CHAPTER TWO

The Measurement of Time

Solar Time

In antiquity the time of day was measured by the direction of a shadow cast in sunlight. This resulted in the development of a wide variety of sophisticated and elegant sundials, which became the standard timekeepers. Sundials were also used as reference for other modes of time-keeping such as hourglasses.

Time kept by this method is called apparent solar time. The time between successive appearances of the Sun at the local meridian defines the apparent solar day. Because of Earth's elliptical orbit, the angular distance it covers per day varies. It moves more rapidly in winter when it approaches perihelion than in summer when it's near aphelion. As a consequence, the rate at which the apparent Sun moves eastward along the ecliptic, varies by the same amount. This causes the time between consecutive appearances of the Sun at the local meridian, the apparent solar day, to change as the year progresses. In ancient times this was not seen as a problem. But as more rigorously regulated civil activities and the expansion of intercontinental trade developed, a more consistent basis for time-keeping was needed.

Mean solar time was invented as a method for averaging out the inequalities of apparent solar time. Currently, it is defined in terms of a fictitious Sun that moves eastward along the celestial equator at a constant rate. The difference between mean solar time and apparent solar time for any particular date is called the equation of time.

For the convenience of civil activities, mean solar time is divided into global time zones that progress in increments of 1 hour, or approximately 15° westward, from the Greenwich meridian. For example, the Eastern Standard Time zone begins at 75° west longitude, making mean solar time for that zone 5 hours earlier than Greenwich.

The difference between time read on a sundial and a watch (mean solar time) in minutes is

$$\text{Apparent Solar time} = \text{Watch Time} + \text{Equation of Time}$$

The equation of time can be either negative or positive depending on the time of year.

Sundials can be constructed in a wide variety of forms and are an ideal medium for combining art and science. Devices can be constructed that compensate for the equation of time and longitude, and read mean solar time to an accuracy of one minute.

Horizontal sundials are simply the projection of the equatorial plane onto a horizontal plane as illustrated in Figure 2.1. The angle the gnomon makes with the horizontal plane equals local latitude. Vertical dials placed on a south-facing wall are constructed by the same principle. On those, the gnomon points downward opposite to the direction of the celestial pole. All forms of sundial must be aligned with the celestial pole in order to measure apparent solar time.

Another form of dial is illustrated in Figure 2.2. There the gnomon is the axis of a semicylinder that points in the direction of the celestial pole. The hour lines, 15° apart, are laid off parallel to the gnomon.

For those of you who would like to apply your esthetic sense to a practical artistic endeavor, more information can be found in the references at the end of the book.

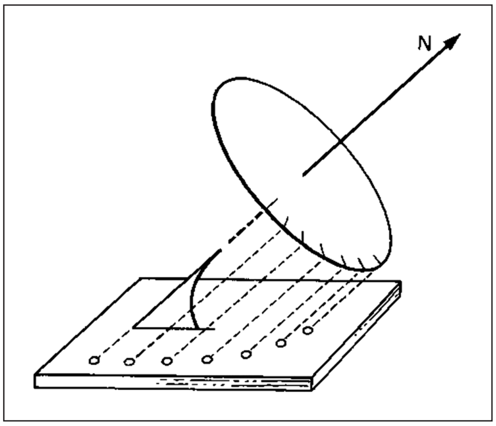

Figure 2.1. The horizontal sundial.

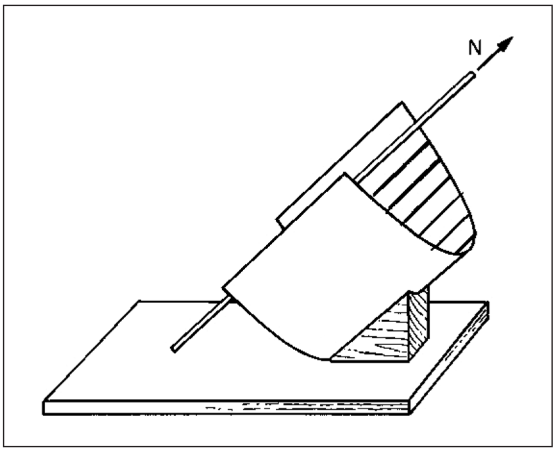

Figure 2.2. An equatorial sundial.

Sidereal Time

Apparent solar time and mean solar time are both related to consecutive appearances of the Sun or a representation of the Sun at the local meridian. Since the apparent Sun moves approximately one degree per day eastward relative to the stars, no form of solar time is useful in making measurements in reference to the stars.

The sidereal day is the time between consecutive transits of a particular star across the local meridian. Sidereal time is equal to the right ascension of a star at the meridian. Conversely, the right ascension of a star is the sidereal time at which it crosses the local meridian. This, in fact, is the way right ascensions are measured.

Because of the precession of the Earth's axis relative to the stars, however, the sidereal positions of the celestial poles, the celestial equator and the equinoxes change. In addition, each star has a proper motion relative to other stars. Consequently, the sidereal day is more rigorously defined as the time between the consecutive transits of the vernal equinox, thus tying it to a fixed reference frame. The position of the vernal equinox relative to the stars can be determined by measuring the time at which the Sun during its annual motion crosses the celestial equator from south to north.

The sidereal day is $3^m55.91^s$ shorter than the mean solar day. Since civil activities are geared to solar time, sidereal time is only useful for astronomical observations.

Right ascension and declination are defined relative to the vernal equinox and the celestial equator. The equinox moves westward through the constellations of the zodiac in a 25800-year cycle. As a result, the cataloged values of equatorial coordinates for the stars are always referred to the position of the equinox for a particular epoch. For example, the positions for all stars in the current catalogs are referred to the equinox of 2000.0. The effects of precession and proper motion on the coordinates of a star are cataloged as annual variations in right ascension and declination. The exact current position is determined from the difference between the current time and the catalog epoch. Except for the nearest stars, the annual variations are fractions of an arc second.

Dating Observations

No astronomical observation is useful unless the time at which it was made is recorded. For observations at different geographical locations to be related, it is necessary for time measurement to be independent of the longitude or civil time of the observer.

Universal Time (UT), regulated by an international atomic clock, is mean solar time observed at the Greenwich meridian (GMT). Coordinated Universal Time is the time given by broadcast time signals.

Observations of phenomena that span long periods of time are dated by the Julian day, a period of numbered days devised in 1582 by Joseph Justus Scaliger and named after his father Julius Caesar Scaliger. Scaliger devised this dating scheme so that references to historic events would be independent of local calendars. Astronomers have adopted it for the same reasons. The Julian day for an observation can be obtained from the [Time Set] menu on Guide 8.0. A Julian day calendar can be downloaded from the American Association of Variable Star Observers (AAVSO) website.

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