference.

**BRITISH SUMMER TIME**

In 1916 an Act ordained that during a defined period of that year the legal time for general purposes in Great Britain should be one hour in advance of Greenwich Mean Time. The Summer Time Acts 1922 and 1925 defined the period during which Summer Time was to be in force, stabilising practice until the Second World War.

During the Second World War (1941–5) and in 1947 Double Summer Time (two hours in advance of Greenwich Mean Time) was used for the period in which ordinary Summer Time would have been in force. During these years clocks were also kept one hour in advance of Greenwich Mean Time in the winter. After the war, ordinary Summer Time was invoked each year from 1948–68.

Between 1968 October 27 and 1971 October 31 clocks were kept one hour ahead of Greenwich Mean Time throughout the year. This was known as British Standard Time.

The most recent legislation is the Summer Time Act 1972, which enacted that ‘the period of summer time for the purposes of this Act is the period beginning at two o’clock, Greenwich Mean Time, in the morning of the day after the third Saturday in March or, if that day is Easter Day, the day after the second Saturday in March, and ending at two o’clock, Greenwich Mean Time, in the morning of the day after the fourth Saturday in October.’

The duration of Summer Time can be varied by Order in Council and in recent years alterations have been made to synchronise the period of Summer Time in Britain with that used in Europe. The rule for 1981–94 defined the period of Summer Time in the UK as from the last Sunday in March to the day following the fourth Saturday in October and the hour of changeover was altered to 01h Greenwich Mean Time.

There was no rule for the dates of Summer Time between 1995–7. Since 1998 the 9th European Parliament and Council Directive on Summer Time has harmonised the dates on which Summer Time begins and ends across member states as the last Sundays in March and October respectively. Under the directive Summer Time begins and ends at 01hr Greenwich Mean Time in each member state. Amendments to the Summer Time Act to implement the directive came into force on 11 March 2002.

The duration of Summer Time in 2021 is:

March 28 01h GMT to October 31 01h GMT