The Handbook of the British Astronomical Association

AN EXPLANATORY SUPPLEMENT

by

HOWARD MILES, B.E.M., B.Sc.

Director of the Association's Artificial Satellite Section

Assistant to the Director of the Computing Section

BRITISH ASTRONOMICAL ASSOCIATION

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AUTHOR'S PREFACE

For years, Directors of the Observing Sections of the British Astronomical Association have remarked that many members do not use to full advantage the information given in the annual *Handbook*, the principal reason being, they suggest, that the information looks rather frightening, especially to beginners and particularly the younger members. The Council therefore decided that members might benefit from a publication that would explain the *Handbook* and how to use it. Thus the primary purpose of this booklet is to encourage young and inexperienced members to make more use of the information presented in the yearly *Handbook*.

No doubt too there are members who, although experienced in particular fields, may be discouraged from expanding their activities into further fields through lacking knowledge of the way the technical data in the *Handbook* are used. Others, perhaps excellent observers, may hesitate to handle data in need of some mathematical treatment, and it is hoped that this publication will help to remove any reluctance to carry out these calculations.

It is also hoped that, by assembling articles and tables from past occasional issues of the *Handbook*, the publication will become a convenient single source of much useful and interesting astronomical information.

Readers will notice some repetition of explanatory notes and definitions. The repetition is deliberate; it is intended to make technical terms familiar more quickly than if constant reference to a glossary were needed.

No attempt has been made to give observing instructions, for which members are requested to contact the appropriate Director of Section.

It has been appreciated that more and more members have at their disposal elaborate calculators and even home computers. Where appropriate, formulae have been given to enable members to carry out their own calculations instead of just relying on the graphs and tables provided.

Some material formerly appearing every year in the *Handbook* is now given in this publication and may not in future be printed in the *Handbook*.

Although no data relating to artificial satellites are given in the *Handbook* at the time of writing, orbital information for some stable satellites may be included in the future. Hence the appearance of the notes in this *Explanatory Supplement*.

A recent I.A.U. recommendation is that terrestrial longitudes should be measured positive towards the east, i.e. in the direction of the Earth's rotation. This recommendation has not so far been implemented in the *Handbook*, in which terrestrial longitudes are reckoned positive westwards from the Greenwich meridian. In other words, for the Earth as for other planets, e.g. Mercury, Mars, and Jupiter, surface longitudes are measured positive in the direction opposite to the direction of rotation.

I have received useful guidance and help from many Section Directors, to whom I am particularly grateful. The notes on Moonrise and Moonset are a slightly modified version of notes prepared by Gordon E. Taylor for *Journal*, **86**, 416, 1976. For the section on meteors, I have drawn heavily on notes kindly supplied by Harold B. Ridley. The section on the Brightest Stars was produced by John Isles. The sections on Astronomical Catalogues and Messier Objects and the Calendar Notes were compiled by R. H. Garstang and have appeared in past issues of the *Handbook*. Other parts of the publication have been based on my experiences while a Section Director and member of the Education Committee and during my life as a lecturer. No blame for errors or omissions can be attributed to any other Director or member of the Association.

Many suggestions for improvement have been put forward by Gordon E. Taylor, Director of the Computing Section, and Neville J. Goodman, Editor of the *Handbook*, who has also seen all the material for the publication through the press. To them and to Alan Dowdell, who prepared the line drawings, and Martin Wace, who drew the chart of the Pleiades, I extend my sincere thanks.

HOWARD MILES

DIRECTOR'S PREFACE

Since its first publication in 1922 to the present day, the *Handbook* has increased almost threefold in size. The work load on the Computing Section has increased proportionately. Thus I am very grateful to Howard Miles for his offer to write this *Explanatory Supplement*, which I commend unreservedly to all members of the Association.

GORDON E. TAYLOR
Director, Computing Section

AN EXPLANATORY SUPPLEMENT

Explanatory Supplement to the Handbook

ERRATA

p. 21 Modified J.D.: *for* 240,000·5 *read* 2,400,000·5.

p. 33 Maximum distance of Moon from Earth's centre:
for 378,300 *read* 406,720.
Minimum distance of Moon from Earth's centre:
for 355,385 *read* 356,375.
Minimum distance of Moon from the Earth's surface:
for 349,007 *read* 349,997.
Vertex of cone beyond the sub-eclipse point:
for 29,293 *read* 29,742.
Width of totality band:
for 268 *read* 272.

p. 34, line 5, *for* penumbral *read* partial.

p. 36, lines 8 and 20, *for* 0·9972 *read* 0·99727.

p. 37, line 14, Distance of Earth from Sun:
for 4676395 km × angular diameter of the Sun in minutes of arc
read 4787166000 km divided by the angular diameter of the Sun in minutes of arc.

Comment on page 36

In the calculations of the time of rising and setting of the Sun and planets, some of the quantities can be expressed either in degrees or in time (hours and minutes).

To find U.T.:

(i) in formulae on lines 8 and 20,
express longitude (west) in hours and decimals of an hour;
express R.A. (α) in hours and decimals of an hour;

(ii) line 8, divide arc $\cos(-\tan\phi\tan\delta)$ by 15;

(iii) line 20, divide h (in degrees) by 15.

CONTENTS

Part 1

EXPLANATION OF ASTRONOMICAL TERMS AND SYMBOLS

ASTRONOMICAL TERMS

Aberration: The angular displacement of the observed position of an object from its geometric position. It is due to the finite speed of light combined with the motions of the observer and of the observed body.

Altitude: The angular distance of an object above the observer's horizon. Altitude is 90° minus zenith distance.

Anomalistic period: Period of revolution relative to apse line.

Aphelion: The point in an orbit round the Sun that is at the greatest distance from the Sun. The prefix 'ap-' (or 'apo-') refers to the point at which any orbiting body is farthest from its primary, e.g. the Moon is at apogee when farthest from the Earth.

Apse line, Line of apsides: The line joining the two points on an ellipse at which the curvature is greatest. It is identical with the major axis of the ellipse.

Aries, First Point of: The ascending node of the ecliptic on the celestial equator.

Astronomical unit: The length of the semi-major axis of the Earth's orbit round the Sun, approximately. For the precise definition, see the *Astronomical Almanac*.

Azimuth: The angular distance measured along the horizon from the north point through east.

Celestial equator: The great circle in which the celestial sphere is intersected by any plane parallel to the plane of the Earth's equator.

Conjunction: The aspect or configuration of two or more objects when they have the same celestial longitude or the same right ascension as seen from a third body.

Co-ordinated Universal Time (U.T.C.): The timescale used as the basis of time signals broadcast by radio stations.

Culmination: The passage of a celestial body across the observer's meridian. At Upper Culmination, the zenith distance is least; at Lower Culmination, the zenith distance is greatest.

Declination: The angular distance on the celestial sphere north or south of the celestial equator.

Direct motion: (1) For orbital motion in the solar system, motion that is counterclockwise as seen from the north pole of the ecliptic. (2) Motion of a body eastwards on the celestial sphere as seen from the Earth.

Eccentricity: The orbital element that defines the shape of an orbit.

Eclipse: The obscuration of one celestial body by the shadow of another, loosely and incorrectly used for some occultations.

Ecliptic: The great circle in which the celestial sphere is intersected by planes parallel to the plane of the Earth's orbit round the Sun. It is the apparent annual path of the Sun round the sky.

Elements, orbital: The parameters that define the shape, size, and orientation of an orbit and the position of a body in that orbit.

Elongation: The angular distance of a planet from the Sun as seen from the centre of the Earth. The angular distance of a satellite from its parent planet.

Ephemeris (pl. ephemerides): A table of predicted positions of a body at a series of times.

Epoch: A given moment in time.

Equation of time: Apparent solar time minus mean solar time (see page 28).

Equinox: Either of the two points at which the ecliptic crosses the celestial equator.

Flattening: The distortion of a planet's figure from that of a sphere. It is expressed by

$$f = (a-b)/a$$

where a and b are the equatorial and polar radii respectively.

Geocentric: With reference to the centre of the Earth.

Heliocentric: With reference to the centre of the Sun.

Heliographic: Relating to a co-ordinate system considered fixed on the surface of the Sun.

Horizontal parallax: The angle subtended at a celestial body by the Earth's equatorial radius.

Hour angle: Angular distance on the celestial sphere measured westwards along the celestial equator from the meridian to the hour circle passing through the object.

Hour circle: Any great circle on the celestial sphere that passes through the celestial poles. It is perpendicular to the celestial equator.

Julian Date (J.D.): The interval of time in days and decimals of a day since Greenwich Noon on 4713 January 1 B.C.

Latitude, celestial: The angular distance on the celestial sphere measured north or south of the ecliptic.

Libration: Variation in the orientation of the Moon's surface as seen by an observer on the Earth.

Longitude, celestial: The angular distance on the celestial sphere measured eastwards along the ecliptic from the vernal equinox.

Magnitude, stellar: A measure on a logarithmic scale of the brightness of a celestial object.

Nadir: The point on the celestial sphere diametrically opposite to the zenith.

Node: Either of the points on the celestial sphere at which the plane of an orbit intersects a reference plane.

Obliquity: The angle between the equatorial and orbital planes, usually of the Earth, when it is known as the obliquity of the ecliptic.

Occultation: The obscuration, partial or total, of one celestial body by another.

Opposition: The aspect or configuration of a planet when its celestial longitude differs from that of the Sun by 180°.

Osculating elements: A set of orbital elements that specifies the instantaneous position and velocity of a celestial body in a perturbed orbit.

Parsec: The distance at which 1 astronomical unit subtends an angle of 1 second of arc.

Perihelion: The point at which a body in orbit round the Sun is nearest to the Sun. The prefix 'peri-' refers to the point at which any orbiting body is nearest to its primary, e.g. the Moon is at perigee when nearest to the Earth.

Planetocentric: Relating to celestial co-ordinates centred on a planet.

Planetographic: Relating to a co-ordinate system fixed on the surface of a planet.

Precession: A change in the direction of the spin axis of the Earth, observed as a motion of the equinox along the celestial equator.

Retrograde motion: (1) For motion in the solar system, motion that is clockwise as seen from the north pole of the ecliptic. (2) Motion of a body westwards on the celestial sphere as seen from the Earth.

Right Ascension: Angular distance on the celestial sphere measured eastwards along the celestial equator from the vernal equinox.

Selenographic: With reference to the surface of the Moon.

Sidereal time: Measurement of time defined by the apparent motion of the vernal equinox. It is a measure of the rotation of the Earth relative to the stars and not the Sun.

Synodic period: The interval of time between two consecutive conjunctions of a planet as seen from the Earth.

Vertex: The point on a celestial object that is nearest to the zenith.

Zenith: The point in the sky immediately above the observer's head. The equivalent point on the celestial sphere.

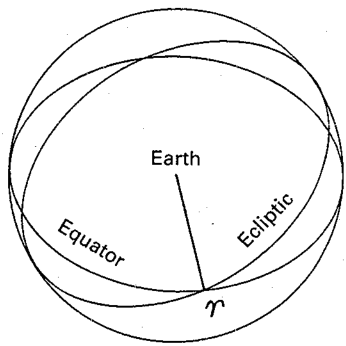
Zenith distance: Angular distance on the celestial sphere measured from the zenith to the object.

Every body orbiting the Sun and every satellite orbiting one of the planets travels round its primary in an elliptical path according to Kepler's First Law. In order to define precisely the shape, size, and orientation of this path, it is necessary to know certain parameters called ELEMENTS.

Consider a body orbiting the Sun. The chosen zero point along the ecliptic (the track made by the Sun as it moves against the background stars) is the position where the Sun is located at the Vernal Equinox. This point is known as the FIRST POINT OF ARIES. It can also be expressed as the point along the

Geocentric Celestial Sphere

Fig. 1



ecliptic where the Sun crosses the Earth's equatorial plane in a northerly direction (see Fig. 1). The First Point of Aries can be likened to the reference point for measuring longitude on the surface of the Earth, i.e. the point where the Earth's equator passes through the Greenwich meridian. Unlike the Greenwich meridian, which is fixed in position, the First Point of Aries moves slowly relative to the stars, and so it is necessary when referring to it to specify the date or EPOCH.

The position of the First Point of Aries is given the symbol ♈.

The elements which define an orbit are as follows:

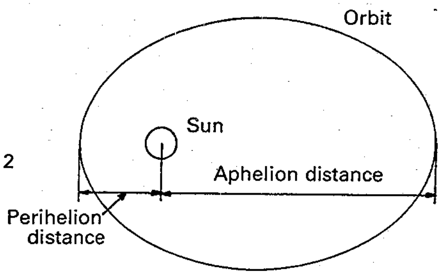
i, the INCLINATION of the orbital plane to the ecliptic, i.e. the angle between the orbital plane and the ecliptic.

☊, the LONGITUDE OF THE ASCENDING NODE, i.e. the angle at the centre of the Sun between the direction of the First Point of Aries and the point on the ecliptic where the orbit in question crosses the ecliptic in a northbound direction. This point is known as the ASCENDING NODE. (The position where the orbiting body crosses the ecliptic in a south-bound direction is called the DESCENDING NODE. A line joining the two nodes is called the LINE OF NODES.)

These first two elements unambiguously define the orientation of the plane of the orbit in space.

Because the body is moving in an ellipse, there is a position where the Sun–body distance is a minimum and another position where it is a maximum.

Fig. 2



The positions are respectively called the PERIHELION and the APHELION (see Fig. 2). The line joining the perihelion and the aphelion is called the LINE OF APSIDES. To define its direction, the following element is required:

ω, the ARGUMENT OF PERIHELION, the angle at the centre of the Sun between the ascending node and the direction of perihelion. It is measured in the plane of the orbit and in the *direction of motion* of the body along its track. This creates no problem in dealing with bodies moving with direct motion, but for bodies having retrograde orbits (and many comets are in this category, including P/Halley), care must be taken to ensure correct location of this point in the orbit.

To define the shape and size of the orbit, we need:

e, the ECCENTRICITY, a measure of the deviation of the shape of the orbit from that of a circle.

a, the SEMI-MAJOR AXIS, which is half the sum of the aphelion and perihelion distances.

To calculate the position of a body in its orbit, a further element is required:

τ or T, the TIME OF PERIHELION PASSAGE or the EPOCH OF PERIHELION. T is used in the cometary ephemerides in the *Handbook*.

All six elements, i, Ω, ω, e, a, and τ, are needed to fix the position of an orbiting body in the space round its primary.

Orbital elements for comets

In addition to the orbital elements defined above, the *Handbook* lists an extra quantity for comets, n degrees. This is the mean daily motion expressed in degrees about the Sun. It is found by the formula:

$$n = 360/(365{\cdot}25 \times P)$$

where P is the anomalistic period in years.

Osculating elements

The orbit of say a comet round the Sun is not a simple ellipse or parabola because the Sun–comet system cannot be isolated from the gravitational effects of the planets. The perturbations caused by the planets will differ at different times, and so the orbit of the comet is defined by OSCULATING ELEMENTS, the values of which are applicable at only one particular time, the EPOCH OF OSCULATION. Osculating elements are defined as the elements of an unperturbed elliptical orbit in which the position and velocity of the comet are identical with the actual position and velocity in its perturbed orbit at the epoch. Unlike mean elements, osculating elements are subject to change. The advantage of using them is that they may be used to give approximately the actual position and motion over short periods of time.

Osculating elements are always used in cometary work and in the ephemerides of minor planets.

ASTRONOMICAL SYMBOLS AND SIGNS

A or Az	Azimuth
a	(1) Semi-major axis of an ellipse
	(2) Altitude
alt.	Altitude
a.u.	Astronomical unit
B_0	Heliographic latitude of centre of Sun's disk
C.M.	Central meridian
c	Velocity of light *in vacuo*
D	Disappearance (in occultations)
Dec.	Declination
E	Egress
E	Equation of time
E.T.	Ephemeris time
e	Eccentricity
e.e.	Eastern elongation
f	Following
G.M.A.T.	Greenwich Mean Astronomical Time
G.M.T.	Greenwich Mean Time
G.S.T.	Greenwich Sidereal Time
g	Acceleration due to gravity
h	(1) Altitude
	(2) Hour angle
I	Ingress
i	Inclination
J.D.	Julian Date
L_0	Heliographic longitude of centre of Sun's disk
L.M.T.	Local Mean Time
L.S.T.	Local Sidereal Time
M	Messier Catalogue number
M.J.D.	Modified Julian Date
m	Magnitude

N.G.C.	New General Catalogue
n	Mean angular motion per solar day
Oc	Occulted
O.H.R.	Observed hourly rate (of meteors)
P	(1) Position angle
	(2) Orbital period
P.A.	Position angle
p	Preceding
pc	Parsec
Q	(1) Aphelion distance
	(2) Position angle of greatest defect of illumination
q	Perihelion distance
R	Reappearance (from occultation)
R.A.	Right ascension
r	Distance from Sun in astronomical units
S	Sun's selenographic colongitude
S.A.O.	Smithsonian Astrophysical Observatory
Sh	Shadow
S.T.	Sidereal Time
T	Time
T.D.T.	Terrestrial Dynamical Time
Tr	Transit
U.T.	Universal Time
U.T.C.	Co-ordinated Universal Time
Z.H.R.	Zenithal hourly rate (of meteors)
Z or Z.D.	Zenith distance
z	Zenith distance
α	Right ascension
β	(1) Geocentric latitude
	(2) Ecliptic latitude
Δ	Geocentric distance in astronomical units
	(Note: Δ followed by the symbol for a variable stands for a small change in the value of that variable)
δ	Declination
ε	Obliquity of the ecliptic
λ	Longitude, geocentric or ecliptic
$\lambda_{\odot}$	Longitude of the Sun
π	Horizontal parallax
τ	Time
ϕ	Geodetic latitude
ϕ'	Geocentric latitude
ω	Argument of perihelion or of perigee

Signs for astronomical bodies and critical positions

☉	Sun
☿	Mercury

♀	Venus		
⊕ or ♁	Earth		
☾	Moon	○ Full Moon	● New Moon
♂	Mars		
♃	Jupiter		
♄	Saturn		
♅ or ⛢	Uranus		
♆ or ♆	Neptune		
♇	Pluto		
♈	First Point of Aries		
♎	First Point of Libra		
☊	Ascending node		
☋	Descending node		
☌	Conjunction		
☍	Opposition		
ϖ	Longitude of perihelion, i.e. ☊ $+\omega$		

CO-ORDINATE AND REFERENCE SYSTEMS

The main positional reference systems used in astronomical work are based on the celestial equator and the ecliptic, respectively the great circles in which the plane of the Earth's equator and the plane of the ecliptic (i.e. of the Earth's orbit round the Sun) intersect the celestial sphere. It is useful to remember that the celestial sphere is a fictitious construct of infinite radius and that 'plane of the equator (or ecliptic)' here means 'any plane parallel to the plane of the equator (or ecliptic)'. The co-ordinates in these great circles are measured from the ascending node of the ecliptic on the celestial equator, this being the point where the Sun in its annual journey round the celestial sphere crosses the equator in a northbound direction. Angles from this position are measured as positive in the *following* direction, i.e. towards the east if you are looking south in the northern hemisphere, but towards the west if you are looking north at circumpolar objects below the celestial pole.

The ascending node of the ecliptic is referred to in astronomical work as the vernal equinox (or simply the equinox) or as the First Point of Aries.

If the origin of the co-ordinate system is the centre of the Sun, the co-ordinates are said to be *heliocentric*. If the origin is the centre of the Earth, they are said to be *geocentric*; if the origin is a point on the surface of the Earth, they are said to be *topocentric*; and if the origin is the centre of a planet, they are said to be *planetocentric*.

Reference planes	**Directions**
Horizon and local meridian	Altitude (a) and azimuth (A)
Equator and local meridian	Hour angle (h) and declination (δ)
Equator and equinox	Right ascension (α) and declination (δ)
Ecliptic and equinox	Celestial longitude (λ) and latitude (β)

Azimuth is measured in degrees along the horizon from north through east, south, west, to north.

Altitude is measured in degrees upwards from the horizon. In some astronomical work, the term *zenith distance* is used; the zenith distance is equal to 90° minus the altitude.

Hour angle is measured westwards along the celestial equator from the meridian.

Declination is measured at right angles to the equator, positive to the north and negative to the south.

Right ascension is measured from the equinox eastwards along the equator.

Celestial longitude is measured eastwards from the equinox along the ecliptic.

Celestial latitude is measured at right angles to the ecliptic, positive to the north and negative to the south.

Conversion formulae

The formulae for converting hour angle and declination to altitude and azimuth are:

$$\begin{aligned}\cos a \sin A &= -\cos\delta \sin h\\ \cos a \cos A &= \sin\delta\cos\phi - \cos\delta\cos h\sin\phi\\ \sin a &= \sin\delta\sin\phi + \cos\delta\cos h\cos\phi\end{aligned}$$

For converting altitude and azimuth to hour angle and declination, the formulae are:

$$\begin{aligned}\cos\delta \sin h &= -\cos a \sin A\\ \cos\delta \cos h &= \sin a\cos\phi - \cos a\cos A\sin\phi\\ \sin\delta &= \sin a\sin\phi + \cos a\cos A\cos\phi\end{aligned}$$

where ϕ is the latitude of the observer.

For converting hour angle to right ascension and *vice versa*, use the equation:

$$h = \text{local sidereal time} - \alpha$$

where local sidereal time = Greenwich sidereal time − longitude of the observer.

To convert right ascension and declination to celestial longitude and latitude, the formulae are:

$$\begin{aligned}\cos\beta\cos\lambda &= \cos\delta\cos\alpha\\ \cos\beta\sin\lambda &= \cos\delta\sin\alpha\cos\varepsilon + \sin\delta\sin\varepsilon\\ \sin\beta &= -\cos\delta\sin\alpha\sin\varepsilon + \sin\delta\cos\varepsilon\end{aligned}$$

To convert celestial longitude and latitude to right ascension and declination, the formulae are:

$$\begin{aligned}\cos\delta\cos\alpha &= \cos\beta\cos\lambda\\ \cos\delta\sin\alpha &= \cos\beta\sin\lambda\cos\varepsilon - \sin\beta\sin\varepsilon\\ \sin\delta &= \cos\beta\sin\lambda\sin\varepsilon + \sin\beta\cos\varepsilon\end{aligned}$$

11

where ε is the obliquity of the ecliptic, i.e. the inclination of the ecliptic to the celestial equator.

Precession

Unlike the reference circles on the surface of the Earth, i.e. the lines of latitude and longitude, the reference circles used in astrometric work, i.e. the ecliptic and the celestial equator, are in continuous motion. This means that the position of the equinox is also in continuous motion.

Movement of the celestial equator is due to the constantly changing orientation of the Earth's equatorial plane, principally owing to two components:

(a) **Luni-solar precession,** a motion of the spin axis of the Earth round the pole of the ecliptic once in about 26,000 years; it is caused by a wobble in the direction of the axis.

(b) **Nutation,** a short-period variation superimposed on the luni-solar precession, having an amplitude of about 9 seconds of arc and a period of about 18·6 years.

These phenomena are due to the gravitational action of the Sun and the Moon on the Earth's equatorial bulge.

Motion of the ecliptic is due to the gravitational action of the planets on the Earth as a whole. It results at present in a decrease in the obliquity of the ecliptic of about 47 seconds of arc a century. Current values are given in the *Handbook*.

In consequence of precession and nutation, it is necessary to quote the date or epoch when recording positions that necessarily depend on the position of the equinox. Two systems are customarily in use; one refers positions to a standard mean equinox and the other refers them to the mean equinox of date. The standard mean equinox most commonly used at present is the mean equinox of 1950·0, but before long it is likely that the mean equinox of 2000·0 will take its place. The mean equinox of date defines the epoch of the reference system which is the same as that at the time for which positions are being given.

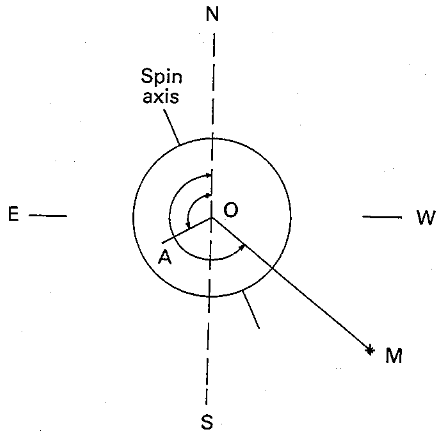
The intersection of the true equatorial plane with the true ecliptic is known as the true equinox of date. If allowance is made for aberration and nutation, it is known as the apparent equinox. In the latter case, the right ascension and declination required for setting a telescope are obtained directly from the ephemeris. In the *Handbook*, the ephemerides for all the planets except Pluto and the minor planets are referred to the apparent equinox. The ephemerides for Pluto, the minor planets, and the comets are referred to the equinox of 1950·0 and precession has to be applied before setting on a telescope.

12

POSITION ANGLE

The position angle of any object relative to another, or a feature on the surface of a body relative to the visual centre of the body, is given as the angle from the north point through east (90°), south (180°), west (270°), and back to north. In some cases, e.g. occultations and eclipses, it may also be given from the vertex.

Fig. 3



In Fig. 3, the position angle of the point A, a surface feature on say a planet, is the angle NOA, i.e. 120°, whilst the position angle of a satellite at M relative to the planet is the angle NOM through east, i.e. 240°.

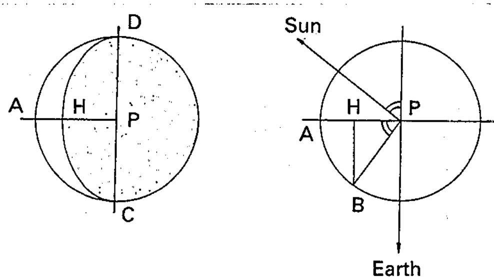
PHASE

In the *Handbook*, phase is defined as the illuminated fraction of the area of the disk. In many standard texts, phase is defined as the illuminated fraction of the diameter of the disk. For a circular disk, the values are the same.

In Fig. 4, the area ADHC (i.e. the illuminated area)

$$= \tfrac{1}{2}\pi r^2 - \tfrac{1}{2}\pi r\,.\,\mathrm{PH}$$
$$= \tfrac{1}{2}\pi r^2(1 - \mathrm{PH}/r)$$
$$= \tfrac{1}{2}\pi r^2(1 - \cos \mathrm{APB})$$

Fig. 4



Let d be the angle between the Sun and the Earth as seen from the body. Then

$$\begin{aligned} \text{APB} &= 180° - d \qquad\qquad \cos \text{APB} = -\cos d \\ \text{Area shaded} &= \tfrac{1}{2}\pi r^2(1 + \cos d) \\ \text{Phase} &= \tfrac{1}{2}\pi r^2(1 + \cos d)/\pi r^2 \\ &= \tfrac{1}{2}(1 + \cos d) \end{aligned}$$

If phase is measured as the illuminated fraction of the diameter, then

$$\begin{aligned} \text{Phase} &= \text{AH}/2r \\ &= (r - \text{PH})/2r = \tfrac{1}{2}(1 - \text{PH}/r) \\ &= \tfrac{1}{2}(1 - \cos \text{BPH}) \\ &= \tfrac{1}{2}(1 + \cos d) \end{aligned}$$

TWILIGHT

The interval between darkness and sunrise and that between sunset and darkness is called twilight, the length of the interval depending on the time of year and the latitude of the observer. Twilight has been subdivided into the following categories.

1. *Civil Twilight*, which begins or ends when the Sun's centre is 6° below the horizon.
2. *Nautical Twilight*, which begins or ends when the Sun's centre is 12° below the horizon, which marks the time when the sky can be considered dark.
3. *Astronomical Twilight*, which begins or ends when the Sun's centre is 18° below the horizon, which marks the theoretical time of perfect darkness.

NAMES OF THE CONSTELLATIONS AND THEIR ABBREVIATIONS

NB. Some authorities give slight variants of the names of a few constellations.

Name	*Genitive*	*I.A.U. Abbreviation*
Andromeda	Andromedae	And
Antlia	Antliae	Ant
Apus	Apodis	Aps
Aquarius	Aquarii	Aqr
Aquila	Aquilae	Aql
Ara	Arae	Ara
Aries	Arietis	Ari
Auriga	Aurigae	Aur
Bootes	Bootis	Boo
Caelum	Caeli	Cae

14

Camelopardus	Camelopardalis	Cam
Cancer	Cancri	Cnc
Canes Venatici	Canum Venaticorum	CVn
Canis Major	Canis Majoris	CMa
Canis Minor	Canis Minoris	CMi
Capricornus	Capricorni	Cap
Carina	Carinae	Car
Cassiopeia	Cassiopeiae	Cas
Centaurus	Centauri	Cen
Cepheus	Cephei	Cep
Cetus	Ceti	Cet
Chamaeleon	Chamaeleontis	Cha
Circinus	Circini	Cir
Columba	Columbae	Col
Coma Berenices	Comae Berenices	Com
Corona Austrina	Coronae Austrinae	CrA
Corona Borealis	Coronae Borealis	CrB
Corvus	Corvi	Crv
Crater	Crateris	Crt
Crux	Crucis	Cru
Cygnus	Cygni	Cyg
Delphinus	Delphini	Del
Dorado	Doradus	Dor
Draco	Draconis	Dra
Equuleus	Equulei	Equ
Eridanus	Eridani	Eri
Fornax	Fornacis	For
Gemini	Geminorum	Gem
Grus	Gruis	Gru
Hercules	Herculis	Her
Horologium	Horologii	Hor
Hydra	Hydrae	Hya
Hydrus	Hydri	Hyi
Indus	Indi	Ind
Lacerta	Lacertae	Lac
Leo	Leonis	Leo
Leo Minor	Leonis Minoris	LMi
Lepus	Leporis	Lep
Libra	Librae	Lib
Lupus	Lupi	Lup
Lynx	Lyncis	Lyn
Lyra	Lyrae	Lyr
Mensa	Mensae	Men
Microscopium	Microscopii	Mic
Monoceros	Monocerotis	Mon
Musca	Muscae	Mus
Norma	Normae	Nor

15

Octans	Octantis	Oct
Ophiuchus	Ophiuchi	Oph
Orion	Orionis	Ori
Pavo	Pavonis	Pav
Pegasus	Pegasi	Peg
Perseus	Persei	Per
Phoenix	Phoenicis	Phe
Pictor	Pictoris	Pic
Pisces	Piscium	Psc
Piscis Austrinus	Piscis Austrini	PsA
Puppis	Puppis	Pup
Pyxis	Pyxidis	Pyx
Reticulum	Reticuli	Ret
Sagitta	Sagittae	Sge
Sagittarius	Sagittarii	Sgr
Scorpius	Scorpii	Sco
Sculptor	Sculptoris	Scl
Scutum	Scuti	Sct
Serpens	Serpentis	Ser
Sextans	Sextantis	Sex
Taurus	Tauri	Tau
Telescopium	Telescopii	Tel
Triangulum	Trianguli	Tri
Triangulum Australe	Trianguli Australis	TrA
Tucana	Tucanae	Tuc
Ursa Major	Ursae Majoris	UMa
Ursa Minor	Ursae Minoris	UMi
Vela	Velorum	Vel
Virgo	Virginis	Vir
Volans	Volantis	Vol
Vulpecula	Vulpeculae	Vul

16

ARTIFICIAL SATELLITE NOMENCLATURE

Scientific satellites and spaceprobes are often identified by popular names, and such names are extensively used, not only by press and radio, but also in literature concerned with the experiments on board the satellites. However, the system becomes unwieldy for all the odd components that often accompany an instrumental payload in orbit—such objects as spent rocket cases and protective nose cones and panels. For scientific studies involving the orbital behaviour of an object, the object is identified in the manner of the following example.

Example: The orbiting rocket that placed the Soviet satellite *Cosmos 1398* in orbit on 1982 August 3 is recorded as 1982–77B, which designation is to be interpreted thus:

1982 – the year of the launch
77 – the 77th launch of that year
B – the spent rocket case

For this particular launch, the instrumental payload is identified as 1982–77A, while the capsule and a fragment are respectively catalogued as 1982–77C and 1982–77D.

In computer outputs, the notation is modified to an all-figure form and the above rocket would be referred to as 8207702.

When, prior to 1963, the number of satellite launches was relatively small, use was made of the Greek alphabet in place of the numbers now used. For example, the American communications satellite *Telstar 1* was known as 1962 Alpha–Epsilon.

An orbiting object is also given a catalogue number by NORAD, the American radar defence network. *Telstar 1* has NORAD number 340, and *Cosmos 1398* is designated 13397.

Part 2

EXPLANATION OF INFORMATION AND TABLES IN THE *HANDBOOK*

19

20

In astronomical work, the date is written in (logical) form, thus:

year, month, day, hour, minute, second

Many countries, including Great Britain [British Standard 4795 (1972)] and Canada, have adopted the notation of year, month, day as the standard way of writing the date. This is of particular value in computerized work, both in scientific and in business applications, since tomorrow's date is always numerically larger than today's (for example, 19890101 is larger than 19881231).

Julian Date

In computing work, time intervals may spread over many years and so it is convenient to use the Julian Date, which is not based on the orbital period of the Earth round the Sun. In this system, the day begins at noon and the days are numbered consecutively from Greenwich mean noon on 4713 B.C. January 1, an epoch far enough in the past for the whole of the historic period to have occurred with positive day numbers. The *Julian Date* corresponding to any moment is the Julian Day followed by that part of the day after 12^h expressed in decimal form, i.e. U.T. expressed as a decimal of a day − 0·5. The *Handbook* gives the *Julian Day* at 5-day intervals throughout the year. Alternatively, it can be found by adding the day of the year to the Julian Day for the corresponding January 0. (See page 22.)

If dates not too far back in time are the only requirement, it is often more convenient to use the *Modified Julian Date* (*M.J.D.*). This is defined as:

$$M.J.D. = J.D. - 240{,}000{\cdot}5$$

Note that *M.J.D.* is reckoned from midnight, in a similar way to *U.T.*

Converting day of year to civil form

	Normal Year	*Leap Year*		*Normal Year*	*Leap Year*
Day 1	Jan. 1		Day 160	June 9	June 8
10	Jan. 10		170	June 19	June 18
20	Jan. 20		180	June 29	June 28
30	Jan. 30		190	July 9	July 8
40	Feb. 9		200	July 19	July 18
50	Feb. 19		210	July 29	July 28
60	Mar. 1	Feb. 29	220	Aug. 8	Aug. 7
70	Mar. 11	Mar. 10	230	Aug. 18	Aug. 17
80	Mar. 21	Mar. 20	240	Aug. 28	Aug. 27
90	Mar. 31	Mar. 30	250	Sept. 7	Sept. 6
100	Apr. 10	Apr. 9	260	Sept. 17	Sept. 16
110	Apr. 20	Apr. 19	270	Sept. 27	Sept. 26
120	Apr. 30	Apr. 29	280	Oct. 7	Oct. 6
130	May 10	May 9	290	Oct. 17	Oct. 16
140	May 20	May 19	300	Oct. 27	Oct. 26
150	May 30	May 29	310	Nov. 6	Nov. 5

21

	Normal Year	Leap Year		Normal Year	Leap Year
Day 320	Nov. 16	Nov. 15	Day 360	Dec. 26	Dec. 25
330	Nov. 26	Nov. 25	365	Dec. 31	Dec. 30
340	Dec. 6	Dec. 5	366	—	Dec. 31
350	Dec. 16	Dec. 15			

Converting civil date to day of year

Date	*Day in Year*			
Date in Month	*Normal Year*		*Leap Year*	
January	January	date	January	date
February	February	date+ 31	February	date+ 31
March	March	date+ 59	March	date+ 60
April	April	date+ 90	April	date+ 91
May	May	date+120	April	date+121
June	June	date+151	June	date+152
July	July	date+181	July	date+182
August	August	date+212	August	date+213
September	September	date+243	September	date+244
October	October	date+273	October	date+274
November	November	date+304	November	date+305
December	December	date+334	December	date+335

To determine the Julian Day

Jan. $0^d\ 0^h$	1900	2415019·5
	2000	2451543·5

Year		*Year*		*Year*	
70	25567	80	29219	90	32872
71	25932	81	29585	91	33237
72	26297	82	29950	92	33602
73	26663	83	30315	93	33968
74	27028	84	30680	94	34333
75	27393	85	31046	95	34698
76	27758	86	31411	96	35063
77	28124	87	31776	97	35429
78	28489	88	32141	98	35794
79	28854	89	32507	99	36159

To determine the Julian Day for a given calendar date, ADD

Julian Day for the century
Julian Day for the year (from table above)
Day of year

Example: To find the Julian Date for 1985 April $5^d\ 18^h\ 30^m$ U.T.

Julian Day for 1900		2415019·5
+ From table	85	31046
+ Day of year		95
+ Fraction of day		0·771
		2446161·271

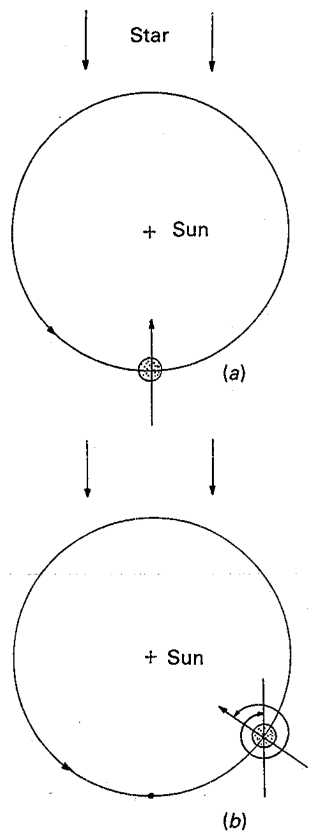
22

Measurement of time

For civil and general astronomical work, the unit of time is the rotational period of the Earth, i.e. the day. The value of this rotational period depends on the reference frame used. The *solar day* is the time interval between successive passages of the Sun through the local meridian. This interval is divided into 24 hours, with each hour divided into 60 minutes and each minute into 60 seconds. This is called solar time. If however the interval between successive passages of the Vernal Equinox through the local meridian is taken, this period is called the *sidereal* day and is likewise divided into hours, minutes and seconds. *Sidereal time* is defined by the apparent diurnal motion of the *Vernal Equinox*. It can therefore be considered as a measure of the Earth's rotation with respect to the stars rather than the Sun.

There is a difference of about 4 minutes between the solar and sidereal days owing to the motion of the Earth round the Sun. Consider the positions of the Earth, Sun and stars on a particular day as shown in Fig. 5. One day later the

Fig. 5



Earth will have moved on average about 360°/365·25636°, i.e. 0°·98561 or very nearly 1°, along its orbit. It will therefore have rotated through approximately 361° with reference to the stars. It takes the Earth about 3 minutes 56 seconds to rotate through the extra degree. Hence solar and sidereal time differ by this mean amount each day. The *Handbook* prints tables which permit the finding of sidereal time if solar time is known (see later).

Because the Earth's orbit round the Sun is not circular, but elliptical, and the spin axis of the Earth not at right angles to the orbital plane of the Earth round the Sun, the solar day is not constant. The mean value over the year is taken as standard and is referred to as the *Mean Solar Day*. The length of a particular day can differ by as much as half a minute from the mean value.

A sundial gives the actual or true solar time (called the *Apparent Solar Time*), whereas an ordinary watch gives the *mean solar time*. The difference between these two values is referred to as the *Equation of Time* (see later). The mean or fictitious Sun is assumed to move along the celestial equator at a uniform rate around the Earth.

Greenwich Mean Time (G.M.T.) links solar mean time with the Prime Meridian, which passes through the observatory at Greenwich, London. The mean Sun is on this meridian at 12 hours G.M.T. each day. The beginning of each day is defined as starting 12 mean hours earlier. In the *G.M.T.* system the hours are numbered from 0 to 24. All other time zones are linked directly with *G.M.T.*, their clock times differing usually by an integral number of hours, but in a few cases by an odd half hour. Although the term *G.M.T.* is used generally in the non-astronomical world, it is more usual for astronomers to use the term *Universal Time (U.T.)*. This is defined as *G.M.T.* beginning at Greenwich midnight.

Greenwich Mean Astronomical Time (G.M.A.T.) is Greenwich Mean Time beginning at noon; it was widely used before 1925 January 1. Many astronomical events prior to that date are referred to this system. Care must be taken to ensure that a consistent system is being used throughout a calculation.

To convert *U.T.* to *G.M.A.T.*, subtract 12^h.
To convert *G.M.A.T.* to *U.T.*, add 12^h.

Sidereal Time, based solely on the Earth's rotational period relative to the Vernal Equinox, is free from the irregularities of solar time. It is linked directly with *U.T.* by a numerical formula. *Greenwich Sidereal Time (G.S.T.)* can be found to an accuracy suitable for setting circles on a telescope by using the tables published in the *Handbook*. One table gives *G.S.T.* for 0^h *U.T.* at intervals of 5 days. A subsidiary table gives the correction for parts of a day. This subsidiary table is also given below.

Greenwich Sidereal Time (G.S.T.) is given in the table in the *Handbook* at 0^h U.T. It may be obtained with sufficient accuracy for setting the circles of a telescope at any other time by adding 3^m·94 for every complete day after a

24

tabulated date, together with the correction for parts of a day from the critical table which follows:

h m	m	h m	m	h m	m	h m	m
0 00·0		5 46·9		11 52·2		17 57·4	
	0·0		1·0		2·0		3·0
0 18·2		6 23·5		12 28·7		18 33·9	
	0·1		1·1		2·1		3·1
0 54·7		7 00·0		13 05·2		19 10·5	
	0·2		1·2		2·2		3·2
1 31·3		7 36·5		13 41·7		19 47·0	
	0·3		1·3		2·3		3·3
2 07·8		8 13·0		14 18·3		20 23·5	
	0·4		1·4		2·4		3·4
2 44·3		8 49·6		14 54·8		21 00·0	
	0·5		1·5		2·5		3·5
3 20·8		9 26·1		15 31·3		21 36·6	
	0·6		1·6		2·6		3·6
3 57·4		10 02·6		16 07·8		22 13·1	
	0·7		1·7		2·7		3·7
4 33·9		10 39·1		16 44·4		22 49·6	
	0·8		1·8		2·8		3·8
5 10·4		11 15·6		17 20·9		23 26·1	
	0·9		1·9		2·9		3·9
5 46·9		11 52·2		17 57·4		24 02·7	
	1·0		2·0		3·0		4·0
6 23·5		12 28·7		18 33·9		24 39·2	

In critical cases ascend

(A 'critical case' is a case that separates two particular ranges of correction. Where, as in the above table, the instruction is to *ascend* in critical cases, the required correction at a critical time is the correction printed *above* the time. For example, at $5^h\ 10^m{\cdot}4$ U.T., the correction is $0^m{\cdot}8$; but immediately after $5^h\ 10^m{\cdot}4$ U.T., the correction is $0^m{\cdot}9$.)

Therefore to find G.S.T. for a given date and U.T., add the following:

1. Time U.T.
2. G.S.T. for the tabulated date immediately preceding the required date.
3. $3^m{\cdot}94$ multiplied by the integral number of days needed to bring the date in (2) to the required date.
4. The value given in the Subsidiary Table corresponding to the fraction of the day.

Example: To find G.S.T. for 1981 June $7^d\ 15^h\ 17^m\ 24^s$ U.T.

Extracted from the *Handbook* for 1981, the G.S.T. for June 5 at 0^h was $16^h\ 53^m{\cdot}3$

June 5 at 0^h	$16^h\ 53^m{\cdot}3$
To correct for June 7, 2 days at $3^m{\cdot}94$	$7^m{\cdot}88$
Time U.T.	$15^h\ 17^m{\cdot}40$
Correction for part of day	$2^m{\cdot}5$
	$32^h\ 21^m{\cdot}08$
Subtract 24^h	$8^h\ 21^m{\cdot}08$

Required time is $8^h\ 21^m{\cdot}1$

If greater accuracy is required, the following formula can be used:

$G.S.T. = x + 236^s{\cdot}55536\ d$

where x = *G.S.T.* at 0^h on January 0 for a given year. This is given in the *Handbook*.

d = number of days and fraction of a day that has elapsed since January 0. (See page 21.)

This will give a value to within a few tenths of a second.

The *Equation of the Equinoxes* is defined as the right ascension of the *Mean Equinox* referred to the *True Equinox and Equator*, i.e. the *Apparent Sidereal Time* minus *Mean Sidereal Time*.

The *Mean Equinox and Equator* provide the celestial reference system determined by ignoring small variations of short period in the motion of the celestial equator and ecliptic. The system is affected only by precession. Positions in star catalogues are normally referred to the *Mean Equinox and Equator* of the beginning of a Besselian year, denoted by '·0' after the year number (e.g. 1950·0). The Besselian solar year is the period of one complete revolution of the fictitious mean Sun in right ascension, beginning at the instant when the right ascension is $18^h\ 40^m$. It is shorter than the tropical year by $0^s{\cdot}148T$, where T is the number of centuries after 1900·0.

The *True Equinox and Equator* (or *Ecliptic*) provide the celestial reference system determined by the instantaneous positions of the celestial equator and ecliptic. The motion of this system is due to precession and short-period variations such as nutation. The *True Equinox and Equator* lead to the *apparent place* of an object in the celestial sphere, which is the position the object would have if seen from the centre of the Earth. The error attributable to the topographical location of the observer and to refraction and parallax is therefore removed.

Local Time

To obtain *local sidereal time (L.S.T.)* from *G.S.T.* use

$$\text{L.S.T.} = \text{G,S.T.} - \lambda$$

where λ is the longitude of the observer measured *westward* from Greenwich. (See Preface.)

Examples:

1. Find *L.S.T.* for the following longitudes, given that *G.S.T.* is $8^h\ 21^m{\cdot}4$

   (*a*) 3° 17′ W (*b*) 12° 56′ E

   (*a*) Convert 3° 17′ into equivalent of time

   i.e. $3^\circ{\cdot}283 \times \frac{24\times60}{360}$ i.e. $3^\circ{\cdot}283\times4 = 13^m{\cdot}1$

   $L.S.T. = 8^h\ 21^m{\cdot}4 - 13^m{\cdot}1 = 8^h\ 8^m{\cdot}3$

   (*b*) $12^\circ\ 56' = 12^\circ{\cdot}93 = 51^m{\cdot}72$

   $L.S.T. = 8^h\ 21^m{\cdot}4 + 51^m{\cdot}7 = 9^h\ 13^m{\cdot}1$

The same rules apply if local solar mean time is required when given *U.T.*

For the reckoning of *Civil Time*,the world is divided into zones in which the Sun is approximately on the local meridian at 1200 local time. *Summer Time* may be in use in many of these zones at certain times of the year. Care must therefore be taken to allow for these local variants when reporting an observation. *Observations should always be reported in U.T.*

For the British Isles, when British Summer Time is in operation,

$$U.T. = B.S.T. - 1 \text{ hour}$$

26

With the ability to record time more accurately, it was discovered that the Earth did not rotate uniformly. Detailed analysis of observations made since the 17th century showed that the Sun, Moon and planets departed from their predicted positions by amounts proportional to their mean motions. A time-scale which brought the ephemeris into line with observations was therefore adopted. This scale is known as *Ephemeris Time* (*E.T.*). *Ephemeris Time* is defined as a uniform measure of time determined by the laws of dynamics and based on the orbital motion of the Earth as given by Newcomb's tables of the Sun. The determination of *E.T.* requires observations over an extended period and is found by adding a correction to *U.T.* in retrospect.

$$E.T. = U.T. + \Delta T$$

The values of ΔT for previous years can be found in *The Astronomical Almanac* and a predictive estimate for the current year is given in the *Handbook*.

An exceedingly accurate time system, independent of astronomical observations has been developed using the natural vibration frequencies characteristic of the absorption and emission spectra of atoms during changes in their energy levels. Atomic clocks calibrated in this manner have enabled the development of a time system known as *International Atomic Time* (*T.A.I.*). From this system the standard second has been defined.

Universal Time found directly from observation is referred to as *U.T.0.* If this is corrected for variations of the meridian of the observer due to observed motion of the geographic poles, it is referred to as *U.T.1.* When *U.T.1* is corrected for the mean seasonal variation in the Earth's rotational period, it is labelled *U.T.2.* The smoothed version of *U.T.2* transmitted as time signals by certain radio stations such as MSF Rugby, England, is called *U.T.C.* (*Co-ordinated Universal Time*). *U.T.C.* is kept very close to *U.T.2* and when the difference exceeds $0^s{\cdot}9$, a discontinuity of 1 second (i.e. a leap second) is introduced. The times at which these changes are to be carried out are published in advance. Coded values of *U.T.1* are transmitted by the radio stations so that it is possible to convert *U.T.C.* directly to *U.T.1.*

NB. Observers should *always* report their observations in *U.T.C.*

The step adjustments of exactly 1 second (the leap seconds) allow *Universal Time* (*U.T.*) to be derived directly from *U.T.C.* with an accuracy of 1 second or better, while *T.A.I.* may be obtained with the same accuracy by the addition of an integral number of seconds.

In 1984, the concept of *Dynamical Time* was introduced. *Terrestrial Dynamical Time* (*T.D.T.*) is used as a time-scale for observations from the Earth's surface. It has replaced *Ephemeris Time* (*E.T.*). For most purposes, *E.T.* up to 1983 December 31 and *T.D.T.* from 1984 January 1 can be regarded as a continuous time-scale.

27

Summary of Time-Scales

U.T. (= U.T.1)	Universal Time, starting from 0^h at midnight.
U.T.0	Local approximation to Universal Time, but not corrected for polar motion.
G.M.S.T.	Greenwich Mean Sidereal Time; G.H.A. of mean equinox of date.
T.A.I.	International Atomic Time; unit is the SI second.
U.T.C.	Co-ordinated Universal Time: it differs from T.A.I. by an integral number of seconds. It is the basis of most radio time signals.
ΔU.T.	U.T.–U.T.C. Increment to be applied to U.T.C. to give U.T.
E.T.	Ephemeris Time: this was used in dynamical theories and in the *Handbook* up to 1983, but it has now been replaced by T.D.T.
ΔT	E.T.–U.T. (prior to 1984). T.D.T.–U.T. (1984 onwards).
T.D.T.	Terrestrial Dynamical Time, used in ephemerides for observations from the Earth's surface.
G.M.A.T.	Greenwich Mean Astronomical Time. Used before 1925 January 1. Day began at 12^h noon.

References

For greater detail of the various time systems and their derivation, see

Explanatory Supplement to the Ephemeris and
The Astronomical Almanac, a yearly publication.

Both are published by H.M.S.O.

A full list of radio time signals and details of their transmissions will be found in the *Admiralty Handbook of Radio Signals* published by H.M.S.O.

Equation of Time

The Equation of Time is the difference between Mean Time (i.e. clock time) and Apparent Time (i.e. time indicated by a sundial). It is the resultant of two components, one due to the eccentricity of the Earth's orbit round the Sun and the other to the fact that the spin axis of the Earth is not at right angles to the ecliptic. Unfortunately, there is no standard method of recording it. The *Astronomical Almanac*, 1983, employs the following definition:

Local mean solar time = local apparent solar time − equation of time.

Many older textbooks do the same, but several recent textbooks have used the following definition:

Local mean solar time = local apparent solar time + equation of time.

Therefore, take care when applying the Equation of Time that the data conform to the appropriate definition.

28

The information given in this publication is based on the definition used in the *Astronomical Almanac*. The following table gives the Equation of Time to the nearest minute for each day of the year.

Date	*Equation of Time*	*Date*	*Equation of Time*	*Date*	*Equation of Time*
Jan. 1	− 3	Apr. 23–28	+ 2	Sept. 26–28	+ 9
2– 3	− 4	Apr. 29–May 7	+ 3	Sept. 29–Oct. 1	+10
4– 5	− 5	May 8–20	+ 4	Oct. 2– 5	+11
6– 7	− 6	21–30	+ 3	6– 8	+12
8–10	− 7	May 31–June 5	+ 2	9–12	+13
11–12	− 8	June 6–11	+ 1	13–16	+14
13–15	− 9	12–15	+ 0	17–22	+15
16–18	−10	16–20	− 1	23–Nov. 14	+16
19–21	−11	21–25	− 2	Nov. 15–19	+15
22–26	−12	26–30	− 3	20–23	+14
27–31	−13	July 1– 5	− 4	24–27	+13
Feb. 1–22	−14	6–11	− 5	28–30	+12
23–28	−13	12–Aug. 9	− 6	Dec. 1– 2	+11
Mar. 1– 5	−12	Aug. 10–15	− 5	3– 5	+10
6– 9	−11	16–19	− 4	6– 7	+ 9
10–13	−10	20–23	− 3	8– 9	+ 8
14–17	− 9	24–27	− 2	10–11	+ 7
18–20	− 8	28–30	− 1	12–14	+ 6
21–23	− 7	Aug. 31–Sept. 2	+ 0	15–16	+ 5
24–27	− 6	Sept. 3– 5	+ 1	17–18	+ 4
28–30	− 5	6– 8	+ 2	19–20	+ 3
Mar. 31–Apr. 2	− 4	9–11	+ 3	21–22	+ 2
Apr. 3– 6	− 3	12–14	+ 4	23–24	+ 1
7– 9	− 2	15–17	+ 5	25–26	+ 0
10–13	− 1	18–20	+ 6	27–28	− 1
14-17	+ 0	21–23	+ 7	29–30	− 2
18–22	+ 1	24–25	+ 8	31	− 3

A more precise value can be obtained using the Transit time as given in the tables for the Sun.

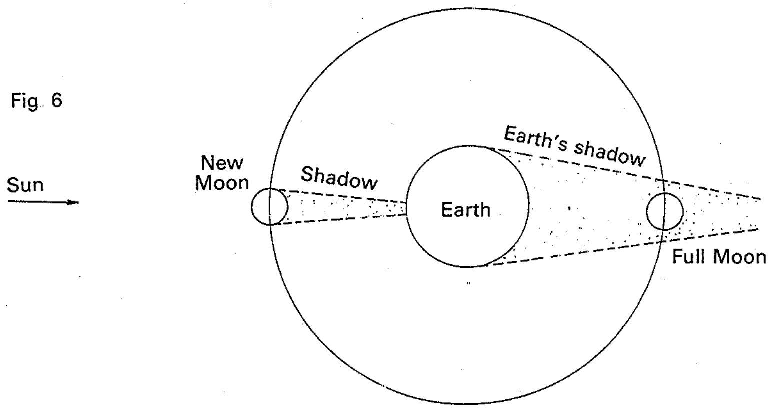
Equation of time = 12^h − Transit time.

RADIO TIME SIGNALS

The list of radio signals in the *Handbook* should be useful to observers. The stations transmit Co-ordinated Universal Time (U.T.C.). The transmissions (except those from O.M.A.) also carry a coded correction so that it is possible to convert U.T.C. to U.T.1: however, observers should always report their observations in U.T.C.

Solar and lunar eclipses occur when the Sun, Moon and Earth lie in a straight line or nearly so. If the Moon is situated between the Sun and the Earth, there will be points on the Earth's surface from which a segment of the Sun's disk will be hidden by the Moon. This can occur only at New Moon. If the Earth lies between the Sun and the Moon, the shadow of the Earth cast by the Sun will hit part or all of the Moon's disk. This can occur only at Full Moon.

Fig. 6



If the Moon's orbital plane coincided with the ecliptic (the Earth's orbital plane round the Sun), solar and lunar eclipses would occur each month. The ecliptic and the Moon's orbital plane round the Earth intersect at two points known as the nodal points (or simply the nodes), so eclipses can occur only at times when New or Full Moon occurs when the Moon is at or near one of these nodes. A partial solar eclipse is possible when a conjunction of the Sun and Moon occurs at longitudes as far from the nodes as 18° 31′ and will certainly occur if it is less than 15° 21′ from the node. This variation is due mainly to the eccentricity of the Moon's orbit and the resulting variation in the Earth–Moon distance and the apparent size of the Moon. A lunar eclipse is possible when the Moon is in opposition within 12° 15′ from the node and will definitely occur if it is less than 9° 30′. These figures establish the so-called eclipse limits.

Number of eclipses that can occur in any one year

In one month, the Sun moves about 29° in longitude, i.e. less than the range from −18° 31′ to +18° 31′, a range of 37° 2′. It is therefore possible for a solar eclipse to occur at two consecutive New Moons and a lunar eclipse at the Full Moon in between them. But 29° is much greater than 24° 30′ (the range from −12° 15′ to +12° 15′) and hence lunar eclipses at successive Full Moons are not possible.

The Moon's nodes regress along the ecliptic in 18⅔ years, about 20° per annum. Ascending and descending nodes (for meaning refer to page 6)

30

occur alternately at intervals of $\frac{1}{2}$ (360°–20°), i.e. about 173 days. Since the synodic month (New Moon to New Moon) is approximately 29·5 days, then six lunations = 177·0 days, i.e. four days greater than the interval between the nodes. It is therefore possible for three nodal passages to occur in a given calendar year, i.e. an interval of 346 days, leaving about 19 days which can be distributed either at the beginning of January or the end of December. It is therefore possible to have in one year, either

Four solar eclipses and three lunar eclipses, or
Five solar eclipses and two lunar eclipses.

A solar eclipse must occur on each occasion on which New Moon is near to a node but a lunar eclipse need not necessarily occur when a Full Moon approaches a node. The minimum number of eclipses that can occur in any one year is two and both of these will be solar.

Using more precise values for the quantities mentioned above, the mean length of the synodic month = 29·53059 days.

Because of the regression of the Moon's orbit, the Sun will pass through the corresponding nodes at intervals of 346·62003 days.

Now 223× 29·53059 days = 6585·32 days
19×346·62003 days = 6585·78 days

This period is known as the Saros.

If a New Moon occurred exactly at a node on one particular occasion, it will precede the node by 0·46 days at the beginning of the next Saros. During 0·46 day the Sun will move

$$\frac{0{\cdot}46}{346{\cdot}62} \times 360° = 28'{\cdot}7$$

Therefore the Sun will be 28′·7 from the node at the time of New Moon. The net effect is to have a series of eclipses as the Sun moves through the eclipse limits of 37° 2′.

The Moon's orbit has a large varying eccentricity, with its apse (see page 3) making a complete revolution in 8·85 years. The anomalistic month (apse to apse) = 27·55455 days. Now 239×27·55455 = 6585·54 days, i.e. only 0·22 days different from the length of the Saros. The Moon's distance and hence its apparent diameter will change little in an interval of a Saros. The net effect is that the length of a corresponding eclipse of the Sun will change very little.

In any one series of the passage through the eclipse limits, there will be more than 70 solar eclipses. A typical case describing an eclipse series is illustrated in the example below.

As the Sun enters the eclipse limits, a partial eclipse will occur as seen from the South Pole. The size of these partial eclipses will gradually increase and the eclipse path will travel northwards until a total (or annular) eclipse occurs. Also, because of the fraction of 0·32 days in the Saros, there will be a proportional change in the longitude at which the eclipse occurs. In the interval of 0·32 days, the Earth will rotate approximately 115° and so the eclipse track will be moved westward by 115° in longitude at each successive

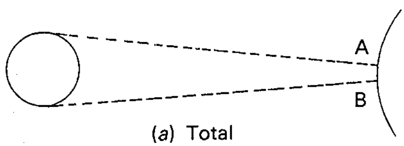
31

eclipse of the series. The eclipse track will also move slowly northwards until the north polar region is reached when a series of partial eclipses, decreasing in size, will occur. The series will end when the Moon's shadow just misses the Earth's surface.

Although the above describes a series starting in the south polar regions and ending in the north, a similar series can take place at the other node with eclipses starting in the north and gradually moving south.

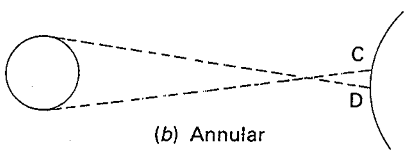
Solar Eclipses

At times when the line joining the centres of the Sun and Moon cuts the Earth's surface, the eclipse will be either total or annular, depending mostly on the distance of the Moon from the Earth. An annular eclipse occurs when the angular size of the Moon is not sufficiently large to cover the Sun's image completely. At the middle of the eclipse, there will be a bright ring of sunlight surrounding the black Moon. Expressed differently, if the vertex of the shadow cone of the Moon lies below the Earth's surface, the eclipse will be total, but if the vertex lies above the Earth's surface the eclipse will be annular.



(*a*) Total

Fig. 7



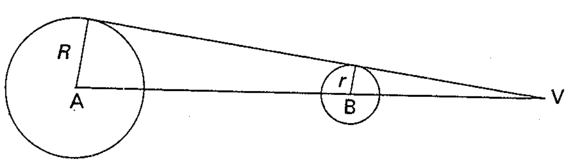
(*b*) Annular

In Fig. 7*a*, the eclipse will be total, but in Fig. 7*b* it will be annular.

Because the Earth's orbit round the Sun is an ellipse, the Earth–Sun distance can vary, producing an angular diameter (S) of the Sun that can range from 32′ 36″ to 31′ 32″. Similarly because the Earth–Moon distance can vary, the angular diameter (M) of the Moon can have values ranging from 29′ 22″ to 33′ 30″

If $M > S$—total eclipse
$M < S$—annular eclipse

Fig. 8



Referring to Fig. 8

$$\frac{BV}{r} = \frac{AB}{R-r}$$

For maximum duration of totality, the Sun's distance must be at a maximum and the Moon's distance a minimum.

Maximum distance of Moon from the Earth's centre = 378,300 km

Minimum distance of Moon from the Earth's centre = 355,385 km

Minimum distance of Moon from the Earth's surface
= 355,385 − 6378 = 349,007 km

If the shadow axis is normal to the Earth's surface, the vertex of the cone will lie 29,293 km beyond the sub-eclipse point on the Earth's surface. Under these conditions the shadow cone has an angle of 31′ 28″. This gives a width of the totality band of 268 km. This value can never be exceeded. The length will be greater when the projection is oblique. The maximum duration of the total phase is 7 min. 58 sec. but away from the equatorial regions the time is much less. In the case of the other extreme, with an annular eclipse, the Moon can remain completely in front of the Sun for as long as 12 min. 24 sec., once again in the equatorial regions.

When the angular sizes of the Sun and Moon are roughly the same, it is possible that along the eclipse track, parts may be total and parts annular, the total phase lasting just a few seconds or even just a fraction of a second.

For points outside and near to the track of totality, an observer will see a partial phase, the magnitude of this being defined as the maximum fraction of the diameter of the Sun eclipsed.

The *Handbook* provides details of all solar eclipses that occur during a particular year:

Date (U.T.).
The path of totality (or central path when the eclipse is annular).
The regions where a partial phase is visible.

In cases where the eclipse is total at a selected site, the times of the commencement and ending of the totality phase are given, with the position angles (2nd and 3rd contacts).

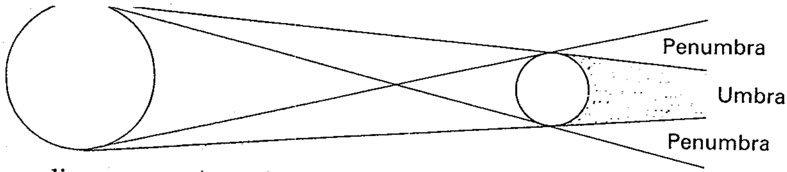
Note that the magnitude of a total eclipse can be greater than 1 and is defined as the ratio of the angular diameters of the Moon and Sun.

Lunar Eclipses

A lunar eclipse occurs when the Moon passes through the Earth's shadow. It can be seen from the whole of the hemisphere facing the Moon. Indeed, it can be seen from somewhat more than a hemisphere, being visible from all places between those where the Moon is just setting as the eclipse begins and those where the Moon is just rising as the eclipse ends. This considerable area contrasts with the severely restricted area from which an eclipse of the Sun is visible.

33

Fig. 9



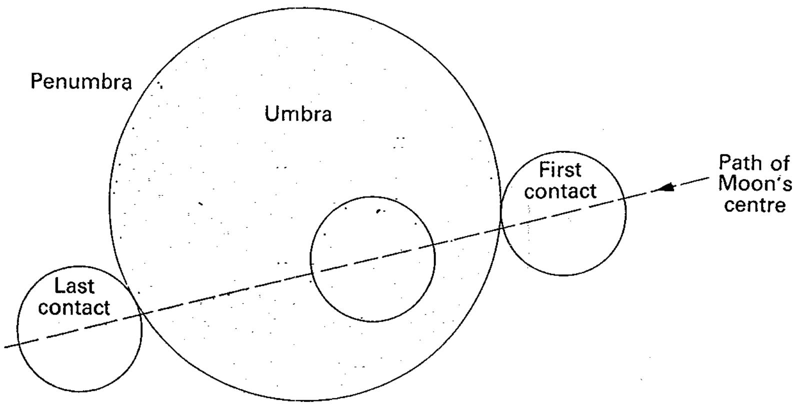
Lunar eclipses occur in series, in a similar way to solar eclipses, but the number in the series is just over 50 in a time span of about 900 years.

The *Handbook* provides the following details:

Date
Descriptions, whether eclipse is penumbral or total
Regions where the eclipse is visible
Times with position angles for entering and leaving the penumbra
Times and position angles for entering and leaving the umbra
Times for the commencement, middle and end of the total phase
Magnitude, defined as

$$\frac{\text{length of chord of Moon's path through the umbra}}{\text{diameter of the Moon}}$$

Fig. 10



Solar Eclipses until A.D. 1999

Date	Type of Eclipse	Maximum Duration of Total Phase (if Total)	Maximum Phase (if Partial)	Track
1988 Mar. 18	Total	3ᵐ 46ˢ		Indian Ocean, East Indies, Pacific Ocean
1988 Sept. 11	Annular			Indian Ocean, south of Australia, Antarctic
1989 Mar. 7	Partial		0·83	Arctic
1989 Aug. 31	Partial		0·63	Antarctic
1990 Jan. 26	Annular			Antarctica
1990 July 22	Total	2ᵐ 33ˢ		Finland, U.S.S.R., Pacific Ocean
1991 Jan. 15–16	Annular			Australia, New Zealand, Pacific Ocean
1991 July 11	Total	6ᵐ 54ˢ		Pacific Ocean, Central America, Brazil

1992 Jan. 4–5	Annular			Central Pacific Ocean
1992 June 30	Total	$5^m 20^s$		South Atlantic Ocean
1992 Dec. 24	Partial		0·84	Arctic
1993 May 21	Partial		0·74	Arctic
1993 Nov. 13	Partial		0·93	Antarctic
1994 May 10	Annular			Pacific Ocean, Mexico, U.S.A., Canada, Atlantic Ocean
1994 Nov. 3	Total	$4^m 23^s$		Peru, Brazil, South Atlantic Ocean
1995 Apr. 29	Annular			South Pacific Ocean, Peru, Brazil, South Atlantic Ocean
1995 Oct. 24	Total	$2^m 5^s$		Iran, India, East Indies, Pacific Ocean
1996 Apr. 17	Partial		0·88	Antarctic
1996 Oct. 12	Partial		0·76	Arctic
1997 Mar. 9	Total	$2^m 50^s$		U.S.S.R., Arctic Ocean
1997 Sept. 2	Partial		0·90	Antarctic
1998 Feb. 26	Total	$3^m 56^s$		Pacific Ocean, just south of Panama, Atlantic Ocean
1998 Aug. 22	Annular			Indian Ocean, East Indies, Pacific Ocean
1999 Feb. 16	Annular			Indian Ocean, Australia, Pacific Ocean
1999 Aug. 11	Total	$2^m 23^s$		Atlantic Ocean, England, France, Central Europe, Turkey, India

Lunar Eclipses from A.D. 1987 to 2000

Date of mid-eclipse	Type of Eclipse	Magnitude of Eclipse	Duration of Totality (min.)	Sub-lunar Long. at mid-eclipse (East positive)	Sub-lunar Lat. at mid-eclipse
1987 Oct. 7	Partial	0·01		− 63	+ 5
1988 Aug. 27	Partial	0·30		−166	−10
1989 Feb. 20	Total	1·28	76	+129	+11
1989 Aug. 17	Total	1·60	98	− 45	−14
1990 Feb. 9	Total	1·09	46	+ 76	+14
1990 Aug. 6	Partial	0·68		+149	−17
1991 Dec. 21	Partial	0·09		−159	+23
1992 June 15	Partial	0·69		− 74	−23
1992 Dec. 10	Total	1·27	74	+ 3	+23
1993 June 4	Total	1·58	98	+165	−22
1993 Nov. 29	Total	1·11	50	− 99	+21
1994 May 25	Partial	0·28		− 53	−21
1995 Apr. 15	Partial	0·12		+176	−10
1996 Apr. 4	Total	1·37	84	− 1	− 6
1996 Sept. 27	Total	1·24	72	− 46	+ 1
1997 Mar. 24	Partial	0·93		− 69	− 1
1997 Sept. 16	Total	1·22	66	+ 77	− 3
1999 July 28	Partial	0·42		−172	−19
2000 Jan. 21	Total	1·35	84	− 68	+20
2000 July 16	Total	1·78	102	+153	−21

NOTE: It is easy to determine whether a given eclipse is visible from a particular point on the Earth's surface by means of a globe. Turn the globe so that the position of the sub-lunar point at mid-eclipse is uppermost and the eclipse can be seen from any point in the upper half of the globe.

35

VISIBILITY OF SUN AND PLANETS

The *Handbook* gives in graphical form the local time of the rising and setting of the Sun and principal planets as seen from two standard latitudes, N. 52° and S. 35°. The times are in L.M.T. and are therefore in G.M.T. (U.T.) for the Greenwich meridian.

More accurate values for the time of rising and setting of a planet (or for any point source) when the right ascension α and declination δ of the body are known is given by:

$$\text{U.T. of rising/setting} = 0{\cdot}9972\,(\alpha + \lambda \pm \arccos(-\tan\phi\tan\delta) - (\text{G.S.T. at } 0^h \text{ U.T.}))$$

where λ = longitude (west) } of observer
φ = latitude }

The negative sign is used for rising and positive sign for setting. This formula does not allow for refraction.

A still more accurate value can be obtained using the following formulae:

Hour angle (h) is determined from

$$\cos h = -\tan\phi\tan\delta + \frac{\cos z}{\cos\delta\cos\phi}$$

where z = zenith distance, i.e. 90° − altitude.

To allow for refraction, a value of $z = 90° 34'$ should be used.

Then $\text{U.T.} = 0{\cdot}9972\,(\alpha + \lambda \pm h - (\text{G.S.T. at } 0^h \text{ U.T.}))$

If the rising and setting times for the Sun are required, the value of z should be increased to 90° 50′ to compensate for the semi-diameter of the Sun, the rise being defined as the time when the upper limb of the Sun is on the horizon.

EARTH

The essential data for the Earth's orbit round the Sun and the obliquity are given for each year:

Equinoxes—the dates on which the Sun crosses the Earth's equator, i.e. the times when the Sun lies on both the ecliptic and the equatorial planes. The Vernal Equinox occurs when the Sun passes through the equatorial plane in a northerly direction. This point is called the ascending node. When the Sun crosses the equatorial plane in a southerly direction, it is said to pass through the descending node.

Solstices—the dates when the Sun reaches its most northerly or southerly declinations. The corresponding geographic latitudes are known as the Tropics of Cancer and Capricorn respectively. At the solstices, the time intervals between sunrise and sunset are either a maximum or a minimum.

36

Obliquity—the degree of tilt of the Earth's spin axis. It is the angle between the Earth's equatorial plane and the ecliptic. The value of the obliquity varies slowly and the values are given for the 1950·0 and 2000·0 Epochs, the current year and the following year.

Perihelion—the date on which the Earth is nearest to the Sun. The actual distance is also given.

Aphelion—the date on which the Earth is farthest from the Sun. This distance is also given.

The varying distance of the Earth from the Sun is due to the Earth's motion round the Sun in an ellipse, as expressed by Kepler's 1st Law. Because the eccentricity is only 0·01672, the ellipse deviates little from a circle. The actual distance on any day in the year can be found from the value of the solar diameter given in the tables in the Section on the Sun.

Distance of Earth from Sun = 4676395 kilometres × angular diameter of the Sun in minutes of arc.

Positions of celestial objects with reference to the Earth are given either in geocentric co-ordinates, i.e. with reference to the centre of the Earth, or geodetic (or geographic) co-ordinates, i.e. with reference to a given position on the surface of the Earth.

Because the Earth is not a perfect sphere, the geodetic and geocentric latitudes for a given position on the Earth's surface are not identical. They are related by the formula:

$$\phi - \phi' = 692''\cdot74 \sin 2\phi - 1''\cdot16 \sin 4\phi$$

where ϕ = geodetic latitude

ϕ' = geocentric latitude

The radius of the Earth at a given latitude is given by:

$$R = r_e (1 - 0\cdot00335 \sin^2\phi)$$

where r_e = the equatorial radius

The following table gives the mean radius for different latitudes.

ϕ°	R (km)	ϕ°	R (km)	ϕ°	R (km)
0	6378	35	6371	65	6361
5	6378	40	6370	70	6359
10	6378	45	6368	75	6358
15	6377	50	6366	80	6358
20	6376	55	6364	85	6357
25	6375	60	6362	90	6357
30	6373				

The flattening of the Earth is given by

$$f = \frac{r_e - r_p}{r_e}$$

where r_e = equatorial radius (6378·14 km)

r_p = polar radius (6356·755 km)

Hence f = 1/298·257

37

The changes in the gravitational field caused by the Earth's oblateness produce two major perturbations in the orbit of any body travelling round the Earth.

1. The orbital plane rotates about the Earth's spin axis in a direction opposite to that of the object's revolution about the Earth. The rate of change of the right ascension of the ascending node is given approximately by the formula.

$$\dot{\Omega} = -9{\cdot}97\left(\frac{R}{a}\right)^{3{\cdot}5}(1-e^2)^{-2}\cos i \text{ degrees per day,}$$

where R = the Earth's equatorial radius
a = semi-major axis of the elliptical orbit of the object around the Earth
e = eccentricity of the orbit
i = inclination of the orbit to the Earth's equatorial plane.

2. The major axis of the orbit rotates in the orbital plane, so that the argument of perigee ω increases at a rate given by

$$\dot{\omega} = 4{\cdot}98\left(\frac{R}{a}\right)^{3{\cdot}5}(1-e^2)^{-2}(5\cos^2 i - 1) \text{ degrees per day.}$$

Note that this value is zero when the factor $5\cos^2 i - 1$ is zero, i.e. when $i = 63°{\cdot}4$. For $i < 63°{\cdot}4$, perigee moves forward round the orbit, but for $i > 63°{\cdot}4$, the motion is backwards.

SUN

The main table provides data at 5-day intervals. These will enable an observer to find the position of the Sun in celestial co-ordinates and also to determine the heliographic latitude and longitude of any markings on its surface. The following information is given:

Date—0^h U.T.

Position—in right ascension and declination. R.A. is given in hours and minutes; declination in degrees and minutes, + if north, − if south.

Diameter—the angular diameter of the Sun in minutes and seconds of arc. This can be used for determining the distance of the Sun from the Earth (see Section on 'Earth').

Transit—The time (U.T.) when the Sun crosses the Greenwich meridian. This value can be used for determining the equation of time (see Section headed 'Equation of Time').

Although the rates of change of both right ascension and declination are not linear, approximate values for intermediate dates can be found by simple interpolation. If more accurate values are required, reference should be made to such publications as the *Astronomical Almanac* (H.M.S.O.).

Because the spin axis of the Sun is inclined at 7° 15′ to the normal to the ecliptic, the centre of the Sun's visible disk does not necessarily lie on the solar equator (Fig. 11). The last three columns, giving the quantities P, B_0

Orientation of Sun's axis, as seen with the naked eye. The diagrams are for observers in the northern hemisphere. Observers in the southern hemisphere should view them upside down.

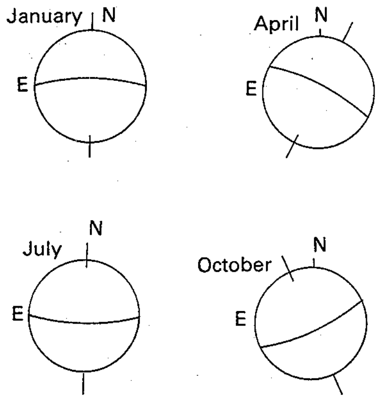


Fig. 11

The orientations are for the beginnings of the months shown. In June and December the equator appears straight.

and L_0, permit the determination of the heliographic latitude and longitude of any surface feature.

P—in degrees. This is the position angle of the north end of the axis of rotation, measured positive if east of the north point of the solar disk, and negative if west.

B_0—in degrees. The heliographic latitude of the centre of the disk. It is a measure of the tilt of the spin axis in the direction of the Earth.

L_0—in degrees. This is the heliographic longitude of the centre of the Sun's disk. Longitude is measured from a nominal reference point, the solar meridian that passed through the ascending node of the solar equator on the ecliptic on 1854 January 1^d 12^h. Longitude is reckoned from 0° to 360° in the direction of rotation, westward on the apparent disk.

For any date in between the tabulated values, it is safe to interpolate linearly for both *P* and B_0, because the changes in their values over a few days are small. The value for L_0 however decreases at an average rate of 13°·2 per day. A subsidiary table enables its value for a particular time to be determined quite quickly. The table given below is given each year in the *Handbook*.

Decrease of L_0 with Time

h m	°	h m	°	h m	°	h m	°	h	°
0 00		1 43		3 32		5 21		6	3·3
	0·0		1·0		2·0		3·0	8	4·4
05		54		43		32		10	5·5
	0·1		1·1		2·1		3·1	12	6·6
16		2 05		54		43		14	7·7
	0·2		1·2		2·2		3·2	16	8·8
27		16		4 05		54		18	9·9
	0·3		1·3		2·3		3·3	20	11·0
38		27		16		6 05		22	12·1
	0·4		1·4		2·4		3·4	24	13·2
49		38		27		16			
	0·5		1·5		2·5		3·5		
1 00		49		38		27			
	0·6		1·6		2·6		3·6		
10		3 00		49		38			
	0·7		1·7		2·7		3·7		
21		10		5 00		49			
	0·8		1·8		2·8		3·8		
32		21		10		7 00			
	0·9		1·9		2·9		3·9		
43		32		21		10			
	1·0		2·0		3·0		4·0		
1 54		3 43		5 32		7 21			

In critical cases ascend

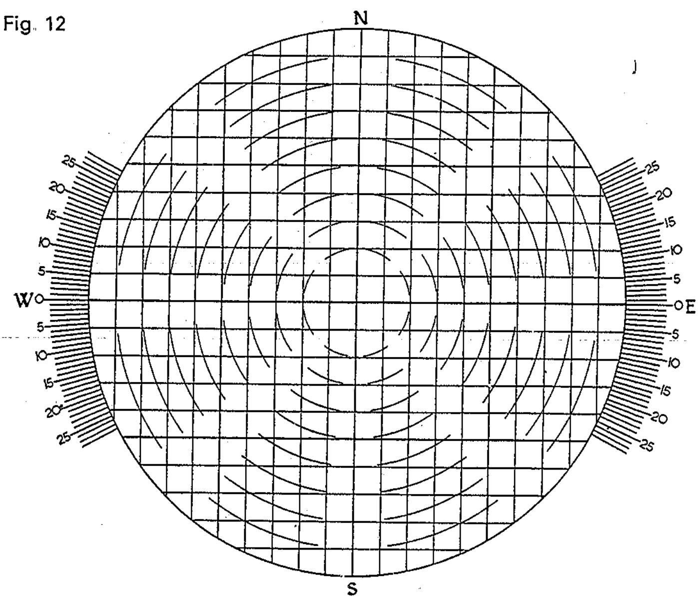
For each complete day, subtract 13°·2.

A table of the dates for the commencement of the synodic rotations, in continuation of Carrington's (Greenwich Photo-Heliographic) series, is given for those starting in a particular year. The sidereal period of rotation of the Sun used in physical ephemerides is 25·38 mean solar days, after Carrington. The mean synodic rotation period is 27^d·2753.

The determination of the heliographic latitude and longitude of a surface feature can be found by various methods:

1. A graphical technique using Stonyhurst disks or equivalent. For the details of the methods of using these,, refer to the Director of the Solar Section.

Fig. 12



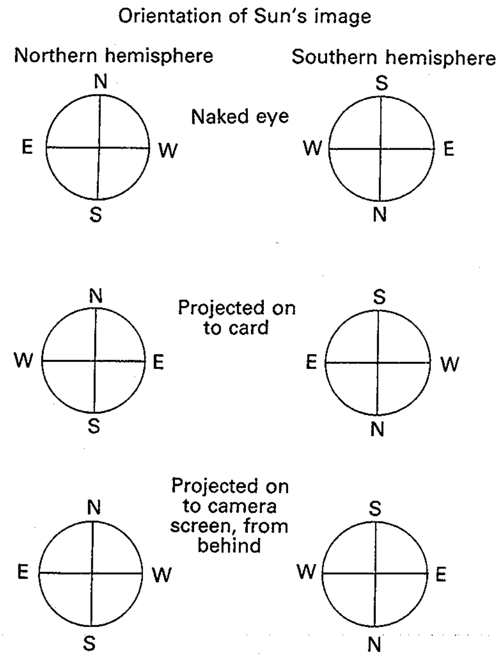
40

2. A graphical method using $x-y$ co-ordinates. The following is a slightly abridged and modified version of that given by J. G. Porter in *Journal*, **53**, 63 (1943).

The method consists simply in measuring the x and y co-ordinates of the spots, as in ordinary graphs, by means of a suitably oriented scale. Care must be taken to ensure that the horizontal diameter coincides with the East–West direction. It is necessary to prepare a diagram similar to that in Fig. 12, but having a disk 15 cm in diameter. The circle is divided into 20 parts along each axis. A protractor is used to mark angles up to 28° from the ends of the E–W axis. A series of concentric circles is drawn about the centre, having as radii multiples of a tenth of a radius of the disk.

Place the drawing of the Sun (on thin paper) over the diagram so that the E–W lines and the 15 cm circles coincide. Rotate the drawing about its centre through the angle P (i.e. the position angle of the Sun's axis, which is given for the date of the drawing in the *Handbook*), anti-clockwise if P is positive, clockwise if P is negative.

Fig. 13



Now that the drawing is correctly oriented (Fig. 13), estimate the position of the spot to two decimal places as x (along the E–W line) and y (along the N–S axis). There is one difference from ordinary graphical methods:

x is measured as positive to the west;
y is measured positive to the north.

At the same time a rough estimate of d, the distance of the spot from the centre, is obtained by means of the concentric circles. It should be noted that

x and y are needed as accurately as possible, but d need be only a rough estimate.

The latitude is found by

$$\sin B = y + \text{correction}$$

the correction being given in the table below as a function of d and B_0. The latter quantity is given in the *Handbook*. Adding the correction to y (with due regard to the sign) gives sin B. The angle B can be found from trigonometric tables.

Correction to y

(This correction has the same sign as B_0)

d	B_0 0	1	2	3	4	5	6	7
0·0	0·00	0·02	0·03	0·05	0·07	0·09	0·10	0·12
0·1	00	02	03	05	07	09	10	12
0·2	00	02	03	05	07	09	10	12
0·3	00	02	03	05	07	08	10	12
0·4	00	02	03	05	06	08	10	11
0·5	00	02	03	05	06	08	09	11
0·6	00	01	03	04	06	07	08	10
0·7	00	01	02	04	05	06	07	09
0·8	00	01	02	03	04	05	06	07
0·9	00	01	02	02	03	04	05	05
1·0	00	0·00	0·00	0·00	0·00	0·00	0·00	0·00

The longitude may then be obtained if required from

$$\sin L_1 = x.\ \sec B$$

Although sec B is always positive, care must be taken over the sign of x. The longitude of the spot is then $L_1 + L_0$, the latter being obtained from the *Handbook*. A point worth mentioning is that it is hardly profitable to attempt to obtain longitudes nearer to the limb than 60° from the central meridian.

Example: A drawing was made at 1943 January $24^d\ 13^h$ U.T.

From the *Handbook*, the following were obtained:

$P = -8{\cdot}7, \quad B_0 = -5{\cdot}4, \quad L_0 = 163{\cdot}6$

The drawing was placed over the grid and rotated clockwise through 9° and the co-ordinates of the spot estimated.

Let $x = +0{\cdot}26$, $y = -0{\cdot}37$, $\quad d =$ about 0·45

The correction from Table $\quad = -0{\cdot}09$

$\sin B = -0{\cdot}37 - 0{\cdot}09 = -0{\cdot}48, \quad B = 29°\text{S}$

$\sin L_1 = +0{\cdot}26 \times 1{\cdot}14 = +0{\cdot}30, \quad L_1 = +17{\cdot}5$

$L_0 = 163{\cdot}6$

Long. = 181°

Heliographic co-ordinates of the spot are lat. = S29°, long. = 181°.

42

3. A mathematical method, similar to the graphical method described above, is as follows:

Let L = Heliographic longitude } of the spot.
B = Heliographic latitude }

θ = position angle of the feature, i.e. the angle subtended at the centre of the disk by the lines joining the feature and the north end of the solar axis (positive to the east).

r/R = ratio expressed as a decimal of the distance from the centre of the disk to the feature divided by the radius of the disk.

Derive α such that $\sin \alpha = r/R$

Derive N such that $\tan N = \tan \alpha \cos (P - \theta)$

Then

$$\tan (L - L_0) = \frac{\tan (P - \theta) \sin N}{\cos (B_0 + N)}$$

Hence L.

$$\tan B = \tan (B_0 + N) \cos (L - L_0)$$

Hence B.

MOON

The information provided in the *Handbook* gives the basic information for all aspects of lunar studies carried out by members:

(a) orbital behaviour,

(b) data for calculating the longitude of the terminator of sunrise and sunset on the lunar surface,

(c) data for estimating times of moonrise and moonset on the surface of the Earth,

(d) predictions for occultations by the Moon of the brighter stars.

The first table gives the times to the nearest minute for New and Full Moon and also the intermediate First and Last Quarters. This is followed by orbital data, which include the times of perigee and apogee, together with the Moon's angular diameter at these points as measured from the centre of the Earth.

Because the Moon has a captured rotation, it always keeps the same face towards the Earth. To an observer on the Earth's surface, this is only approximately true. Owing to the rather complex orbit of the Moon round the Earth, about 60 per cent of the lunar surface can be seen at one time or another. The apparent wobble in the Moon's rotational motion, known as libration, is of paramount importance when studying the limb regions of the Moon.

Libration in longitude, which can produce a displacement of the centre of the lunar disk by as much as 7° 45′, east or west, is a result of a uniform rotation and a varying orbital velocity. The orbital velocity depends on the radius vector of the Moon in accordance with Kepler's 2nd Law.

Libration in latitude, which can produce a displacement by as much as 6° 44′ north or south of the mean position, is due to the Moon's spin axis not being at right angles to the lunar orbital plane.

In addition, because the Moon is relatively near to the Earth, there is a diurnal libration due to the varying displacement of the observer's viewpoint resulting from the Earth's rotation and this can amount to an additional 1° approximately.

The table in the *Handbook* gives the dates for maximum and minimum librations, measured as an angular displacement at the centre of the lunar disk. For each critical condition, the position angle (P.A.) in degrees for the maximum displacement is given. The P.A. is measured through east on the figure of the Moon from the north point of the disk (NOT the north pole of the Moon).

Of fundamental importance in all studies of the lunar surface is the value of the Sun's Selenographic Colongitude. The co-ordinates of a point on the lunar surface where the Sun is in the zenith, i.e. directly overhead, are called the selenographic longitude and latitude of the Sun.

(90° − Sun's selenographic longitude) = Sun's selenographic colongitude. This is the quantity tabulated in the *Handbook* and is given the symbol S. This value is numerically equal to the selenographic longitude of the morning terminator, measured eastward from the mean centre of the lunar disk. Its value is approximately 270° at New Moon, 0° at First Quarter, 90° at Full Moon and 180° at Last Quarter. The longitude of the evening terminator differs by 180° from that of the morning terminator.

The table gives the Sun's selenographic colongitude for each day of the year at 0^h U.T. Although the daily increase is slightly in excess of 12°, an hourly change of 0°·5 can be used for all normal work. Observers should always quote the west or east longitude of the morning or evening terminator, as appropriate. These values are obtained from the Sun's selenographic colongitude S as follows:

Phase	*Terminator*	*S*	*Longitude*	
New Moon to First Quarter	Morning	270° to 360°	360°−*S*	West
First Quarter to Full Moon	Morning	0° to 90°	*S*	East
Full Moon to Last Quarter	Evening	90° to 180°	180°−*S*	West
Last Quarter to New Moon	Evening	180° to 270°	*S*−180°	East

MOONRISE AND MOONSET TIMES

The method adopted in the *Handbook* involves the tabulation of moonrise and moonset times for two standard latitudes, N.52° and S.35°, on the Greenwich meridian. These latitudes are the same as those for which the planet rise/set diagrams are constructed. Observers living within a few degrees of latitude of these two standard latitudes should find the times accurate enough for most purposes. An inspection of Table II will indicate the maximum differences between the times for the standard latitude and that of the required latitude.

44

The method describes how the times for a standard latitude can be used in conjunction with auxiliary tables to calculate the moonrise and moonset times for other latitudes.

By definition, the rising and setting times given in astronomical almanacs are those at which the upper limb of the body appears on the horizon. Thus, in calculating these times for the Moon allowance is made for

(1) R = mean refraction, taken as 34′

(2) s = semi-diameter, which varies from 14′·7 to 16′·8

(3) π = horizontal parallax, which varies from 53′·9 to 61′·5

Therefore the times calculated are those for which the zenith distance, z, of the centre of the Moon is $90°+R+s-\pi$

$$\text{i.e. } z = 90°\ 34' + s - \pi \qquad (1)$$

Thus z can vary between 89° 49′ and 89° 55′. In the following calculations a mean value of

$$z = 89°\ 52' \text{ is adopted.} \qquad (2)$$

For a zenith distance of 90° the hour angle, h, is found from

$$h = \text{arc cos } (-\tan\phi \tan\delta) \qquad (3)$$

where ϕ is the latitude and δ is the declination. h is usually converted into time and is known as the semi-diurnal arc.

Since we need the hour angle at a zenith distance of 89° 52′ we must apply a small correction to h for a change in z of −8′. In minutes of time the correction, c, to be applied to h is given by

$$c = \frac{dh}{dz} = -\frac{8}{15}(\cos^2\phi - \sin^2\delta)^{-\frac{1}{2}} \qquad (4)$$

If the object is a star h can be converted directly to an interval of sidereal time; if the object is the Sun h can be converted directly to an interval of solar time. For the Moon, a correction factor, f, has to be determined, to allow for the Moon's motion, before h can be converted into either sidereal or solar time. The synodic period of revolution of the Moon with respect to the Sun is 29·5306 mean solar days. Thus the Moon will cross the meridian, on the average, every

$$\frac{29{\cdot}5306}{28{\cdot}5306} = 1{\cdot}03505 \text{ mean solar days} = 1490{\cdot}47 \text{ minutes.}$$

Since the mean lunar orbit lies on the ecliptic (at an angle to the equator, $\varepsilon = 23°{\cdot}45$) then the time interval, Q, in minutes of mean solar time, between successive upper transits of the Moon at a particular declination is given by

$$Q = 1440 + 50{\cdot}47 \cos\varepsilon \sec^2\delta \qquad (5)$$

The correction factor, f, in revolutions, is given by

$$f = \frac{Q}{1440} = 1 + 0{\cdot}03216 \sec^2\delta \qquad (6)$$

45

We are now able to calculate the diurnal arc, d, for the Moon at a given declination. Actually we shall need the value of twice the diurnal arc for the moonrise/set calculations, hence

$$2d = 0{\cdot}99727\, f\,(4h+4c) \tag{7}$$

where 0·99727 is the factor to convert the hour angle from sidereal to solar time. From equations (6) and (7) we can deduce that

$$2d-Q = (3{\cdot}9891+0{\cdot}1283 \sec^2 \delta)\,(h+c-360^{m}{\cdot}98). \tag{8}$$

Now let

$$g = (3{\cdot}9891+0{\cdot}1283 \sec^2 \delta) \tag{9}$$

We can define quantities a and b, by

$$a = g\,(h-360^{m}) \tag{10}$$

$$b = -g\,(c-0^{m}{\cdot}98) \tag{11}$$

Thus

$$a = 2d-Q+b \tag{12}$$

Since the value of b varies only slightly throughout the range of declination required, it is possible to adopt a mean value. For latitude N.52° the average value is $+9^{m}$, for S.35° it is $+7^{m}$. Thus a mean value of $+8^{m}$ has been adopted for both latitudes.

Table I gives values of a for the two standard latitudes.

Method

The method for determining times of moonrise and moonset for other latitudes is as follows. Let the times of any three successive phenomena be called P_0, P_1, P_2, (i.e. rise, set, rise or set, rise, set). The intervals (P_1-P_0) and (P_2-P_1) are those for which the Moon is above and below the horizon on either side of the chosen phenomenon P_1. Clearly, as these intervals are dependent on the declination and angular rate of motion of the Moon, we can determine the declination from the diurnal arc, d, and we shall assume a mean motion for the Moon.

If P_1 refers to a moonrise then the interval (P_1-P_0) indicates the time for which the Moon was below the horizon before it rose. Now if instead it had been *above* the horizon with the same declination as it had been below then the diurnal arc would be equal to $Q-(P_1-P_0)$. The diurnal arc following the moonrise would be equal to (P_2-P_1). Thus a mean value of twice the diurnal arc at the time of moonrise is given by

$$2d = Q-2P_1+P_0+P_2 \tag{13}$$

Similar reasoning for the case where P refers to a moonset leads to

$$2d = Q+2P_1-P_0-P_2 \tag{14}$$

Substituting R for a moonrise and S for a moonset, instead of P in equations (13) and (14), and combining them with equation (12) gives

$$a = -2R_1+S_0+S_2+b \quad \text{for a moonrise} \tag{15}$$

$$a = 2S_1-R_0-R_2+b \quad \text{for a moonset} \tag{16}$$

The value of the declination, δ, is obtained by simple interpolation in Table I, using argument a. The correction to the time for the standard latitude to give the time for the required latitude is obtained by interpolation in Table II, using argument δ.

The times thus obtained apply to a longitude of 0°. For other longitudes it is necessary to calculate the time of the previous (following) similar phenomenon if the observer is east (west) of Greenwich and interpolate the times to the observer's longitude.

Accuracy

Since the motion of the Moon is so complicated it must be obvious that a method as simple as the one just described necessarily contains some approximations and the derived times will not be correct to the nearest minute. In practice it will be found that the error is unlikely to exceed 3 minutes. Thus the times derived using this method should be adequate for practically all purposes.

Tables

Table I has been calculated using equation (10).

Table II is a copy of the one that appears in the *Handbook* in the section describing the visibility of the planets. It gives the correction, Δh, to be applied to the rise/set times at two standard latitudes (N.52° and S.35°) to obtain the times of the same phenomenon at other latitudes. It is based on a zenith distance of the body of 90° whereas the old table it replaces was based on 90° 34′. The range of declinations has been increased to 29° to cover the complete range of declination of the Moon. Equation (3) was used to construct the table.

TABLE I

N. 52°		S. 35°	N. 52°		S. 35°	N. 35°		S. 35°
	Dec.			Dec.			Dec.	
a		*a*	*a*		*a*	*a*		*a*
h m	°	h m	h m	°	h m	h m	°	h m
0 00	0	0 00	3 35	10	1 57	7 39	20	4 04
0 21	1	0 12	3 58	11	2 09	8 07	21	4 18
0 42	2	0 23	4 20	12	2 21	8 35	22	4 32
1 03	3	0 35	4 44	13	2 33	9 05	23	4 46
1 25	4	0 46	5 07	14	2 46	9 36	24	5 01
1 46	5	0 58	5 31	15	2 58	10 08	25	5 16
2 07	6	1 10	5 56	16	3 11	10 41	26	5 31
2 29	7	1 21	6 21	17	3 24	11 16	27	5 47
2 51	8	1 33	6 46	18	3 37	11 53	28	6 03
3 13	9	1 45	7 12	19	3 51	12 31	29	6 20
3 35	10	1 57	7 39	20	4 04			
same sign as *a*	Dec.	opp. sign to *a*	same sign as *a*	Dec.	opp. sign to *a*	same sign as *a*	Dec.	opp. sign to *a*

47

TABLE II

Δh TABLE

Latitude N. 58°	N. 55°	N. 50°	N. 40°	N. 30°	N. 20°	Dec.	Latitude 0°	S. 20°	S. 25°	S. 30°	S. 40°	S. 45°
m	m	m	m	m	m	°	m	m	m	m	m	m
+69	+29	−15	−70	−106	−134	29	+91	+45	+31	+17	−20	−43
+62	+26	−14	−66	−100	−127	28	+87	+43	+30	+16	−19	−41
+56	+24	−13	−62	− 94	−120	27	+84	+41	+29	+15	−18	−39
+51	+22	−12	−58	− 89	−114	26	+80	+39	+27	+14	−17	−37
+46	+20	−12	−54	− 84	−107	25	+76	+37	+26	+14	−16	−35
+31	+14	− 8	−40	− 63	− 81	20	+59	+29	+20	+11	−12	−26
+21	+10	− 6	−28	− 45	− 58	15	+43	+21	+15	+ 8	− 9	−19
+13	+ 6	− 4	−18	− 29	− 37	10	+28	+14	+10	+ 5	− 6	−12
+ 6	+ 3	− 2	− 9	− 14	− 18	5	+14	+ 7	+ 5	+ 2	− 3	− 6
0	0	0	0	0	0	0	0	0	0	0	0	0

If Dec. is negative reverse the sign of Δh.

For moonrise and moonset, using the subscript n to refer to the required latitude

$$R_n = R_1 - 1{\cdot}04\ \Delta h \qquad S_n = S_1 + 1{\cdot}04\ \Delta h$$

Examples

The times of moonrise and moonset used in the examples have been taken from the *Astronomical Ephemeris* (*A.E.*) for 1969, when the position of the node of the Moon's orbit was such that an extreme of declination (about 28°·7) was reached.

Example 1. Standard latitude N. 52°. Calculate the time of moonset on 1969 July 29 in longitude (λ) E. 100°, latitude (φ) N. 20°. Since the longitude is east the moonset for the previous day is also calculated, to permit interpolation.

		d h m	d h m
Data for standard latitude	R_0	27 19 37	28 20 12
	S_1	28 02 30	29 04 07
	R_2	28 20 12	29 20 35
	$2S_1$	56 05 00	58 08 14
	$-R_0-R_2$	−56 15 49	−58 16 47
	Sum	−10 49	− 8 33
	b	+ 8	+ 8
	a	−10 41	− 8 25
From Table I	δ	−26°·0 *	−21°·6 *
From Table II	Δh	+114^m	+89^m
	$1{\cdot}04\ \Delta h$	+119^m	+93^m
		d h m	d h m
LMT for λ 0° φ N. 20°	$S_n = S_1 + 1{\cdot}04\ \Delta h$	28 04 29*	29 05 40*
(−100/360) (05^h 40^m–04^h 29^m)			−20
LMT for λ E. 100°, φ N. 20°			29 05 20

(*The values in the *A.E.* are −26·4, −22·2 and 28 04 32, 29 05 43 respectively.)

Example 2. Standard latitude S. 35°. Calculate the time of moonrise on 1969 July 28 in longitude (λ) W. 70°, latitude (φ) S. 45°. Since the longitude is west the moonrise for the following day is also calculated, to permit interpolation.

			d h m	d h m
Data for standard latitude		S_0	27 05 41	28 06 38
		R_1	27 15 15	28 16 32
		S_2	28 06 38	29 07 25
		$-2R_1$	−55 06 30	−57 09 04
		S_0+S_2	55 12 19	57 14 03
		Sum	+ 5 49	+ 4 59
		b	+ 8	+ 8
		a	+ 5 57	+ 5 07
From Table I		δ	$-27°·6$ †	$-24°·4$ †
From Table II		Δh	$+40^m$	$+34^m$
		$1·04\ \Delta h$	$+42^m$	$+35^m$
			d h m	d h m
LMT for λ 0° ϕ S. 45°	$R_n = R_1 - 1·04\ \Delta h$		27 14 33†	28 15 57†
$(+70/360)\ (15^h\ 57^m - 14^h\ 33^m)$			+16	
LMT for λ W. 70°, ϕ S. 45°			27 14 49	

(†The values in the *A.E.* are −27·5, −24·3 and 27 14 33, 28 15 57 respectively.)

OCCULTATIONS

The *Handbook* gives details of occultations by the Moon (except near New and Full Moon) of all stars down to magnitude 7·5 and which will be visible from the British Isles, south eastern Australia and New Zealand. In each locality, data are given for two specific stations. For stations near these standard stations, instructions are given for determining the local data.

The standard stations are: Long. (λ) Lat. (ϕ)

Greenwich	$\lambda = 0°·0$	$\phi = 51°·5$	Edinburgh	$\lambda = 3°·2$	$\phi = 56°·0$
Sydney	$\lambda = -151°·2$	$\phi = -33°·9$	Melbourne	$\lambda = -145°·0$	$\phi = -37°·8$
Dunedin	$\lambda = -170°·5$	$\phi = -45°·9$	Wellington	$\lambda = -174°·8$	$\phi = -41°·3$

The stars are referred to by their numbers in the *Zodiacal Catalogue* (*Astr. Papers of the American Ephemeris*, X, part II, 1940).

The following information is given for each occultation:

Date.
Z.C. Number.
Magnitude of the star.
Ph., the phase, whether disappearance (D) or reappearance (R).
El. of the Moon—the elongation of the Moon from the Sun.

For each of the standard locations, the following information is given:

Time (U.T.).
a and b are coefficients which enable the predicted time at a place $\Delta\lambda$ degrees *west* and $\Delta\phi$ degrees *north* of one of the stations to be found using the formula

$$\text{predicted time} + a.\Delta\lambda + b.\Delta\phi$$

where a and b are given in minutes. If the station is east of the given location $\Delta\lambda$ is negative, and if south, $\Delta\phi$ is taken as negative. For distances up to 500 km the error will not usually exceed 2 minutes.

49

When an occultation is given for one station of a pair but not the other, the reason for the exclusion is as follows:

N = Star not occulted.

A = Star's altitude is less than 10°: planet's less than 2°.

S = The sky is considered to be too bright to allow observation of the phenomenon.

G = An occultation of a very short duration will occur at the standard station. The coefficients *a* and *b* are omitted where their use would cause an unreliable prediction for another station.

B = Occultation occurs at the bright limb of the Moon.

If a more accurate prediction for an intermediate station is required than that provided by the above formula, the following formulae will give better values of *a* and *b*.

If ϕ_1, a_1, and b_1 refer to the station nearer to the required position
ϕ_2, a_2, and b_2 refer to the more distant station
ϕ is the latitude of the observer

$$\text{then } a = a_1 + \frac{(\phi-\phi_1)}{2(\phi_2-\phi_1)}(a_2-a_1)$$

$$b = b_1 + \frac{(\phi-\phi_1)}{2(\phi_2-\phi_1)}(b_2-b_1).$$

The last column gives the position angle, measured through east from the north point of the Moon.

Example:

On 1984 January 9, it was predicted that the star Z.C. No. 18 would be occulted by the Moon. The following information was tabulated.

Greenwich	U.T.	$17^h\ 51^m\!\cdot\!9$	$a = -2\cdot8$,	$b = -2\cdot0$,	$P = 114°$
Edinburgh	U.T.	$17^h\ 40^m\!\cdot\!1$	$a = -1\cdot8$,	$b = -0\cdot5$,	$P = 95°$

For an observer at Manchester, λ 2°·2, ϕ +53°·5, the nearer station is Greenwich, the other being Edinburgh

$$a_1 = -2^m\!\cdot\!8 \quad b_1 = -2^m\!\cdot\!0 \quad \phi_1 = 51°\!\cdot\!5$$
$$a_2 = -1^m\!\cdot\!8 \quad b_2 = -0^m\!\cdot\!5 \quad \phi_2 = 56°\!\cdot\!0$$

whence $a = -2^m\!\cdot\!6$, $b = -1^m\!\cdot\!5$, $\lambda = +2°\!\cdot\!2$, $\phi-\phi_1 = +2°\!\cdot\!0$.

Approximate time at Manchester:

$$= 17^h\ 51^m\!\cdot\!9 + (-2^m\!\cdot\!6)(2\cdot2) + (-1^m\!\cdot\!5)(2\cdot0)$$
$$= 17^h\ 43^m\!\cdot\!2.$$

Grazing Occultations and Occultations by Planets and Comets

When grazing lunar occultations and occultations by planets are predicted in any one year, details of these events are published in the *Handbook* for that year.

50

Because Mercury is an inferior planet, i.e. its orbit lies inside that of the Earth, there are four critical positions in the orbit as far as observations are concerned. These positions are greatest eastern and western elongations, when the planet is at its greatest angular distance east or west from the Sun, and conjunctions, when the planet has the same geocentric longitude as the Sun. At superior conjunction, when the planet is on the far side of the Sun, Mercury cannot be observed. At inferior conjunction, when it lies between the Earth and the Sun, Mercury can be observed only during transits. Observing periods are consequently separated into two distinct time slots. When to the east of the Sun, the planet is an evening object visible in the evening sky just after sunset. When the west of the Sun, the planet is a morning object visible in the morning sky before sunrise.

Times for the critical positions are given at the head of the tables, which divide the ephemeris into two sections covering the evening and morning apparitions. For each, the following information is given at 5-day intervals:

Date (0^h U.T.).
Position of the planet in right ascension and declination.
Magnitude.
Angular diameter in seconds of arc.
Phase (see page 13).
Elongation, the angular separation of the planet from the Sun in degrees.
C.M., the longitude of the central meridian, which is used when reporting visible features on the planet's surface.
Δ, the distance of Mercury from the Earth in astronomical units.

Elongations are always less than 28° and the extreme values at greatest elongations can vary considerably owing to the great eccentricity of the planet's orbit. The mean synodic period is $115^d{\cdot}88$, i.e. about 16·5 weeks. However, the length of one complete cycle of events, say from one greatest western elongation to the next, can differ from another by several weeks because of the eccentricity.

Transits across the Solar Disk

Transits of Mercury across the solar disk as seen from the Earth can occur only when the planet and the Earth are both located near to the same node of Mercury's orbit on the ecliptic. Because changes in the longitudes of the nodes are relatively small, the Earth will be near to the nodes in May and November every year for centuries to come. Owing to the great eccentricity of Mercury's orbit, the conditions and limits for the occurrence of November and May transits are very different.

For the ascending node (November), there are on average nine or ten transits a century. For the descending node (May) there are only about four a century. The times of future transits during the remainder of the twentieth century are:

1993 November 6   1999 November 15

Details of these transits will appear in the relevant issues of the *Handbook*.

VENUS

Although Venus is an inferior planet, its orbit is far more distant from the Sun than that of Mercury. The critical positions of its orbit as seen from the Earth, i.e. the greatest eastern and western elongations, and superior and inferior conjunctions, are given at the head of the page, although not all these positions can occur in any one year. The synodic period is 583·92 days, i.e. just over 19 months.

The main table gives the following information at 10-day intervals, eastern and western elongations being incorporated into a single table:

Date (0^h U.T.).
Position—in right ascension and declination.
Magnitude.
Diam.—angular diameter in seconds of arc.
Ph.—phase (see page 13).
Elong.—the angular separation of the planet from the Sun in degrees, as seen from the Earth's centre.
Δ—the distance of the planet from the Earth in astronomical units.

Elongations can never exceed 47°. The time from greatest eastern elongation to greatest western elongation, i.e. through inferior conjunction, is about 20 weeks but from greatest western elongation through superior conjunction to greatest eastern elongation is approximately 61 weeks. Maximum brightness occurs about 35 days after greatest eastern elongation and about 35 days before greatest western elongation.

Because 13 Venus years (13×a sidereal period of 0·61521 tropical years) equals 7·9977 Earth years (approximately 8 years), there is a good chance that an event associated with Venus will be repeated 8 years later.

Example: A transit of Venus across the solar disk occurred at the ascending node on 1874 December 8. Another transit occurred on 1882 December 6.

Because the relationship is not exact, a transit did not occur on 1890 December 4. The planet passed through inferior conjunction just clear of the Sun as seen from the Earth. The next two transits will occur, this time at the descending node, on 2004 June 7 and 2012 June 5.

The horizontal line in the main table indicates the passage of Venus through either inferior or superior conjunction. For some days on either side of these positions, the planet will be too close to the Sun for visual observations, except possibly when around 90° from a node and passing through inferior conjunction.

MARS

Mars orbits the Sun outside the orbit of the Earth and therefore cannot pass between the Earth and the Sun. The critical positions are *conjunction*, when it is on the far side of the Sun and has the same celestial longitude as the Sun, and *opposition*, when its celestial longitude differs from the Sun's by 180 degrees. Conjunctions and oppositions occur normally in alternate years, but the times between successive oppositions or conjunctions can vary, owing to the eccentricity of the planet's orbit, from 765 to 800 days. From an observational point of view, the most favourable oppositions are those occurring at or near the Martian perihelion and these take place at intervals of 15 or 17 years. Unfortunately for observers in the northern hemisphere, but fortunately for those in the southern, Mars is always in an extreme southerly declination at perihelic oppositions, when it therefore has rather low altitudes for U.K. observers.

The *Handbook* tabulates the following information at 10-day intervals.

Date—at 0^h U.T.

Position—in right ascension and declination.

Magnitude.

Diam.—the apparent diameter in seconds of arc as seen from the centre of the Earth.

P—the position angle of the north pole of the axis of rotation, measured through east from the north point of the disk.

Q—the position angle of the point of greatest defect of illumination owing to phase. The position angle of the line joining the cusps is $Q \pm 90°$.

Ph.—the phase (see page 13).

Tilt—the tilt of the planet's north pole towards (+) or away from (−) the Earth. This is also the planetographic latitude of the centre of the disk.

Hel. long.—the heliocentric ecliptic longitude of the planet, i.e. the ecliptic longitude of the planet as seen from the centre of the Sun. It gives an indication of the Martian seasons and, for historical reasons, is so favoured in the B.A.A. Mars Section. An exact, and more direct, indication of those seasons is afforded by a quantity designated L_s, which is printed in the 1988 issue of the *Handbook* and will be printed in issues thereafter. This quantity is the planetocentric longitude of the Sun measured in the orbital plane from its ascending node on the Martian equator. The seasons in the northern hemisphere of Mars are given by:

L_s °	*Season*
0	Vernal equinox
90	Summer solstice
180	Autumnal equinox
270	Winter solstice

A separate table in the *Handbook* gives the longitude of the central meridian of the planet. It gives the longitude at 0^h U.T. for each day of the year, while a supplementary table allows the longitude to be calculated for any other times.

MINOR PLANETS

The *Handbook* contains ephemerides for those Minor Planets which are brighter than a visual magnitude of about +10 at opposition. The following information is given for each Minor Planet covered by the *Handbook* at 10-day intervals for a period 100 days prior to and 100 days after opposition.

Date (0^h U.T.).

Position in right ascension and declination. Currently these are related to the equinox of 1950·0, which will be replaced by the equinox of 2000·0 in the near future. The position can thus be plotted on a star chart before going to the telescope. Observers who use setting circles to locate Minor Planets should obtain their positions for the current epoch by using the Precession Tables on page 69.

Δ—the distance from the Earth expressed in astronomical units.

r—the distance of the Minor Planet from the Sun, expressed in astronomical units.

Mag.—the photographic magnitude of the Minor Planet, corresponding to the brightness of the planet in the B band of the Johnson UBVRI system: visually most of the Minor Planets appear between 0·70 and 0·85 magnitudes brighter. The value varies with *r*, Δ, phase and phase angle. The brightness also varies as the Minor Planet rotates about its axis, and in some cases this fluctuation can exceed 1 magnitude.

Phase angle—the angle between the Sun and the Earth as seen from the Minor Planet. This is obviously a minimum at opposition. The apparent brightness of the planet varies as its aspect to the Earth changes. Part of this variation is due to the surface texture and is approximately linear for phase angles greater than 7°. The phase angle coefficient is unique to each planet but is approximately 0·023 magnitudes per degree in many cases.

JUPITER

The two critical positions in the orbit of Jupiter are conjunction, i.e. when on the far side of the Sun, and opposition, when in a position directly opposite to that of the Sun. At opposition, the planet appears in the sky directly south, i.e. on the meridian, at midnight. The information printed in the *Handbook* is divided into three sections. The first part gives the position of the planet in the sky and some related information. The second part provides the necessary information used in reporting details of surface features. The last section deals with the positions of the four major satellites.

The mean synodic period, i.e. the period of revolution as seen from the Earth, say from one opposition to the next, is 398·88 days (just over 13 months). With the exception of about one month on either side of conjunction, Jupiter is readily seen as a brilliant object, its magnitude varying only between −2·4 and −1·1. The following information is given at intervals of 10 days.

54

Date (0^h U.T.).
Position in right ascension and declination.
Magnitude.
Equatorial and polar diameters in seconds of arc. Because of the planet's high rotational speed, there is a very noticeable equatorial bulge.
Δ—the distance from the Earth in astronomical units.

Because Jupiter does not rotate as a rigid body like the terrestrial planets, it is necessary to have a recognized method of locating a position on the visible surface. The visual appearance of the planet enables latitude to be estimated quite easily, the feature under study usually being referred to its situation in a particular zone or belt.

The determination of longitude involves timing the passage of a feature across the central meridian, i.e. the line joining the two poles. Unfortunately, the rotational period varies with latitude and so, by convention, there are two systems of measurement.

System I applies to all objects situated on or between the north component of the South Equatorial Belt and the south component of the North Equatorial Belt. The rotational period for this region is $9^h\ 50^m\ 31^s$.

System II applies to all objects situated north of the south component of the North Equatorial Belt or south of the north component of the South Equatorial Belt. This region has a rotational period of $9^h\ 55^m\ 41^s$.

Radio studies require a third system, System III, which has a period of $9^h\ 55^m\ 29^s$.

The tables given in the *Handbook* give the longitude for 0^h U.T. on each day of the year. A subsidiary table gives the increment in longitude for other times. When using these tables make sure that the *correct* system is used.

Example: Calculate the longitude of a feature in the South Tropical Zone and seen to cross the central meridian on 1984 April $16^d\ 22^h\ 17^m$ U.T.

Since $16^d\ 22^h\ 17^m$ U.T. is near to 0^h on April 17, it is more convenient to use April 17 as the reference date.

Longitude of central meridian (System II) at 0^h U.T. on April 17 is $299^\circ{\cdot}8$.

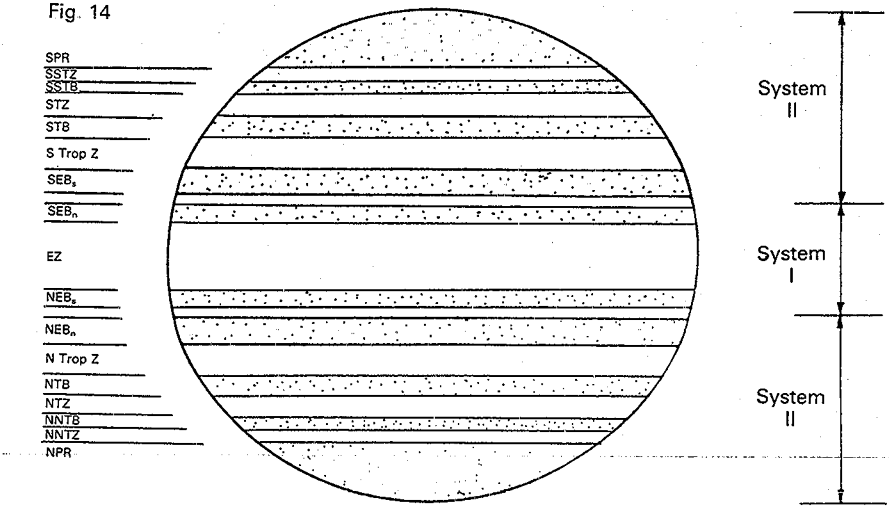
From the subsidiary table	1^h	gives a longitude change of	$36^\circ{\cdot}3$
	40^m	gives a longitude change of	$24^\circ{\cdot}2$
	3^m	gives a longitude change of	$1^\circ{\cdot}8$
		Total	$62^\circ{\cdot}3$

$$\text{Required longitude} = 299{\cdot}8 - 62{\cdot}3 = 237^\circ{\cdot}5$$

A minus sign is used because the time of the observation was prior to 0^h on April 17.

55

Fig. 14



NPR	North Polar Region
NNTZ	North North Temperate Zone
NNTB	North North Temperate Belt
NTZ	North Temperate Zone
NTB	North Temperate Belt
N Trop Z	North Tropical Zone
NEB_n	North Component of the North Equatorial Belt
NEB_s	South Component of the North Equatorial Belt
EZ	Equatorial Zone
SEB_n	North Component of the South Equatorial Belt
SEB_s	South Component of the South Equatorial Belt
S Trop Z	South Tropical Zone
STB	South Temperate Belt
STZ	South Temperate Zone
SSTB	South South Temperate Belt
SSTZ	South South Temperate Zone
SPR	South Polar Region

Satellites of Jupiter

The movements and positions of the four major satellites of Jupiter are given in graphical form. These illustrate the relative positions as seen in an inverting telescope in the northern hemisphere (preceding to the left, following to the right). The vertical band in the centre of each diagram represents the equatorial diameter of Jupiter and the horizontal lines denote 0^h U.T. on each successive day. The satellites move from east to west across the face of the planet and from west to east behind it. The second section tabulates the times of any eclipses, occultations and transits that will occur

56

during the year. Between conjunction and opposition, the shadow of Jupiter falls to the west and eclipse precedes occultation and shadow transit precedes transit. After opposition the order of the phenomena is reversed, with occultation preceding eclipse and transit preceding shadow transit.

Both phases of eclipse (disappearance EcD and reappearance EcR) and of occultation (disappearance OcD and reappearance OcR) of satellites III and IV may be observed if not too near opposition. Satellite I is much too close to the planet and so eclipse and occultation merge into one. EcD is followed by OcR before opposition, but OcD is followed by EcR after opposition. Satellite II normally behaves in the same way but on rare occasions the separate phenomena of II may be observed.

On a few occasions all three of the inner satellites may be involved simultaneously in these phenomena, but the motions of these three are related in such a way that it is impossible for all three to undergo the same phenomenon at the same time.

The times of all such phenomena are given in Table I, and are given for the centre of the satellite. The light of the satellite will therefore begin to fade before the times given and so observation should commence several minutes prior to the times predicted.

Mutual Phenomena of Satellites

On occasions when two satellites lie along the same line of sight as seen from the Earth, it is possible for one satellite to occult another or on other occasions one satellite can pass into the shadow of another. If these occur and can be seen from the Earth, details will be recorded in a supplementary table.

'3,2' signifies that satellite III occults (or eclipses) satellite II, etc. The letters P, A and T respectively indicate whether the phenomenon is partial, annular or total. The column headed S.D. gives the semi-duration of the partial phase in seconds. The column headed Mag. is the percentage of the diameter of the second named satellite occulted (or eclipsed) by the first named satellite. In the column headed Dist., the distance of the second named satellite from the centre of Jupiter's disk is given in terms of the semi-diameter of the disk.

Summary of the symbols used in satellite phenomena.

Ec	Eclipse.
Oc	Occultation.
Tr	Satellite transit over the planet's disk.
Sh	Satellite shadow transit.
D	Disappearance.
R	Reappearance.
I	Ingress.
E	Egress.

Observations of Saturn are generally confined to times within 5½ months on either side of opposition, which occurs roughly every 378 days. No observations are normally possible within three weeks of conjunction. The dates of opposition and conjunction are printed at the top of the *Handbook* page devoted to the ephemeris of the planet.

Data in the ephemeris are tabulated for 10-day intervals throughout the year, except near conjunction. The following information is given:

Date (0^h U.T.).
Position in right ascension and declination.
Magnitude.
Polar diameter in seconds of arc.
The major and minor axes of the rings in seconds of arc.
Tilt, a measure of the openness of the rings as seen from the Earth. It is given the symbol B in theoretical work and in the diagrams provided by the Saturn Section. The tilt is positive if the north face of the rings is inclined towards the Earth and negative if the south face of the rings is inclined towards the Earth. If its value is 0, the rings, if visible at all, appear as a straight line. The maximum degree of opening of the rings as seen from the Earth is about 29°·2.
Δ, the distance of the planet from the Earth measured in astronomical units.

Because of the lack of detailed values for the rotation period of the planet at different latitudes and the relatively few occasions on which prominent markings appear on the surface of the planet, it is valuable to note the time of passage of any feature through the central meridian, i.e. the line joining the north and south poles of the planet.

Satellites of Saturn

The tables printed in the *Handbook* give information for locating the eight principal satellites.

Table 1: Mimas and Enceladus

The elongations, expressed in seconds of arc from the centre of the planet, vary considerably during a year, mainly because of the changing distance of the planet from the Earth. The values at intervals of roughly a month are given in the first part of Table 1 and reflect this changing distance. The second part of the table gives the times of every third eastern elongation for Mimas and every second eastern elongation for Enceladus. The times for intermediate elongations can be found accurately enough by adding:

Mimas	$0^d\ 22^h{\cdot}6$ and $1^d\ 21^h{\cdot}2$
Enceladus	$1^d\ 08^h{\cdot}9$

The times of western elongations are approximately midway between the times for eastern elongations. It should be noted that both satellites are usually brighter near western elongations.

Table 2: Angular Elongation Distances

Table 2 gives the *mean* angular elongation distances in arcseconds from the centre of the planet at 10-day intervals for the satellites Tethys, Dione, Rhea, Titan, and Hyperion. These distances are the distances at which the satellites would appear to be from the planet if they happened to be at eastern elongation on the given dates, but with the eccentricities of their orbits ignored. (As far as this table is concerned, the eccentricities are appreciable only for Titan and Hyperion.) The table is used together with subsequent tables for individual satellites. It illustrates the apparent changes in the sizes of the satellite orbits with changing Earth–Saturn distance.

Table 3: Tethys

Table 3 gives the times of each third eastern elongation of Tethys. For the intervening elongations, add $1^{d}\ 21^{h}{\cdot}3$ and $3^{d}\ 18^{h}{\cdot}6$, with western elongations occurring midway between consecutive eastern elongations.

Table 4: Dione

Table 4 gives the times of alternate eastern elongations of Dione. For the intervening eastern elongation, add $2^{d}\ 17^{h}{\cdot}2$. Western elongations occur midway between consecutive eastern elongations.

Table 5: Rhea

Table 5 gives the times of every eastern elongation of Rhea throughout the apparition.

Using the Tables

To find the angular distance of a particular satellite from the centre of Saturn, proceed as follows:

(1) Find the elongation distance for the satellite for the nearest date given in Table 2.

(2) From the table relating to the particular satellite, determine the elapsed time since the last eastern elongation.

(3) Using the elapsed time in the column headed 'After e.e.' (i.e. after eastern elongation), find the values given for R and P, of which R is the ratio of the separation at the required time to that at eastern elongation and P is the position angle. (The values of R and P are actually calculated for the date of opposition, but they suffice with adequate accuracy for the whole of an apparition.)

(4) Multiply the value obtained in (1) by R to give a value x.

(5) The satellite will be located at a distance of x seconds of arc from the centre of the planet and in position angle P. (See page 13 for the meaning of position angle.)

Example: Find the location of Tethys relative to Saturn on 1985 August 10^{d} 23^{h} U.T.

From the 1985 *Handbook*, the nearest date to August 10 in Table 2 is August 8, when the elongation distance for Tethys is given as 41″.

59

An extract from Table 3 for Tethys is as follows:

	d	h
Aug.	3	02·0
	8	18·0
	14	10·0
	20	01·9

The nearest eastern elongation to August 10 will be the one that follows that given for August 8 and will occur at:

$$\text{Aug. } 8^d\ 18^h.0 + 1^d\ 21^h.3 = \text{Aug. } 10^d\ 15^h.3$$

The time elapsed between the elongation and the observation is Aug. $10^d\ 23^h.0$ – Aug. $10^d\ 15^h.3 = 7^h.7$.

The following extract from the table gives R and P for times after eastern elongation:

After e.e. d h	R	P °
0 05	0·80	107
0 06	0·72	112
0 07	0·63	118
0 08	0·54	126

For $7^h.7$, $R = 0{\cdot}57$ and $P = 124°$ approximately.

Therefore, the angular separation between the centre of the planet and Tethys is $41'' \times 0{\cdot}57 = 23''$ and the position angle is 124°.

Table 6: Titan

The Titan table gives not only the times of all eastern elongations, but also the times of western elongations and of inferior and superior conjunctions. The method for finding the position angle and distance from the centre of Saturn is identical with that described above, but because the orbit of Titan is sensibly eccentric, it is possible for the actual elongation distances to differ from the mean elongation distances given in Table 2; in other words, the value of R may be greater or less than unity when Titan is at or near elongation.

The *Handbook* also gives diagrams of the position of Titan relative to Saturn at 0^h U.T. each day, the orbit in each diagram being depicted as seen on day 15 of each month. The indicated positions are means of the actual positions on any one day and the day 16 days later, which two positions can differ by several arcseconds, but not by enough to affect the accuracy of the drawings. The diagrams give the inverted telescopic view in the northern hemisphere, i.e. they have north downwards.

Table 7: Hyperion

As with the Titan table, Table 7 gives the times of eastern and western elongations and of inferior and superior conjunctions, together with the data which, in use with Table 2, allow the position angle and angular separation at any time to be calculated. The orbit of Hyperion, like that of Titan, being appreciably eccentric, the value of R for this satellite can also be greater or

60

less than unity when the satellite is at elongation. As the orbital periods of Titan and Hyperion are almost exactly in the ratio of 3 to 4, the two satellites are in proximity near certain of the elongations, when it is easier to identify the much fainter Hyperion.

Iapetus

No table is given for the position of Iapetus, but diagrams are provided to show the position angle and distance of the satellite at 4-day intervals. The diagrams give the inverted telescopic view for the northern hemisphere.

Iapetus shows decided variations in brightness and is always brighter at western than at eastern elongations, by as much as two magnitudes. The dates of western elongations are given in the textual note accompanying the diagrams.

URANUS, NEPTUNE AND PLUTO

No numerical tables are given for the positions of these planets during the year. For each, however, an individual diagram is given showing the path through the star background as seen through a telescope. Each diagram is clearly labelled with the appropriate values for right ascension and declination and the positions are given for the first day of each month. The background star field is coded for magnitude.

Dates for opposition are given at the head of the page and the magnitude at opposition is given for each planet.

COMETS

The Association provides a service to astronomers in general by printing ephemerides for most of the returning periodic comets and also, in the *Circulars*, the newly-discovered brighter objects. Many of the periodic comets are very faint and hence beyond the reach of members using relatively small instruments. Nevertheless, some members are now operating larger photographic instruments with the capability of recording comets down to magnitude +16.

For each comet, the orbital elements are calculated for a given epoch. As these are osculating elements, they apply only to that particular epoch. For an explanation of these elements, refer to the section defining and explaining orbital elements on page 6. Based on the elements, ephemerides are given under the following headings:

Date (0^h T.D.T.).
Position—in right ascension and declination to a given equinox, currently 1950·0, but this will change to 2000·0 in the near future.
Δ—the distance of the comet from the Earth in astronomical units.
r—the distance of the comet from the Sun in astronomical units.

61

The orbital elements quoted at the beginning, having been derived from initial and often difficult observations, are liable to error. The data listed are predictions for a standard time of 10 days after perihelion passage. The position of the comet along its orbit may be in error leading to a different time of perihelion passage. The effect can be to displace the comet on the star background by a relatively large amount, even though the other elements are quite well defined. To correct for this error without reprinting the whole ephemeris, the values $\Delta\alpha$ and $\Delta\delta$ (change in R.A. and change in Dec. respectively for perihelion time being one day later) are given. When it is announced that a comet has been recovered but the perihelion date needs an adjustment of so many days or a part of a day, the values of $\Delta\alpha$ and $\Delta\delta$ should be multiplied by the change in perihelion date in days.

This value of ΔT must not be confused with the correction, also denoted by ΔT, to be applied to Universal Time (U.T.) to give Terrestrial Dynamical Time (T.D.T.). Although the same symbol is used, no difficulty should arise.

The last column gives the apparent magnitude (Mag.).

Magnitudes used in Cometary Studies

Magnitudes of comets are defined in two ways, these being given the symbols m_1 and m_2. Either value may be given in the ephemerides of short-period comets. Both are defined as the apparent magnitude as seen from the Earth but whereas m_1 approximates to the total visual brightness of the comet's head measured in a dark sky with the smallest aperture instrument that will show the comet clearly, the m_2 value relates to the photographic image, as recorded by a larger telescope when the comet is faint, usually when it is fainter than magnitude +16 and at a distance from the Sun where the coma is not well developed. Consequently the m_2 value is often referred to as the nuclear magnitude. This term may be a little misleading because, even with a large telescope, the nucleus will not be resolved, and so it is most likely that the value of m_2 refers to the brightness of the circum-nuclear cloud of particles.

The value of m_2 is not precise. A term to allow for the phase effect is frequently included in the formula for m_2 magnitudes of short-period comets (those having periods of less than 200 years). Focal ratio, density of photographic image and seeing all affect the m_2 magnitude, it being brighter for faster instruments and long exposures. But the m_2 value is a useful guide for those attempting to recover a comet when it is faint. (Comets are often recovered when they are as faint as magnitude +20.) Its value may seriously underestimate, even by as much as 5 magnitudes, the total m_1 brightness observed visually or with smaller photographic instruments as the comet approaches the Sun.

The prediction of the brightness of a periodic comet presents special problems, but analysis of earlier returns is permitting more realistic m_1 values to be predicted. In addition, sudden changes in the behaviour of a comet can produce changes of many magnitudes and so the values given in the *Handbook* should be used principally as a guide.

62

Note on the formulae for calculating m

In the formula:

$$m_1 = H_0 + 5 \log \Delta + 2{\cdot}5n \log r$$

m_1—is the apparent visual magnitude of the head of the comet.

H_0—the absolute magnitude, i.e. the magnitude the comet would be expected to have if both Δ and r were unity. This value reflects in an empirical way the size and activity of the comet, and no doubt its composition and structure.

5 log Δ—reflects the way in which the comet's brightness varies with changing distance from the Earth. As the Earth does not affect the comet's intrinsic brightness, this value follows an inverse square law.

$2{\cdot}5n \log r$—as with H_0, n varies from comet to comet and reflects the way in which the intrinsic brightness changes with varying heliocentric distance. An initial value of $n = 4$ is usually used for a newly found comet (i.e. $2{\cdot}5 \times 4 = 10$). Periodic comets often have a higher value, say for example $n = 6$, when $2{\cdot}5n$ equals 15.

The same formula can be used for calculating m_2. In this case it is usual to use $n = 4$, but for comets showing little development, e.g. P/Arend-Rigaux, a value of $n = 2$ has been used and a phase term added so that the formula becomes

$$m_2 = 15{\cdot}5 + 5 \log \Delta + 5 \log r + 0{\cdot}03 \text{ (phase angle)}^\circ.$$

It is interesting to note that even in this case the m_1 magnitudes observed have been as much as 6 magnitudes brighter than these 'recovery' magnitudes.

The values of H_0 and n are not fixed for a given comet for all time, but are determined from observations, and different values may be found for the pre- and post-helion arcs. Periodic comets behave differently at successive apparitions and different values may represent their activity more closely. However, there is little evidence that, in general, the periodic comets are fading from apparition to apparition.

METEORS

The Meteor Diary gives data on all the regular major streams and some of the minor streams. No information is given on daylight streams, i.e. the ones that can only be recorded by using radar techniques. The techniques of observing meteor streams and also of observing sporadic meteors can be obtained from the Director of the Meteor Section.

Meteor showers (or streams) are generally named after the constellation in which the radiant lies, with the syllable -IDS added, but there is a certain amount of chaos in the nomenclature. For example, the constellation of Quadrans (after which the Quadrantids are named) no longer exists and the

63

radiant of the Orionids spends most of its time in the constellation of Gemini. In addition, the Giacobinids and the Bielids are named after the comets with which they are respectively associated. The Ursids should, if the system were applied rigidly, be referred to as the Ursa Minorids. In spite of the exceptions, the system is well established and generally no ambiguities arise.

The showers listed may vary from year to year. The Giacobinids, for example, would tend to be listed only in the year near to the return of the associated comet.

The second column headed $\lambda_{\odot}$ (1950·0) gives the longitude of the Sun at the point where the orbit of the meteor stream and that of the Earth intersect. It is the most significant measure of time in meteor work as meteors are seen when they collide with the Earth and the Earth's position in its orbit is measured by the position of the Sun along the ecliptic, the solar longitude. The two positions—Sun and meteors—are, of course, 180° apart. For example, if the orbit of a meteor stream intersected that of the Earth at the First Point of Aries, meteors would be seen when the Sun's longitude was 180°. In some cases the time of maximum activity of the shower and the solar longitude are more or less the same.

Most meteor showers have rather broad maxima and may be equally strong on two successive nights, but in a few cases the maximum is short and sharp and lasts only for a few hours. The Quadrantids and Leonids have well-defined maxima. On the other hand, activity may be spread over a period of two to three weeks, usually building up rather slowly to a maximum and then dropping fairly quickly. However, a word of warning is necessary: except in the cases of the strongest showers, it may take several hours of watching to establish that a stream is being observed, even at maximum. The diary gives the date (and the time where appropriate) for the predicted maximum and the dates of the normal limits of activity of the stream. These are defined as the dates between which the shower rates are normally greater than a quarter of the sporadic rate for the period.

Meteor rates are notoriously variable and unpredictable. Apart from the innate variability of a given stream, three factors have profound effects on the numbers of meteors actually observed.

1. Sky conditions: moonlight, twilight, haze and patchy cloud cover drastically reduce the number of meteors seen. The observer should always record the magnitude of the faintest stars visible.
2. The altitude of the radiant: the radiant is that region in the sky from which all meteors in the stream appear to originate. If the projections of stream meteors are produced backwards, they tend to meet at a point. This is called the radiant. If the radiant altitude is less than 25°, one will not see more than half the full rate and it is not until the altitude is at least 70° that the shower can be seen at its full strength. This value is called the Zenith Hourly Rate (ZHR). The ZHR is the predicted hourly rate for an experienced observer watching in a sky of limiting magnitude +6·5 (i.e. a *very* clear, moonless sky) and when the radiant is in the zenith.

64

To a first approximation, the observed hourly rate (OHR) varies with the sine of the altitude of the radiant, (a), i.e.

$$\text{OHR} = \text{ZHR} \sin a.$$

A better value is that derived by J. P. M. Prentice:

$$\text{OHR} = \text{ZHR} \sin (a+6°)$$

and the following table is based on this formula. The table gives, for various altitudes of the radiant, the factor (F) by which the observed rate should be multiplied to give the ZHR.

a	F	a	F
°		°	
0		27	
	10		1·67
3		35	
	5		1·43
9		43	
	3·3		1·25
15		52	
	2·5		1·11
21		66	
	2·0		1·0
27		90	

In critical cases ascend

3. Perceptiveness of the observer: sustained concentration and an alert attitude are necessary, otherwise one will only see the brighter meteors and the fainter ones which make up the bulk will be missed.

The next few columns give the positions in right ascension and declination of the radiant at the date of maximum activity. Meteor radiants are not stationary because of the Earth's motion round the Sun. They move at about 1° in ecliptic longitude per day. The tables give, where appropriate, the daily changes in right ascension and declination and these should be applied to determining the radiant at times other than that at the maximum.

Telescopic observations are becoming increasingly important. It is considered that much important information awaits to be discovered from such observations. If a number is given in this column this is an approximate relative telescopic rate (sporadic rate = 1·0). If there is no entry, the shower is thought to be deficient in faint meteors. For the remainder, the data are scanty. The times of telescopic maxima are for meteors of mean magnitude +7. It seems likely that many telescopic showers await to be discovered.

The last column on the first page gives the local time of the transit of the radiant. This will be the time of the maximum altitude of the radiant.

The diary gives full details concerning the Moon. The age of the Moon is given for specific dates. One must regulate the observing times accordingly. If, for example, there is a 7-day-old Moon in Sagittarius and the Orionids are under observation, there will be little trouble, but a Full Moon near the radiant makes observing hopeless. The age and position of the Moon, together with the times of moonrise and moonset (obtained elsewhere in the *Handbook*) provide sufficient information to judge the best times at which to begin and end watches.

There are several kinds of twilight, civil, nautical and astronomical, depending on the angular depression of the Sun below the horizon. In meteor work, nautical twilight is used. This starts when the Sun has reached 12°

65

below the horizon, but local conditions can modify the impact of twilight considerably and so the times are intended as a rough guide. Information is given for the two standard latitudes (N. 52° and S. 35°). For these latitudes a series of times and altitudes for the radiant are given.

The last column gives some rough notes on the physical appearance of the meteors and the anticipated behaviour of the shower for the year in question.

66

Part 3

GENERAL INFORMATION

67

68

PRECESSION

Luni-solar precession is the change of the right ascension and declination of an object caused by the steady motion of the rotation axis of the Earth relative to the pole of the ecliptic. For periods of a few years the rates of change of R.A. and declination may be taken as constant to a reasonable approximation. Right ascension nearly always shows a steady increase with time, except for high declinations, as shown in the table below. Annual precession in declination is a function of the right ascension of the object, and does not depend on the declination of the object.

$$\text{Annual precession in R.A.} = 3^{s}{\cdot}0730 + 1^{s}{\cdot}3362 \sin\alpha \tan\delta$$

$$\text{Annual precession in Dec.} = 20''{\cdot}043 \cos\alpha$$

The corrections are always to be added algebraically. For example, the position of γ Centauri at 1900·0 is given in Lewis Boss' *Preliminary General Catalogue* (1910) as: R.A. $12^{h}\ 36^{m}\ 00^{s}{\cdot}0$, Dec. −48° 24′ 38″. To find its position at 1971·0 add the interpolated corrections from the tables ($+3^{s}{\cdot}3$ in R.A., −19″·4 in Dec.) multiplied by 71, giving R.A. $12^{h}\ 39^{m}\ 54^{s}{\cdot}3$, Dec. −48° 47′ 35″. Reference to *The Astronomical Ephemeris* for 1971 shows that corrections made in this way, even over the greater part of a century, are accurate to within one or two minutes of arc.

Annual Precession in Declination
(In seconds of ARC, + ≡ Declination increasing)

R.A. h	Precess. ″	R.A. h	Precess. ″	R.A. h	Precess. ″	R.A. h	Precess. ″	R.A. h	Precess. ″
0	20	5	5	10	−17	15	−14	20	10
1	19	6	0	11	−19	16	−10	21	14
2	17	7	− 5	12	−20	17	− 5	22	17
3	14	8	−10	13	−19	18	0	23	19
4	10	9	−14	14	−17	19	5		

Annual Precession in Right Ascension
(In seconds of TIME, + ≡ R.A. increasing)

Dec.	Hours of Right Ascension for NORTHERN objects												
	6	7	8	9	10	11	12	13	14	15	16	17	18
		5	4	3	2	1	0	23	22	21	20	19	
80	10·7	10·4	9·6	8·4	6·9	5·0	3·1	1·1	−0·7	−2·3	−3·5	−4·2	−4·5
70	6·7	6·6	6·3	5·7	4·9	4·0	3·1	2·1	1·2	0·5	−0·1	−0·5	−0·6
60	5·4	5·3	5·1	4·7	4·2	3·7	3·1	2·5	1·9	1·4	1·1	0·8	0·8
50	4·7	4·6	4·5	4·2	3·9	3·5	3·1	2·7	2·3	1·9	1·7	1·5	1·5
40	4·2	4·2	4·0	3·9	3·6	3·4	3·1	2·8	2·5	2·3	2·1	2·0	2·0
30	3·8	3·8	3·7	3·6	3·5	3·3	3·1	2·9	2·7	2·5	2·4	2·3	2·3
20	3·6	3·5	3·5	3·4	3·3	3·2	3·1	2·9	2·8	2·7	2·7	2·6	2·6
10	3·3	3·3	3·3	3·2	3·2	3·1	3·1	3·0	3·0	2·9	2·9	2·9	2·8
0	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1	3·1
	18	19	20	21	22	23	0	1	2	3	4	5	6
		17	16	15	14	13	12	11	10	9	8	7	
	Hours of Right Ascension for SOUTHERN objects												

The precession in R.A. is positive except where indicated for high declinations

JULIAN DAY NUMBER

DAYS ELAPSED AT GREENWICH NOON, A.D. 1950–2000

Year	Jan. 0	Feb. 0	Mar. 0	Apr. 0	May 0	June 0	July 0	Aug. 0	Sept. 0	Oct. 0	Nov. 0	Dec. 0
1950	243 3282	3313	3341	3372	3402	3433	3463	3494	3525	3555	3586	3616
1951	3647	3678	3706	3737	3767	3798	3828	3859	3890	3920	3951	3981
1952	4012	4043	4072	4103	4133	4164	4194	4225	4256	4286	4317	4347
1953	4378	4409	4437	4468	4498	4529	4559	4590	4621	4651	4682	4712
1954	4743	4774	4802	4833	4863	4894	4924	4955	4986	5016	5047	5077
1955	243 5108	5139	5167	5198	5228	5259	5289	5320	5351	5381	5412	5442
1956	5473	5504	5533	5564	5594	5625	5655	5686	5717	5747	5778	5808
1957	5839	5870	5898	5929	5959	5990	6020	6051	6082	6112	6143	6173
1958	6204	6235	6263	6294	6324	6355	6385	6416	6447	6477	6508	6538
1959	6569	6600	6628	6659	6689	6720	6750	6781	6812	6842	6873	6903
1960	243 6934	6965	6994	7025	7055	7086	7116	7147	7178	7208	7239	7269
1961	7300	7331	7359	7390	7420	7451	7481	7512	7543	7573	7604	7634
1962	7665	7696	7724	7755	7785	7816	7846	7877	7908	7938	7969	7999
1963	8030	8061	8089	8120	8150	8181	8211	8242	8273	8303	8334	8364
1964	8395	8426	8455	8486	8516	8547	8577	8608	8639	8669	8700	8730
1965	243 8761	8792	8820	8851	8881	8912	8942	8973	9004	9034	9065	9095
1966	9126	9157	9185	9216	9246	9277	9307	9338	9369	9399	9430	9460
1967	9491	9522	9550	9581	9611	9642	9672	9703	9734	9764	9795	9825
1968	9856	9887	9916	9947	9977	*0008	*0038	*0069	*0100	*0130	*0161	*0191
1969	244 0222	0253	0281	0312	0342	0373	0403	0434	0465	0495	0526	0556
1970	244 0587	0618	0646	0677	0707	0738	0768	0799	0830	0860	0891	0921
1971	0952	0983	1011	1042	1072	1103	1133	1164	1195	1225	1256	1286
1972	1317	1348	1377	1408	1438	1469	1499	1530	1561	1591	1622	1652
1973	1683	1714	1742	1773	1803	1834	1864	1895	1926	1956	1987	2017
1974	2048	2079	2107	2138	2168	2199	2229	2260	2291	2321	2352	2382
1975	244 2413	2444	2472	2503	2533	2564	2594	2625	2656	2686	2717	2747
1976	2778	2809	2838	2869	2899	2930	2960	2991	3022	3052	3083	3113
1977	3144	3175	3203	3234	3264	3295	3325	3356	3387	3417	3448	3478
1978	3509	3540	3568	3599	3629	3660	3690	3721	3752	3782	3813	3843
1979	3874	3905	3933	3964	3994	4025	4055	4086	4117	4147	4178	4208
1980	244 4239	4270	4299	4330	4360	4391	4421	4452	4483	4513	4544	4574
1981	4605	4636	4664	4695	4725	4756	4786	4817	4848	4878	4909	4939
1982	4970	5001	5029	5060	5090	5121	5151	5182	5213	5243	5274	5304
1983	5335	5366	5394	5425	5455	5486	5516	5547	5578	5608	5639	5669
1984	5700	5731	5760	5791	5821	5852	5882	5913	5944	5974	6005	6035
1985	244 6066	6097	6125	6156	6186	6217	6247	6278	6309	6339	6370	6400
1986	6431	6462	6490	6521	6551	6582	6612	6643	6674	6704	6735	6765
1987	6796	6827	6855	6886	6916	6947	6977	7008	7039	7069	7100	7130
1988	7161	7192	7221	7252	7282	7313	7343	7374	7405	7435	7466	7496
1989	7527	7558	7586	7617	7647	7678	7708	7739	7770	7800	7831	7861
1990	244 7892	7923	7951	7982	8012	8043	8073	8104	8135	8165	8196	8226
1991	8257	8288	8316	8347	8377	8408	8438	8469	8500	8530	8561	8591
1992	8622	8653	8682	8713	8743	8774	8804	8835	8866	8896	8927	8957
1993	8988	9019	9047	9078	9108	9139	9169	9200	9231	9261	9292	9322
1994	9353	9384	9412	9443	9473	9504	9534	9565	9596	9626	9657	9687
1995	244 9718	9749	9777	9808	9838	9869	9899	9930	9961	9991	*0022	*0052
1996	245 0083	0114	0143	0174	0204	0235	0265	0296	0327	0357	0388	0418
1997	0449	0480	0508	0539	0569	0600	0630	0661	0692	0722	0753	0783
1998	0814	0845	0873	0904	0934	0965	0995	1026	1057	1087	1118	1148
1999	1179	1210	1238	1269	1299	1330	1360	1391	1422	1452	1483	1513
2000	245 1544	1575	1604	1635	1665	1696	1726	1757	1788	1818	1849	1879

1. *Norton's Star Atlas and Reference Handbook*. Publishers: Gall & Inglis, Edinburgh.

Stars down to magnitude +6 are recorded, although some of the sixth magnitude stars are missing. The scale is just over 3 mm per degree and the whole sky is covered by 16 maps. The atlas is ideal for plotting predicted tracks (use a soft pencil!).

Available through any bookseller or direct from the publishers at 62 Buckstone Terrace, Edinburgh, EH10 6RQ.

2. *B.A.A. Star Charts*

Stars down to magnitude +6 are recorded. The scale is about 3·5 mm per degree and the whole sky is covered by five separate maps. The charts are ideal for plotting predicted tracks.

Available from the B.A.A. Office, Burlington House, Piccadilly, London, W1V 9AG.

3. *Sky Atlas 2000·0* by Wil Tirion

Stars down to magnitude +8 are recorded and the whole sky is covered by 26 charts. This atlas replaces the *Atlas Coeli* which has now been discontinued. The scale is about 7·5 mm per degree.

Available from Cambridge University Press, Cambridge, or through any bookseller.

4. *Atlas Borealis 1950·0*
Atlas Eclipticalis 1950·0
Atlas Australis 1950·0 } A. Bečvar, Prague

These three atlases cover the whole sky down to magnitude +10 on a scale of 2 cm per degree. A transparent grid enables accurate stellar co-ordinates to be obtained. The Borealis covers the sky for declinations greater than +30°, the Eclipticalis for declinations from +30° to −30° and the Australis for declinations −30° to −90°. They are ideal for plotting tracks of objects below naked-eye visibility.

Available from Sky Publishing Corporation, 49 Bay State Road, Cambridge, Mass. 02238, U.S.A.

S.A.O. Atlas: 1950·0

The atlas consists of 152 charts, each 22°×22° on a scale of 1 mm per 6·95 minutes of arc. All stars down to magnitude +10 are covered.

Published by The Smithsonian Institution, Cambridge, Mass., U.S.A.

A.A.V.S.O. Variable Star Atlas, prepared by Charles E. Scovil

The whole sky is covered in 178 sheets each 30×35 cm on a scale of 1 mm per 4 arcseconds. The atlas covers stars down to magnitude +9 and galaxies to magnitude +13.

71

Astronomers have compiled many hundreds of catalogues and it can be difficult to find information about any particular object. The lists given below are intended to assist beginners in finding information; the lists are by no means comprehensive, and include only a few of the most important sources.

The brightest stars are known by their names, by the Bayer letters (e.g. β Tauri) or by Flamsteed numbers (e.g. 61 Cygni). These, and fainter stars, are known by their numbers in various star catalogues. In the lists we have sometimes indicated a usual abbreviation by giving a specimen reference.

General

1. C. W. Allen, *Astrophysical Quantities*, Athlone Press, London, 1973 (Third Edition). Contains lists of the 100 nearest stars, 100 brightest stars, visual, spectroscopic and eclipsing binaries, flare stars, novae, pulsars, planetary nebulae, radio sources, star clusters, galaxies, quasars and clusters of galaxies, together with much other information about these objects. A valuable general compilation.

2. *The Observer's Handbook*, Royal Astronomical Society of Canada (published annually). Data for the 286 stars brighter than magnitude 3·55 visual. Includes modern magnitudes, colour indices, spectral types and luminosities, as well as positions, parallaxes, and other data. Also contains lists of selected double and multiple stars, variable stars, the nearest stars, galactic nebulae, Messier objects, star clusters, galaxies and radio sources.

3. A. Bečvar, *Atlas Coeli Skalnate Pleso*, Prague, 1959 (revised edition). The *Atlas Catalogue*, which was designed to accompany the *Atlas*, contains information on 6362 stars to magnitude 6·25 (positions, proper motions, magnitudes, spectral types, parallaxes and radial velocities, and other information), together with lists of double stars, variable stars, novae, star clusters, galactic nebulae and galaxies.

4. *Astronomical Catalogues 1951–75*, M. Collins, Inspec Bibliography Series No. 2, Institution of Electrical Engineers, London, 1977. A bibliography of catalogues, totalling 2500 items.

Bright Stars

1. *Catalogue of Bright Stars*, D. Hoffleit, Yale University Observatory (Third Edition), 1964. Approximate positions, proper motions, magnitudes, spectral types, parallaxes, radial velocities, etc., for 9110 stars brighter than magnitude 6·5 visual. Also contains constellation limits, index to Bayer and Flamsteed numbers and star names. Stars are the same as Revised Harvard Photometry. This is a most valuable general compilation (e.g. BS 5058 or HR 5058).

2. *Arizona-Tonantzintla Catalogue*. Data on 1325 bright stars. *Sky and Telescope*, July 1965.

See also under "General" above.

72

General Star Catalogues

1. *Bonner Durchmusterung*, by F. W. A. Argelander, 1859–62, with extension by E. Schönfeld, 1886. Argelander observed declinations +90° to −2°, and Schönfeld −2° to −23°; about 458,000 stars in all. Nominally to magnitude 9·5 visual, but magnitudes fainter than 9 are erroneous, and many stars range down to 10·5. Positions (for 1855·0) and magnitudes are given; they are not of high accuracy (all observed visually) but are very valuable for tracing and identifying stars because of comprehensive nature of catalogue (e.g. BD +70° 1275).

2. *Cordoba Durchmusterung*, published in *Cordoba Resultados*, Vols. **16, 17, 18** and **21**. About 614,000 stars, declinations −22° to −90°. (Limiting magnitude appreciably brighter for stars south of −52° than for stars north of −52°.) Positions (for 1875·0) and magnitudes (e.g. CoD −34° 6041). Magnitude limit about 10.

3. *Cape Photographic Durchmusterung*, published in *Cape Annals*, **3, 4** and **5**. About 455,000 stars, declinations −19° to −90°. Positions (for 1875·0) and magnitudes (e.g. CPD −47° 9461). Magnitude limit about 10.

4. *Astronomische Gesellschaft Catalogues*. Older catalogues are based on meridian circle observations, later catalogues on photographic observations. For the former, zones of declination were allocated to various observatories. For the latter, the work was done at Hamburg-Bergedorf and Bonn. The former catalogues became known as the *Astronomische Gesellschaft Zone Catalogues*. The later work is known as the AGK2. It is published in 15 volumes, covering the northern hemisphere. AGK2 contains accurate positions (for 1950·0) and approximate photographic magnitudes for about 183,000 stars. A new catalogue, AGK3, in eight volumes, was published in 1975.

5. *Yale Catalogues*. Published in *Yale Observatory Transactions*, Vols. **11–31**. They are complete from declination +30° to −50°, together with zones +85° to +90°, +50° to +60° and −70° to −90°. They have the great merit that proper motions are given for all the stars as well as magnitudes and accurate positions and spectral types for most stars. Most catalogues are for 1950·0. The very brightest stars are omitted. Magnitude limit about 9 visual (e.g. Yale 17, 8089).

6. *Smithsonian Astrophysical Observatory Star Catalog*, Smithsonian Publication 4652, U.S. Government Printing Office, Washington, D.C., 1966 (four volumes). Positions, proper motions and magnitudes for 258,997 stars (e.g. SAO 85009). (Epoch 1950·0.)

Fundamental Star Catalogues

These contain positions of the highest possible accuracy for a limited number of stars, and form the basic frame of reference against which other star positions are measured.

1. *Fourth Fundamental Catalogue (FK4)*, W. Fricke *et al.*, *Veröffentl. Astron. Rechen-Institut, Heidelberg*, No. 10, 1963. This catalogue contains the

most accurately known positions, and these 1535 stars are listed in the annual volumes *Apparent Places of Fundamental Stars*.

2. *General Catalogue of 33,342 Stars*, B. Boss, Carnegie Institution Publication 468, 1936 (five volumes). All stars to magnitude 7 and some fainter ones. Of lower accuracy than FK4, but larger number of stars is an important feature. Contains positions, proper motions, magnitudes and spectral types (e.g. GC 12104).

Stellar Parallaxes, Radial Velocities and Proper Motions

1. *General Catalogue of Trigonometrical Stellar Parallaxes*, L. F. Jenkins, Yale University Observatory, 1952. 5822 stars, all known parallaxes as at 1950. A *Supplement* appeared in 1963.

2. *General Catalogue of Stellar Radial Velocities*, R. E. Wilson, Carnegie Institution Publication 601, 1953. 15,107 stars, all known radial velocities as at 1950.

3. *Bibliography of Stellar Radial Velocities*, H. A. Abt and E. S. Biggs, Kitt Peak National Observatory, 1972. Contains about 44,000 references for 25,000 stars.

4. W. J. Luyten, *Catalogue of 9867 Stars in the Southern Hemisphere with proper motions exceeding 0″·2 annually*, University of Minnesota, 1957. Luyten has published numerous other lists of stars of large proper motion.

5. Catalogue of stars within a distance of 22 parsecs from the Sun: W. Gliese, *Veröffentl. Astron. Rechnen-Institut*, Heidelberg, No. 22, 1969. A supplement was published by W. Gliese and H. Jahreiss, *Astron. Astrophys. Suppl.*, **38,** 423, 1979. Another catalogue of nearby stars was given by R. Woolley *et al.*, *Royal Obs. Annals*, **5,** 1970.

6. *Proper Motions of Stars in the Zone Catalogue of 20,847 Stars*, H. Spencer Jones and J. Jackson, Royal Observatory, Cape, 1936; *Cape Photographic Catalogue for 1950*, J. Jackson and R. H. Stoy, *Annals Cape Obs.*, **17–21**. These two catalogues together cover declinations −30° to −90°.

7. *A Catalogue of High Velocity Stars*, O. J. Eggen, *Royal Obs. Bull.*, No. 84, 1964. Lists 656 stars with velocities exceeding 100 km/sec with respect to the Sun.

8. *A Catalogue of Parallax Stars with MK Spectral Classifications*, L. A. Breakiron and A. R. Upgren, *Astrophys. J. Suppl.*, **41,** 709, 1979.

Stellar Spectra

1. Henry Draper Catalogue, *Harvard Annals*, **91–99,** 1918–24. 225,300 spectral types, complete to $8^m{\cdot}25$ in N. Hemisphere and $8^m{\cdot}75$ in S. Hemisphere, with many fainter stars. Also gives BD numbers for $\delta > -23°$, CoD for $-23° > \delta > -52°$ and CPD for $\delta < -52°$. One of the most useful catalogues ever produced (e.g. HD 125248).

2. Henry Draper Extension, *Harvard Annals*, **100** and **102**. 133,700 stars in various regions of sky, to magnitude 12.

74

3. Many spectral types determined at Harvard and elsewhere have been incorporated in other catalogues and not published separately. See, for example, the *Yale Catalogues* and the *General Catalogue*, as well as the parallax and radial velocity catalogues and references listed above.

4. *Catalogue of Stellar Spectra Classified in the Morgan-Keenan System*, C. Jaschek, H. Conde and A. C. de Sierra, *Obs. Astron. Univ. Nacional La Plata*, Ser. Astron. 28 (2), 1964. 20,857 entries.

5. *Michigan Spectral Catalogue*, Vol. **1**, N. Houk and A. Cowley, 1975; Vol. **2**, N. Houk, 1978. Volume 1 contains 36,382 stars between declinations −90° and −53°; Volume 2, 30,400 stars between −53° and −40°. Part of a project to reclassify all the HD stars on the MK system.

6. M. S. Roberts, *A.J.*, **67**, 79, 1962, gives a catalogue of Wolf–Rayet stars; H. W. Babcock, *Ap. J. Suppl.*, **3**, 141, 1958, a catalogue of magnetic stars; J. L. Greenstein, *Handbuch der Physik*, **50**, 162, 1958, data on 81 better-known white dwarfs; W. P. Bidelman, *Ap. J. Suppl.*, **1**, 175, 1954, a catalogue of emission stars of types later than B; L. R. Wakerling, *Mem. Roy. Astron. Soc.*, **73**, 153, 1970, a catalogue of early-type emission-line stars.

Stellar Magnitudes, Colour Indices and Polarizations

Most of the catalogues listed above include the magnitudes of the stars.

1. V. M. Blanco, S. Demers, G. C. Douglass and M. P. Fitzgerald, *Pubs. U.S. Naval Obs.*, **21**, 1968, give a compilation of 34,807 magnitudes on the UBV system.

2. W. A. Hiltner, *Astrophys. J. Suppl.*, **2**, 389, 1956; J. S. Hall, *Pubs. U.S. Naval Obs.*, **17**, No. VI, 1958; D. S. Mathewson and V. L. Ford, *Mem. Roy. Astron. Soc.*, **74**, 139, 1970. Polarization observations of many northern and southern stars.

Double Stars

1. *New General Catalogue of Double Stars*, R. G. Aitken, Carnegie Institution Publication 417, 1932 (two volumes). The standard reference for stars north of −30°. 17,180 stars (e.g. ADS 6175).

2. *Southern Double Star Catalogue*, R. T. A. Innes, Union Observatory, Johannesburg, 1926–27. For stars south of −19° (abbreviation: SDS).

3. *General Catalogue of Double Stars within 121° of the North Pole*, S. W. Burnham, Carnegie Institution Publications 5, 1906 (two volumes). 13,665 stars, selected with wider limits than ADS. Incorporates much information not repeated in ADS.

4. *Index Catalogue of Double Stars*, H. M. Jeffers, W. H. van den Bos and F. M. Greeby, *Lick Obs. Publ.*, **21**, 1963.

5. *Third Catalogue of Orbits of Visual Binary Stars*, W. S. Finsen and C. E. Worley, *Rep. Obs. Circ.* (Johannesburg), No. 129, 1970.

75

6. *Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems*, A. H. Batten, J. M. Fletcher and P. J. Mann, *Pub. Dominion Astrophys. Obs.*, **15,** 121, 1978. Data for 978 systems.

Variable Stars

1. *General Catalogue of Variable Stars*, B. V. Kukarkin *et al.*, Third Edition, Moscow, 1969. Data on 22,649 stars. Supplements appear every few years.

Zodiacal Stars

1. J. Robertson, *Catalog of 3539 Zodiacal Stars for the equinox 1950·0, Astron. Pap. Amer. Ephemeris,* **10,** Part 2, 1940 (e.g. ZC 2372). Used in lists of stars to be occulted by the Moon.

Radio Sources

1. A. S. Bennett, *Mem. Roy. Astron. Soc.*, **68,** 163, 1961. The Cambridge revized 3C catalogue (e.g. 3C 274).

2. J. D. H. Pilkington and P. F. Scott, *Mem. Roy. Astron. Soc.*, **69,** 183, 1965; J. F. R. Gower, P. F. Scott and D. Wills, *ibid.*, **71,** 49, 1967. The Cambridge 4C catalogue (e.g. 4C 58.40).

3. *Australian J. Phys.*, **17,** 340, 1964; **18,** 329, 1965; **19,** 35, 837, 1966; **20,** 109, 1967; **21,** 377, 1968. The Parkes Catalogue. Many additional papers in *ibid.*, 1965–68, discuss identifications of radio sources. A later survey of southern sources appeared in *Australian J. Phys. Supplements*, 1971 onwards (e.g. PKS 2238−31).

4. A master list of radio sources, R. S. Dixon, *Astrophys. J. Suppl.*, **20,** 1, 1970. Incorporates and gives references to many catalogues.

Clusters, Nebulae and Galaxies

1. *New General Catalogue of Nebulae and Clusters of Stars*, J. L. E. Dreyer, *Mem. Roy. Astron. Soc.*, **49,** Part 1, 1888, with supplements (Index Catalogues) in *ibid.*, **51,** 185, 1895; **59,** 105, 1910. Later reprinted in one volume by Royal Astronomical Society (e.g. NGC 4594).

2. *Second Reference Catalogue of Bright Galaxies*, G. de Vaucouleurs, A. de Vaucouleurs and H. G. Corwin, University of Texas Press, 1976. Data on 4364 galaxies.

3. *Revised New General Catalogue of Nonstellar Astronomical Objects*, J. W. Sulentic and W. G. Tifft, University of Arizona Press, 1973. Information on 7840 objects.

4. *Catalogue of Galactic Planetary Nebulae*, L. Perek and L. Kohoutek, Academia, Prague, 1967.

Miscellaneous

1. J. H. Taylor and R. N. Manchester, *Astron. J.*, **80,** 794, 1975. List of properties of 147 pulsars.

2. W. Forman *et al.*, *Astrophys. J. Suppl.*, **38,** 357, 1978. Fourth UHURU catalogue of X-ray sources.

76

CALENDAR NOTES

In the *Handbook of the British Astronomical Association* for 1947 the late Dr L. J. Comrie gave *Some Notes and Tables for Calendar Makers*. I have revised his article by carrying the tabulations forward to A.D. 2000, and by modifying the accompanying descriptive matter in a few respects.

For the Christian calendar, A. De Morgan's *Book of Almanacs* (London, Macmillan; Third Edition, 1907) remains the most valuable source, covering the period A.D. 1 to A.D. 2000. A reference used by Dr Comrie (but unavailable to me) is *Nordisk Astronomisk Tidsskrift*, 1946, No. 1, pp. 13–24, which gives Easter Numbers for the years 1701–2000, ranging from 1 for Easter on March 22 to 35 for Easter on April 25. Details are also given of the Sundays throughout the year for each Easter Number and the years bearing that number. I have used De Morgan in compiling Table I.

For the Jewish calendar I have used A. Spier, *The Comprehensive Hebrew Calendar* (Behrman House, New York, 1952). This book tabulates the Jewish and Christian calendars for every day from A.D. 1900 to A.D. 2000. Another source (unavailable to me) used by Dr Comrie is S. B. Burnaby, *Elements of the Jewish and Muhammadan Calendars* (Bell, London, 1901), which covers A.D. 610 to A.D. 3003 and includes the Christian dates of Tishri 1 and Nisan 15.

A readily available source of information on the Moslem calendar is G. S. P. Freeman-Grenville, *The Muslim and Christian Calendars* (London, Oxford University Press, 1963). I have compiled Table IV from tables in this volume. An older source is an article on Zaman (time) by W. Hartner, *Encyclopaedia of Islam*, Vol. 4, ed. M. T. Houtsman *et al.* (Brill and Luzac, Leiden and London, 1934). I have followed the transliterated spelling of the former volume. The Christian dates of Muharram 1 are given by Burnaby (*loc. cit.*) for A.D. 622 to A.D. 3008.

I am indebted to Dr J. Jankowski of the University of Colorado for advice on the Moslem calendar.

See also the chapter on the Calendar in *Explanatory Supplement to the Astronomical Ephemeris* (H.M.S.O., 1961).

TABLE I

Day of the Week on which the 1st of each Month falls

Year					Jan. Oct. / **Jan. Apr. July**	May / **Oct.**	Aug. / **May**	Feb. Mar. Nov. / **Feb. Aug.**	June / **Mar. Nov.**	Sept. Dec. / **June**	Apr. July / **Sept. Dec.**
1967	..	1978	**1984**	1989	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.
1968	1973	1979	..	1990	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.
..	1974	**1980**	1985	1991	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.	Mon.
1969	1975	..	1986	**1992**	Wed.	Thur.	Fri.	Sat.	Sun.	Mon.	Tues.
1970	**1976**	1981	1987	..	Thur.	Fri.	Sat.	Sun.	Mon.	Tues.	Wed.
1971	..	1982	**1988**	1993	Fri.	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.
1972	1977	1983	..	1994	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.

77

Table I gives the day of the week on which the first day of each month falls. Its application in the compilation of calendars (especially by the scissors and paste-pot method), and in their checking, needs no elaboration.

Leap Years are in bold type.

For earlier years in the present century, subtract 28 from any of the 28 years above; thus 1939 = 1967−28 has the same calendar as 1967. We must not subtract any higher multiples of 28 that would produce a date less than 1901, as 1900 was not a Leap Year.

For later years up to 2099, add multiples of 28 to any of the 28 years above. Thus for 1995 we may use the calendar for 1995−28 = 1967; a glance at the table shows that this is identical with the calendars for 1978 and 1989.

Leap Year calendars do not repeat themselves at any shorter interval than 28 years; all other calendars occur three times every 28 years.

Christmas Day is always on the same day of the week as May Day (May 1).

Table II

Movable Festivals

	Jan. 1	Ash Wednesday	Easter Sunday	Whit Sunday	Advent Sunday	Christmas Day
1966	Sat.	Feb. 23	Apr. 10	May 29	Nov. 27	Sun.
1967	Sun.	Feb. 8	Mar. 26	May 14	Dec. 3	Mon.
1968	Mon.	Feb. 28	Apr. 14	June 2	Dec. 1	Wed.
1969	Wed.	Feb. 19	Apr. 6	May 25	Nov. 30	Thur.
1970	Thur.	Feb. 11	Mar. 29	May 17	Nov. 29	Fri.
1971	Fri.	Feb. 24	Apr. 11	May 30	Nov. 28	Sat.
1972	Sat.	Feb. 16	Apr. 2	May 21	Dec. 3	Mon.
1973	Mon.	Mar. 7	Apr. 22	June 10	Dec. 2	Tues.
1974	Tues.	Feb. 27	Apr. 14	June 2	Dec. 1	Wed.
1975	Wed.	Feb. 12	Mar. 30	May 18	Nov. 30	Thur.
1976	Thur.	Mar. 3	Apr. 18	June 6	Nov. 28	Sat.
1977	Sat.	Feb. 23	Apr. 10	May 29	Nov. 27	Sun.
1978	Sun.	Feb. 8	Mar. 26	May 14	Dec. 3	Mon.
1979	Mon.	Feb. 28	Apr. 15	June 3	Dec. 2	Tues.
1980	Tues.	Feb. 20	Apr. 6	May 25	Nov. 30	Thur.
1981	Thur.	Mar. 4	Apr. 19	June 7	Nov. 29	Fri.
1982	Fri.	Feb. 24	Apr. 11	May 30	Nov. 28	Sat.
1983	Sat.	Feb. 16	Apr. 3	May 22	Nov. 27	Sun.
1984	Sun.	Mar. 7	Apr. 22	June 10	Dec. 2	Tues.
1985	Tues.	Feb. 20	Apr. 7	May 26	Dec. 1	Wed.
1986	Wed.	Feb. 12	Mar. 30	May 18	Nov. 30	Thur.
1987	Thur.	Mar. 4	Apr. 19	June 7	Nov. 29	Fri.
1988	Fri.	Feb. 17	Apr. 3	May 22	Nov. 27	Sun.
1989	Sun.	Feb. 8	Mar. 26	May 14	Dec. 3	Mon.
1990	Mon.	Feb. 28	Apr. 15	June 3	Dec. 2	Tues.
1991	Tues.	Feb. 13	Mar. 31	May 19	Dec. 1	Wed.
1992	Wed.	Mar. 4	Apr. 19	June 7	Nov. 29	Fri.
1993	Fri.	Feb. 24	Apr. 11	May 30	Nov. 28	Sat.
1994	Sat.	Feb. 16	Apr. 3	May 22	Nov. 27	Sun.
1995	Sun.	Mar. 1	Apr. 16	June 4	Dec. 3	Mon.
1996	Mon.	Feb. 21	Apr. 7	May 26	Dec. 1	Wed.
1997	Wed.	Feb. 12	Mar. 30	May 18	Nov. 30	Thur.
1998	Thur.	Feb. 25	Apr. 12	May 31	Nov. 29	Fri.
1999	Fri.	Feb. 17	Apr. 4	May 23	Nov. 28	Sat.
2000	Sat.	Mar. 8	Apr. 23	June 11	Dec. 3	Mon.

78

Epiphany is fixed at January 6.

Shrove Sunday or Quinquagesima Sunday is seven weeks before Easter Sunday and three days before Ash Wednesday.

Shrove Tuesday is the day before Ash Wednesday.

Ash Wednesday is the first day in Lent, and is 46 days before Easter Sunday.

Palm Sunday is the Sunday before Easter Sunday.

Good Friday is two days before Easter Sunday.

Low Sunday is the Sunday after Easter Sunday.

Rogation Sunday is the Sunday before Ascension Day. It is five weeks after Easter Sunday and two weeks before Whit Sunday.

Ascension Day or Holy Thursday is 39 days after Easter Sunday and 10 days before Whit Sunday.

Ascension Sunday is three days after Ascension Day. It is six weeks after Easter Sunday and one week before Whit Sunday.

Whit Sunday or Pentecost is seven weeks after Easter Sunday.

Trinity Sunday is the Sunday after Whit Sunday.

Corpus Christi is the Thursday following Trinity Sunday. It is 60 days after Easter Sunday and three weeks after Ascension Day.

The First Sunday in Advent is the fourth Sunday before Christmas Day; a convenient rule is that it is the Sunday nearest to November 30.

Table III
Jewish Calendar

Year A.M.	Type	Year A.D.	New Year	Day of Atonement	Tabernacles	Year A.D.	Feast of Passover	Pentecost
5726	C.D.	1965	Mon. Sept. 27	Wed. Oct. 6	Oct. 11	1966	Tues. Apr. 5	May 15
5727	E.A.	1966	Thur. Sept. 15	Sat. Sept. 24	Sept. 29	1967	Tues. Apr. 25	June 14
5728	C.R.	1967	Thur. Oct. 5	Sat. Oct. 14	Oct. 19	1968	Sat. Apr. 13	June 2
5729	C.A.	1968	Mon. Sept. 23	Wed. Oct. 2	Oct. 7	1969	Thur. Apr. 3	May 23
5730	E.D.	1969	Sat. Sept. 13	Mon. Sept. 22	Sept. 27	1970	Tues. Apr. 21	June 10
5731	C.R.	1970	Thur. Oct. 1	Sat. Oct. 10	Oct. 15	1971	Sat. Apr. 10	May 30
5732	C.A.	1971	Mon. Sept. 20	Wed. Sept. 29	Oct. 4	1972	Thur. Mar. 30	May 19
5733	E.D.	1972	Sat. Sept. 9	Mon. Sept. 18	Sept. 23	1973	Tues. Apr. 17	June 6
5734	C.A.	1973	Thur. Sept. 27	Sat. Oct. 6	Oct. 11	1974	Sun. Apr. 7	May 27
5735	C.R.	1974	Tues. Sept. 17	Thur. Sept. 26	Oct. 1	1975	Thur. Mar. 27	May 16
5736	E.A.	1975	Sat. Sept. 6	Mon. Sept. 15	Sept. 20	1976	Thur. Apr. 15	June 4
5737	C.D.	1976	Sat. Sept. 25	Mon. Oct. 4	Oct. 9	1977	Sun. Apr. 3	May 23
5738	E.R.	1977	Tues. Sept. 13	Thur. Sept. 22	Sept. 27	1978	Sat. Apr. 22	June 11
5739	C.A.	1978	Mon. Oct. 2	Wed. Oct. 11	Oct. 16	1979	Thur. Apr. 12	June 1
5740	C.A.	1979	Sat. Sept. 22	Mon. Oct. 1	Oct. 6	1980	Tues. Apr. 1	May 21
5741	E.D.	1980	Thur. Sept. 11	Sat. Sept. 20	Sept. 25	1981	Sun. Apr. 19	June 8
5742	C.R.	1981	Tues. Sept. 29	Thur. Oct. 8	Oct. 13	1982	Thur. Apr. 8	May 28
5743	C.A.	1982	Sat. Sept. 18	Mon. Sept. 27	Oct. 2	1983	Tues. Mar. 29	May 18
5744	E.A.	1983	Thur. Sept. 8	Sat. Sept. 17	Sept. 22	1984	Tues. Apr. 17	June 6
5745	C.R.	1984	Thur. Sept. 27	Sat. Oct. 6	Oct. 11	1985	Sat. Apr. 6	May 26
5746	E.D.	1985	Mon. Sept. 16	Wed. Sept. 25	Sept. 30	1986	Thur. Apr. 24	June 13
5747	C.A.	1986	Sat. Oct. 4	Mon. Oct. 13	Oct. 18	1987	Tues. Apr. 14	June 3
5748	C.R.	1987	Thur. Sept. 24	Sat. Oct. 3	Oct. 8	1988	Sat. Apr. 2	May 22
5749	E.D.	1988	Mon. Sept. 12	Wed. Sept. 21	Sept. 26	1989	Thur. Apr. 20	June 9
5750	C.A.	1989	Sat. Sept. 30	Mon. Oct. 9	Oct. 14	1990	Tues. Apr. 10	May 30

79

Year A.M.	Type	Year A.D.	New Year	Day of Atonement	Tabernacles	Year A.D	Feast of Passover	Pentecost
5751	C.R.	1990	Thur. Sept. 20	Sat. Sept. 29	Oct. 4	1991	Sat. Mar. 30	May 19
5752	E.A.	1991	Mon. Sept 9	Wed Sept 18	Sept. 23	1992	Sat. Apr. 18	June 7
5753	C.D.	1992	Mon. Sept. 28	Wed. Oct 7	Oct. 12	1993	Tues. Apr. 6	May 26
5754	C.A.	1993	Thur. Sept. 16	Sat Sept. 25	Sept. 30	1994	Sun. Mar. 27	May 16
5755	E.R.	1994	Tues. Sept 6	Thur. Sept. 15	Sept. 20	1995	Sat. Apr. 15	June 4
5756	C.A.	1995	Mon. Sept. 25	Wed. Oct 4	Oct. 9	1996	Thur. Apr 4	May 24
5757	E.D.	1996	Sat. Sept 14	Mon. Sept. 23	Sept. 28	1997	Tues. Apr 22	June 11
5758	C.R.	1997	Thur. Oct 2	Sat. Oct. 11	Oct. 16	1998	Sat. Apr. 11	May 31
5759	C.A.	1998	Mon. Sept. 21	Wed. Sept. 30	Oct. 5	1999	Thur. Apr. 1	May 21
5760	E.A.	1999	Sat. Sept. 11	Mon. Sept. 20	Sept. 25	2000	Thur. Apr 20	June 9

The Jewish calendar is luni-solar. It was established by Hillel II in the fourth century A.D. The letters A.M. stand for Anno Mundi (in the Year of the World). There are 12 months in common years, with 30 and 29 days in each, alternatively, as indicated:

Tishri	30	Shebat	30	Sivan	30
Heshvan	29 (or 30)	[Adar I	30]	Tammuz	29
Kislev	30 (or 29)	Adar [II]	29	Ab	30
Tebeth	29	Nisan	30	Ellul	29
		Iyar	29		

In leap (embolismic) years an additional month (Adar I) of 30 days is inserted between Shebat and Adar (then called Adar II), as indicated in the above table. In certain years Heshvan has an extra day, and in certain other years Kislev loses a day. There are therefore six types of Jewish year, as follows:

Type	Days	Type	Days
Common Deficient	353	Embolismic Deficient	383
Common Regular	354	Embolismic Regular	384
Common Abundant	355	Embolismic Abundant	385

Days begin and end at sunset, an event occurring between sunset and midnight belongs to the following Jewish day.

Embolismic years occur when the remainder on dividing the year (A.M.) by 19 is 0, 3, 6, 8, 11, 14 or 17. This enables the calendar to keep approximately the correct seasons of the year while remaining related to the Moon (19 years is approximately equal to 235 lunar months), finer adjustments to the lunar period being made by adding an extra day to Heshvan or taking a day from Kislev. In certain years the day of New Year is postponed one or two days (for purely ecclesiastical reasons, by rules which are too complicated to describe here) from the mathematically computed date. This is accomplished by adding a day to Heshvan or taking a day from Kislev in the years affected. It can be shown that all possibilities can be accounted for by the six types of years listed above. The error in the reproduction of the lunar synodic month is roughly one day in 10,000 years, the error in the solar tropical year being one day in 200 years.

The Jewish New Year (Rosh Hoshanah = Tishri 1) never falls on a Sunday, Wednesday or Friday.

The Day of Atonement (Yom Kippur = Tishri 10) is always nine days after New Year. It never falls on a Sunday, Tuesday or Friday.

The first day of the Feast of Tabernacles (Succoth = Tishri 15) is always 14 days after New Year, and therefore on the same day of the week.

The first day of the Feast of the Passover (Nisan 15) never falls on a Monday, Wednesday or Friday.

The first day of the Feast of Weeks (Shavuoth = Pentecost = Sivan 6) is always 50 days after the first day of the Passover, and so falls one weekday later; it never falls on a Tuesday, Thursday or Saturday.

80

Table IV

Moslem Calendar

A.H	Type	New Year Begins	Ramadhan Begins
1387	7 K	Tues. 1967 Apr. 11	Sun. 1967 Dec. 3
1388	8	Sun. 1968 Mar. 31	Fri. 1968 Nov. 22
1389	9	Thur. 1969 Mar. 20	Tues. 1969 Nov. 11
1390	10 K	Mon 1970 Mar. 9	Sat. 1970 Oct. 31
1391	11	Sat. 1971 Feb. 27	Thur. 1971 Oct. 21
1392	12	Wed. 1972 Feb. 16	Mon. 1972 Oct. 9
1393	13 K	Sun. 1973 Feb. 4	Fri. 1973 Sept. 28
1394	14	Fri 1974 Jan. 25	Wed. 1974 Sept. 18
1395	15	Tues. 1975 Jan. 14	Sun. 1975 Sept. 7
1396	16 K	Sat 1976 Jan. 3	Thur. 1976 Aug. 26
1397	17	Thur. 1976 Dec. 23	Tues. 1977 Aug. 16
1398	18 K	Mon. 1977 Dec. 12	Sat. 1978 Aug. 5
1399	19	Sat. 1978 Dec. 2	Thur. 1979 July 26
1400	20	Wed. 1979 Nov. 21	Mon. 1980 July 14
1401	21 K	Sun. 1980 Nov. 9	Fri. 1981 July 3
1402	22	Fri. 1981 Oct. 30	Wed. 1982 June 23
1403	23	Tues. 1982 Oct. 19	Sun. 1983 June 12
1404	24 K	Sat. 1983 Oct. 8	Thur. 1984 May 31
1405	25	Thur. 1984 Sept. 27	Tues. 1985 May 21
1406	26 K	Mon. 1985 Sept. 16	Sat. 1986 May 10
1407	27	Sat. 1986 Sept. 6	Thur. 1987 Apr. 30
1408	28	Wed. 1987 Aug. 26	Mon. 1988 Apr. 18
1409	29 K	Sun. 1988 Aug. 14	Fri. 1989 Apr. 7
1410	30	Fri. 1989 Aug. 4	Wed. 1990 Mar. 28
1411	1	Tues. 1990 July 24	Sun. 1991 Mar. 17
1412	2 K	Sat. 1991 July 13	Thur 1992 Mar. 5
1413	3	Thur. 1992 July 2	Tues 1993 Feb. 23
1414	4	Mon. 1993 June 21	Sat. 1994 Feb. 12
1415	5 K	Fri. 1994 June 10	Wed. 1995 Feb. 1
1416	6	Wed. 1995 May 31	Mon. 1996 Jan. 22
1417	7 K	Sun. 1996 May 19	Fri. 1997 Jan. 10
1418	8	Fri. 1997 May 9	Wed. 1997 Dec. 31
1419	9	Tues. 1998 Apr. 28	Sun 1998 Dec. 20
1420	10 K	Sat. 1999 Apr. 17	Thur. 1999 Dec. 9
1421	11	Thur. 2000 Apr. 6	Tues 2000 Nov. 28

This Islamic calendar begins with the year of Mohammed's flight or Hijra from Mecca to Medina on July 16, A.D. 622. It is purely lunar, the months of each year having 30 and 29 days alternately, except when the year is Kabisa (extended, leap year), which happens when the remainder after dividing the Hijral year by 30 is 2, 5, 7, 10, 13, 16, 18, 21, 24, 26 or 29; the last month then has 30 days. The names of the months, and the order of their first day in the year, are:

Muharram	1	Rabi' II	90	Rajab	178	Shawwal	267
Safar	31	Jumada I	119	Sha'ban	208	Dhu Al-Qa'da	296
Rabi' I	60	Jumada II	149	Ramadhan	237	Dhu Al-Hijja	326

As the year is only 354 days (or 355 in Kabisa years), its beginning retrogrades 10, 11 or 12 days each year by the Christian calendar. Two successive Hijral years can begin in the same Christian year—one in January and one in December; this happened in 1943 and again in 1976. This calendar is remarkably accurate. 360 lunar synodical months occupy ($11\times355+19\times354$) days, so that the synodical month is 29·53056 days. The true value is 29·53059 days. The error is about one day in 2000 years.

The importance of Ramadhan is that it is very strictly observed by all Moslems as a month of daytime abstinence from all food and drink.

81

MAGNITUDES OF ARTIFICIAL SATELLITES

It is very difficult to give accurate values for the brightness of a satellite because there are so many variables. The figures quoted in the predictions are therefore to be used only as a guide.

The absolute magnitude of a satellite is its half-phase magnitude at a range of 1000 km when seen at an altitude of 90°. It is this figure which is quoted in the 'equator crossing' predictions. The following table gives the magnitude change for various ranges based on the absolute value at 1000 km.

Range (km)	200	400	600	800	1000	1200	1400	1600	2000
Change in magnitude	−3·4	−2·0	−1·0	−0·5	0	+0·4	+0·7	+1·0	+1·5

The change in magnitude due to atmospheric absorption is negligible for altitudes greater than 70°, but is considerable below 30°.

Altitude (°)	10	20	30	40	50	60	70–90
Decrease in magnitude	3·8	2·3	1·5	1·0	0·6	0·3	negligible

Example: A satellite of absolute magnitude +2 will appear at a range of 1200 km and altitude 30° with a magnitude of +2+0·4+1·5, i.e. magnitude +3·9.

The intrinsic brightness depends on the nature of the reflecting surface and also the curvature of this surface. A plane surface will produce a very bright reflection but reflections from a curved surface come from quite a small percentage of the total curved surface area.

The angle between the Sun and the observer as seen from the satellite, the phase angle, affects the brightness of the satellite, the actual change being dependent on the nature of the surface. As a general guide the problem can be likened to the changes in the magnitude of the Moon as it changes phase. The standard predictions are based on half phase, i.e. a phase angle of 90°.

82

NAMES OF STARS

Acamar	θ Eri	Atria	α TrA	Mintaka	δ Ori
Achernar	α Eri	Avior	ε Car	Mira	o Cet
Acrux	α Cru	Bellatrix	γ Ori	Mirach	β And
Adara	ε CMa	Betelgeuse	α Ori	Mirphak	α Per
Agena	β Cen	Canopus	α Car	Mizar	ζ UMa
Albireo	β Cyg	Capella	α Aur	Nihal	β Lep
Alcor	80 UMa	Caph	β Cas	Nunki	σ Sgr
Alcyone	η Tau	Castor	α Gem	Peacock	α Pav
Aldebaran	α Tau	Cor Caroli	α CVn	Phad, Phecda	γ UMa
Alderamin	α Cep	Deneb	α Cyg	Polaris	α UMi
Algenib	γ Peg	Denebola	β Leo	Pollux	β Gem
Algieba	γ Leo	Diphda	β Cet	Procyon	α CMi
Algol	β Per	Dubhe	α UMa	Ras-Algethi	α Her
Alhena	γ Gem	Elnath, Alnath	β Tau	Rasalhague	α Oph
Alioth	ε UMa	Eltamin	γ Dra	Regulus	α Leo
Alkaid	η UMa	Enif	ε Peg	Rigel	β Ori
Almach	γ And	Fomalhaut	α PsA	Rigil Kent	α Cen
Alnath, Elnath	β Tau	Gacrux	γ Cru	Sabik	η Oph
Alnair	α Gru	Gienah	γ Crv	Sadalmelik	α Aqr
Alnilam	ε Ori	Hadar	β Cen	Scheat	β Peg
Alnitak	ζ Ori	Hamal	α Ari	Schedir, Shedir	α Cas
Alphard	α Hya	Izar	ε Boo	Shaula	λ Sco
Alphekka	α CrB	Kaus Australis	ε Sgr	Sirius	α CMa
Alpheratz	α And	Kochab	β UMi	Spica	α Vir
Alshain	β Aql	Markab	α Peg	Suhail	λ Vel
Altair	α Aql	Megrez	δ UMa	Tarazed	γ Aql
Ankaa	α Phe	Menkar	α Cet	Thuban	α Dra
Antares	α Sco	Menkent	θ Cen	Unukalhai	α Ser
Arcturus	α Boo	Merak	β UMa	Vega	α Lyr
Arneb	α Lep	Miaplacidus	β Car	Vindemiatrix	ε Vir

BRIGHTEST STARS

Name	R.A. (1950·0) h m s	Dec. ° ′ ″	R.A. (2000·0) h m s	Dec. ° ′ ″	*V* m	*B−V* m	Spec.
α And	0 05 47·8	+28 48 52	0 08 23·2	+29 05 26	2·06	−0·11	A0 P
β Cas	0 06 29·7	+58 52 27	0 09 10·6	+59 08 59	2·27	+0·34	F2 IV
α Cas	0 37 39·3	+56 15 49	0 40 30·4	+56 32 15	2·23	+1·17	K0 II–III
β Cet	0 41 04·8	−18 15 39	0 43 35·3	−17 59 12	2·04	+1·02	K0 III
β And	1 06 55·5	+35 21 22	1 09 43·8	+35 37 14	2·06	+1·58	M0 III
α Eri	1 35 51·3	−57 29 25	1 37 42·9	−57 14 12	0·46	−0·16	B5 IV
α UMi	1 48 48·8	+89 01 44	2 31 50·4	+89 15 51	2·02	+0·60	F8 Ib
γ^1 And	2 00 49·2	+42 05 27	2 03 53·9	+42 19 47	2·18	+1·20	K2 III
α Ari	2 04 20·9	+23 13 37	2 07 10·3	+23 27 45	2·00	+1·15	K2 III
β Per	3 04 54·4	+40 45 52	3 08 10·1	+40 57 21	2·12	−0·05	B8 V
α Per	3 20 44·4	+49 41 06	3 24 19·3	+49 51 40	1·80	+0·48	F5 Ib
α Tau	4 33 02·9	+16 24 38	4 35 55·2	+16 30 33	0·85	+1·54	K5 III
β Ori	5 12 08·0	− 8 15 29	5 14 32·2	− 8 12 06	0·12	−0·03	B8 Ia
α Aur	5 12 59·5	+45 56 58	5 16 41·3	+45 59 53	0·08	+0·80	G8 III
γ Ori	5 22 26·8	+ 6 18 22	5 25 07·8	+ 6 20 59	1·64	−0·22	B2 III

83

Name	R.A. (1950·0)	Dec.	R.A. (2000·0)	Dec.	V	$B-V$	Spec
	h m s	° ′ ″	h m s	° ′ ″	m	m	
β Tau	5 23 07·7	+28 34 02	5 26 17·5	+28 36 27	1·65	−0·13	B7 III
δ Ori A	5 29 27·0	− 0 20 04	5 32 00·3	− 0 17 57	2·23	−0·22	O9·5 II
ε Ori	5 33 40·5	− 1 13 56	5 36 12·7	− 1 12 07	1·70	−0·19	B0 Ia
ζ Ori	5 38 14·0	− 1 58 03	4 40 45·5	− 1 56 34	1·77	−0·21	O9·5 Ib
κ Ori	5 45 23·0	− 9 41 09	5 47 45·3	− 9 40 11	2·06	−0·17	B0·5 Ia
α Ori	5 52 27·8	+ 7 23 58	5 55 10·2	+ 7 24 26	0·50	+1·85	M2 Iab
β Aur	5 55 51·6	+44 56 41	5 59 31·7	+44 56 51	1·90	+0·03	A2 IV
β CMa	6 20 29·8	−17 55 47	6 22 41·9	−17 57 22	1·98	−0·23	B1 II–III
α Car	6 22 50·5	−52 40 03	6 23 57·1	−52 41 44	−0·72	+0·15	F0 Ia
γ Gem	6 34 49·4	+16 26 37	6 37 42·7	+16 23 57	1·93	0·00	A0 IV
α CMa	6 42 56·7	−16 38 46	6 45 08·9	−16 42 58	−1·46	+0·01	A1 V
ε CMa	6 56 39·6	−28 54 10	6 58 37·5	−28 58 20	1·50	−0·21	B2 II
δ CMa	7 06 21·4	−26 18 45	7 08 23·4	−26 23 36	1·86	+0·65	F8 Ia
α Gem	7 31 24·7	+31 59 59	7 34 35·9	+31 53 18	1·58	+0·04	A1 V
α CMi	7 36 41·1	+ 5 21 17	7 39 18·1	+ 5 13 30	0·38	+0·42	F5 IV
β Gem	7 42 15·5	+28 08 55	7 45 18·9	+28 01 34	1·14	+1·00	K0 III
ζ Pup	8 01 49·6	−39 51 41	8 03 35·0	−40 00 12	2·25	−0·26	O5·8
γ Vel	8 07 59·5	−47 11 18	8 09 31·9	−47 20 12	1·78	−0·22	WC7
ε Car	8 21 29·4	−59 20 53	8 22 30·8	−59 30 34	1·86	+1·27	K0 II
δ Vel	8 43 19·4	−54 31 28	8 44 42·2	−54 42 30	1·96	+0·04	A0 V
λ Vel	9 06 09·3	−43 13 48	9 07 59·7	−43 25 57	2·21	+1·66	K5 Ib
β Car	9 12 39·7	−69 30 40	9 13 12·2	−69 43 02	1·68	0·00	A0 III
ι Car	9 15 45·1	−59 03 54	9 17 05·4	−59 16 31	2·25	+0·18	F0 Ib
α Hya	9 25 07·8	− 8 26 27	9 27 35·2	− 8 39 31	1·98	+1·44	K3 III
α Leo	10 05 42·6	+12 12 45	10 08 22·2	+11 58 02	1·35	−0·11	B7 V
γ^1 Leo	10 17 13·1	+20 05 43	10 19 58·3	+19 50 30	2·28	+1·08	K0 III
α UMa	11 00 39·6	+62 01 17	11 03 43·6	+61 45 03	1·79	+1·07	K0 III
β Leo	11 46 30·6	+14 51 06	11 49 03·5	+14 34 19	2·14	+0·09	A3 V
α^1 Cru	12 23 48·1	−62 49 19	12 26 35·9	−63 05 56	1·41	+0·10	B1 IV
γ Cru A	12 28 22·7	−56 50 00	12 31 09·9	−57 06 47	1·63	+1·59	M3 III
γ Cen	12 38 44·9	−48 41 07	12 41 30·9	−48 57 34	2·17	−0·01	A0 III
β Cru	12 44 47·0	−59 24 57	12 47 43·2	−59 41 19	1·25	−0·23	B0 III
ε UMa	12 51 50·1	+56 13 51	12 54 01·7	+55 57 35	1·77	−0·02	A0 P
ζ UMa A	13 21 54·9	+55 11 09	13 23 55·5	+54 55 31	2·27	+0·02	A2 V
α Vir	13 22 33·3	−10 54 03	13 25 11·5	−11 09 41	0·98	−0·23	B1 V
ε Cen	13 36 42·3	−53 12 46	13 39 53·2	−53 27 58	2·30	−0·22	B1 V
η UMa	13 45 34·3	+49 33 44	13 47 32·3	+49 18 48	1·86	−0·19	B3 V
β Cen	14 00 16·5	−60 07 58	14 03 49·4	−60 22 22	0·61	−0·24	B1 II
θ Cen	14 03 43·9	−36 07 30	14 06 40·9	−36 22 12	2·06	+1·01	K0 III–IV
α Boo	14 33 22·8	+19 26 31	14 15 39·6	+19 10 57	−0·04	+1·23	K2 III P
η Cen	14 32 19·3	−41 56 22	14 35 30·3	−42 09 28	2·31	−0·19	B3 III
α^1 Cen	14 36 11·3	−60 37 49	14 39 36·7	−60 50 02	0·00	+0·68	G2 V
α Lup	14 38 35·5	−47 10 29	14 41 55·7	−47 23 17	2·30	−0·20	B1 III
β UMi	14 50 49·6	+74 21 36	14 50 42·2	+74 09 19	2·08	+1·47	K4 III
α CrB	15 32 34·1	+26 52 55	15 34 41·2	+26 42 53	2·23	−0·02	A0 V
δ Sco	15 57 22·3	−22 28 51	16 00 19·9	−22 37 18	2·32	−0·12	B0 V
α Sco	16 26 20·2	−26 19 22	16 29 24·3	−26 25 55	0·96	+1·83	M1 Ib
α TrA	16 43 21·1	−68 56 20	16 48 39·8	−60 01 39	1·92	+1·44	K2 III
ε Sco	16 46 55·2	−34 12 16	16 50 09·7	−34 17 36	2·29	+1·15	K2 III
λ Sco	17 30 12·6	−37 04 10	17 33 36·4	−37 06 14	1·63	−0·22	B2 IV

84

Name	R.A. (1950·0) h m s	Dec. ° ′ ″	R.A. (2000·0) h m s	Dec. ° ′ ″	V m	B−V m	Spec.
α Oph	17 32 36·7	+12 35 42	17 34 55·9	+12 33 36	2·08	+0·15	A5 III
θ Sco	17 33 43·4	−42 58 05	17 37 19·0	−42 59 52	1·87	+0·40	F0 I–II
γ Dra	17 55 26·6	+51 29 39	17 56 36·2	+51 29 20	2·23	+1·52	K5 III
ε Sgr	18 20 51·2	−34 24 37	18 24 10·2	−34 23 05	1·85	−0·03	B9 IV
α Lyr	18 35 14·7	+38 44 10	18 36 56·2	+38 47 01	0·03	0·00	A0 V
σ Sgr	18 52 09·9	−26 21 38	18 55 15·7	−26 17 48	2·02	−0·22	B3 IV–V
α Aql	19 48 20·6	+ 8 44 06	19 50 46·8	+ 8 52 06	0·77	+0·22	A7 IV–V
γ Cyg	20 20 25·9	+40 05 45	20 22 13·5	+40 15 24	2·20	+0·68	F8 Ib
α Pav	20 21 42·3	−56 53 50	20 25 38·7	−56 44 06	1·94	−0·20	B3 IV
α Cyg	20 39 43·5	+45 06 03	20 41 25·8	+45 16 49	1·25	+0·09	A2 Ia
α Gru	22 05 05·5	−47 12 15	22 08 13·8	−46 57 40	1·74	−0·13	B5 V
β Gru	22 39 41·4	−47 08 48	22 42 39·9	−46 53 05	2·11	+1·62	M3 II
α PsA	22 54 53·5	−29 53 16	22 57 38·9	−29 37 20	1·16	+0·09	A3 V

THE TWENTY NEAREST STARS

star	apparent visual magnitude m_v	absolute visual magnitude M_v	spectral class	luminosity class	proper motion (arc sec per year)	distance (pc)	mass ($M_\odot$)	radius ($R_\odot$)
Proxima Centauri C	11·05	15·45	M5		3·85	1·31	0·1	
Alpha Centauri A	−0·01	4·3	G2	V	3·68	1·34	1·1	1·23
Alpha Centauri B	1·33	5·69	K5	V	3·68	1·34	0·89	0·87
Barnard's Star	9·54	13·25	M5	V	10·31	1·81		
Wolf 359	13·53	16·68	M8		4·71	2·33		
HD 95735	7·50	10·49	M2	V	4·78	2·49	0·35	
Sirius A	−1·45	1·41	A1	V	1·33	2·65	2·31	1·8
Sirius B	8·68	11·56	WD*	VII	1·33	2·65	0·98	0·022
UV Ceti A	12·45	15·27	M5		3·36	2·72	0·044	
UV Ceti B	12·95	15·8	M6		3·36	2·72	0·035	
Ross 154	10·6	13·3	M4		0·72	2·90		
Ross 248	12·29	14·8	M6		1·59	3·15		
ε Eridani	3·73	6·13	K2	V	0·98	3·30		0·98
L789–6	12·18	14·60	M7		3·26	3·30		
Ross 128	11·10	13·50	M5		1·37	3·32		
61 Cygni A	5·22	7·58	K5	V	5·21	3·40	0·63	
61 Cgyni B	6·03	8·39	K7	V	5·21	3·40	0·60	
ε Indi	4·68	7·00	K5	V	4·69	3·44		
Procyon A	0·35	2·65	F5	IV	1·25	3·50	1·77	1·7
Procyon B	10·7	13·0	WD*	VII	1·25	3·50	0·63	0·01

*white dwarf

85

AREAS OF THE CONSTELLATIONS

The table below was computed by the late Major A. E. Levin and was first published in the *BAA Handbook* for 1935.

Constellation	*Square degrees*	*Order of size*	*Constellation*	*Square degrees*	*Order of size*
Andromeda	722·278	19	Leo	946·964	12
Antlia	238·901	62	Leo Minor	231·956	64
Apus	206·327	68	Lepus	290·291	51
Aquarius	979·854	10	Libra	538·052	28
Aquila	652·473	22	Lupus	333·683	46
Ara	237·057	63	Lynx	545·386	27
Aries	441·395	38	Lyra	286·476	52
Auriga	657·438	21	Mensa	153·484	76
Bootes	906·831	13	Microscopium	209·513	66
Caelum	124·865	82	Monoceros	481·569	34
Camelopardus	756·828	18	Musca	138·355	78
Cancer	505·872	30	Norma	165·290	75
Canes Venatici	465·194	37	Octans	291·045	50
Canis Major	380·118	43	Ophiuchus	948·340	11
Canis Minor	183·367	72	Orion	594·120	25
Capricornus	413·947	40	Pavo	377·666	44
Carina	494·184	33	Pegasus	1120·794	7
Cassiopeia	598·407	24	Perseus	614·997	23
Centaurus	1060·422	9	Phoenix	469·319	36
Cepheus	587·787	26	Pictor	246·739	59
Cetus	1231·411	4	Pisces	889·417	14
Chamaeleon	131·592	80	Piscis Austrinus	245·375	60
Circinus	93·353	86	Puppis	673·434	20
Columba	270·184	54	Pyxis	220·833	65
Coma Berenices	386·475	42	Reticulum	113·936	83
Corona Austrina	127·696	81	Sagitta	79·923	87
Corona Borealis	178·710	74	Sagittarius	867·432	15
Corvus	183·801	71	Scorpius	496·783	32
Crater	282·398	53	Sculptor	474·764	35
Crux	68·447	89	Scutum	109·114	85
Cygnus	803·983	16	Serpens Caput	428·484	39
Delphinus	188·549	70	Serpens Cauda	208·444	67
Dorado	179·173	73	Sextans	313·515	47
Draco	1082·952	8	Taurus	797·249	17
Equuleus	71·641	88	Telescopium	251·512	57
Eridanus	1137·919	6	Triangulum	131·847	79
Fornax	397·502	41	Triangulum Australe	109·978	84
Gemini	513·761	29	Tucana	294·557	48
Grus	365·513	45	Ursa Major	1279·660	3
Hercules	1225·148	5	Ursa Minor	255·864	56
Horologium	248·885	58	Vela	499·649	31
Hydra	1302·844	1	Virgo	1294·428	2
Hydrus	243·035	61	Volans	141·354	77
Indus	294·006	49	Vulpecula	268·165	55
Lacerta	200·688	69			

86

The Frenchman Charles Messier (1730–1817), who made many discoveries and observations of comets, compiled one of the first important catalogues of nebulous objects. This catalogue was published in parts, one in 1771 containing 45 objects, a further 23 objects in 1780, 35 in 1781 and the complete list of 103 objects was republished in 1784. Most of the earlier ones in this catalogue were discovered independently by Messier, although some had been discovered earlier by other astronomers. Many of the later ones were discovered by Méchain. On Messier's own copy of his catalogue one additional object was added; this has often been called M 104, and it has been included in the lists below although Messier himself did not assign its number. Méchain discovered five other nebulae for which identifications have been suggested (Hogg, 1947; Gingerich, 1953), but we do not include them in our lists.

M 47, M 48, M 91 have never been found; M 102 was identical with M 101. Gingerich (1960) suggests that M 47 is NGC 2422, M 48 is NGC 2548 and M 91 is identical with M 58, and gives photographs of these.

The data in the following Tables have been assembled from various references, including the *Atlas Skalnaté Pleso Catalogue*, the paper by Humason, Mayall and Sandage, *A.J.*, **61**, 97, 1956, the article by H. S. Hogg, *Handbuch der Physik*, **53**, and the following general references.

General References

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O. Gingerich, *Sky and Telescope*, **12**, 255, 288, 1953.
H. S. Hogg, *J.R.A.S. Canada*, **41**, 265, 1947.
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NGC	M	NGC	M	NGC	M	NGC	M	NGC	M
221	32	2447	93	4552	89	6218	12	6681	70
224	31	2632	44	4569	90	6254	10	6694	26
581	103	2682	67	4579	58	6266	62	6705	11
598	33	3031	81	4590	68	6273	19	6715	54
628	74	3034	82	4594	104	6333	9	6720	57
650	76	3351	95	4621	59	6341	92	6779	56
1039	34	3368	96	4649	60	6402	14	6809	55
1068	77	3587	97	IC 4725	25	6405	6	6838	71
1904	79	3623	65	4736	94	6475	7	6853	27
1912	38	3627	66	4826	64	6494	23	6864	75
1952	1	4192	98	5024	53	6514	20	6913	29
1960	36	4254	99	5055	63	6523	8	6981	72
1976	42	4303	61	5194	51	6531	21	6994	73
1982	43	4321	100	5236	83	6603	24	7078	15
2068	78	4374	84	5272	3	6611	16	7089	2
2099	37	4382	85	5457	101	6613	18	7092	39
2168	35	4406	86	5904	5	6618	17	7099	30
2287	41	4472	49	6093	80	6626	28	7654	52
2323	50	4486	87	6121	4	6637	69	Pleiades	45
2437	46	4501	88	6205	13	6656	22		

87

THE MESSIER OBJECTS

M	NGC	R.A. (1950·0) h m	Dec. ° ′	Mag. (Vis)	Distance	Const.	Description
1	1952	5 31·5	+21 59	8·4	1050 pc	Tau	Crab nebula
2	7089	21 30·9	− 1 03	6·3	16 kpc	Aqr	Globular cluster
3	5272	13 39·9	+28 38	6·4	14 kpc	CVn	Globular cluster
4	6121	16 20·6	−26 24	6·4	2·3 kpc	Sco	Globular cluster
5	5904	15 16·0	+ 2 16	6·2	8·3 kpc	Ser	Globular cluster
6	6405	17 36·8	−32 11	5·3	630 pc	Sco	Galactic cluster
7	6475	17 50·6	−34 48	4:	250 pc	Sco	Galactic cluster
8	6523	18 00·1	−24 23	6:	1·5 kpc	Sgr	Gaseous nebula
9	6333	17 16·2	−18 28	7·3	7·9 kpc	Oph	Globular cluster
10	6254	16 54·5	− 4 02	6·7	5·0 kpc	Oph	Globular cluster
11	6705	18 48·4	− 6 20	6·3	1·7 kpc	Sct	Galactic cluster
12	6218	16 44·6	− 1 52	6·6	5·8 kpc	Oph	Globular cluster
13	6205	16 39·9	+36 33	5·7	6·9 kpc	Her	Globular cluster
14	6402	17 35·0	− 3 15	7·7	7·2 kpc	Oph	Globular cluster
15	7078	21 27·6	+11 57	6·0	15 kpc	Peg	Globular cluster
16	6611	18 16·0	−13 48	6·4	1·8 kpc	Ser	Gaseous nebula
17	6618	18 17·9	−16 12	7:	1·8 kpc	Sgr	Gaseous nebula
18	6613	18 17·0	−17 09	7·5	1·5 kpc	Sgr	Galactic cluster
19	6273	16 59·5	−26 11	6·6	6·9 kpc	Oph	Globular cluster
20	6514	17 58·9	−23 02	9:	1·6 kpc	Sgr	Gaseous nebula
21	6531	18 01·7	−22 30	6·5	1·3 kpc	Sgr	Galactic cluster
22	6656	18 33·3	−23 58	5·9	3·0 kpc	Sgr	Globular cluster
23	6494	17 54·0	−19 01	6·9	660 pc	Sgr	Galactic cluster
24	6603	18 15·5	−18 26	4·6	5·0 kpc	Sgr	Galactic cluster
25	IC 4725	18 28·8	−19 17	6·5	600 pc	Sgr	Galactic cluster
26	6694	18 42·6	− 9 27	9·3	1·5 kpc	Sct	Galactic cluster
27	6853	19 57·4	+22 35	7·6	200 pc	Vul	Planetary nebula
28	6626	18 21·5	−24 54	7·3	4·6 kpc	Sgr	Globular cluster
29	6913	20 22·1	+38 22	7·1	1·2 kpc	Cyg	Galactic cluster
30	7099	21 37·5	−23 25	8·4	13 kpc	Cap	Globular cluster
31	224	0 40·0	+41 00	4·8	700 kpc	And	Galaxy
32	221	0 40·0	+40 36	8·7	700 kpc	And	Galaxy
33	598	1 31·0	+30 24	6·7	700 kpc	Tri	Galaxy
34	1039	2 38·8	+42 34	5·5	440 pc	Per	Galactic cluster
35	2168	6 05·8	+24 21	5·3	870 pc	Gem	Galactic cluster
36	1960	5 32·0	+34 07	6·3	1·3 kpc	Aur	Galactic cluster
37	2099	5 49·1	+32 32	6·2	1·3 kpc	Aur	Galactic cluster
38	1912	5 25·3	+35 48	7·4	1·3 kpc	Aur	Galactic cluster
39	7092	21 30·4	+48 13	5·2	250 pc	Cyg	Galactic cluster
40	—						
41	2287	6 44·9	−20 41	4·6	670 pc	CMa	Galactic cluster
42	1976	5 32·9	− 5 25	4:	460 pc	Ori	Orion nebula
43	1982	5 33·1	− 5 18	9:	460 pc	Ori	Orion nebula
44	2632	8 37·4	+20 00	3·7	158 pc	Cnc	Galactic cluster
45	—	3 44·1	+23 58	1·6	126 pc	Tau	Galactic cluster
46	2437	7 39·5	−14 42	6·0	1·8 kpc	Pup	Galactic cluster
47	—						
48	—						
49	4472	12 27·2	+ 8 16	8·6	11 Mpc	Vir	Galaxy
50	2323	7 00·6	− 8 16	6·3	910 pc	Mon	Galactic cluster
51	5194	13 27·8	+47 27	8·1	2 Mpc	CVn	Galaxy
52	7654	23 22·0	+61 19	7·3	2·1 kpc	Cas	Galactic cluster
53	5024	13 10·5	+18 26	7·6	20 kpc	Com	Globular cluster
54	6715	18 52·0	−30 32	7·3	15 kpc	Sgr	Globular cluster
55	6809	19 36·9	−31 03	7·6	5·8 kpc	Sgr	Globular cluster
56	6779	19 14·6	+30 05	8·2	14 kpc	Vir	Globular cluster
57	6720	18 51·7	+32 58	9·3	550 pc	Lyr	Planetary nebula
58	4579	12 35·0	+12 05	8·2	11 Mpc	Vir	Galaxy
59	4621	12 39·5	+11 55	9·3	11 Mpc	Vir	Galaxy

88

M	NGC	R.A. (1950·0) h m	Dec. ° ′	Mag. (Vis)	Distance	Const.	Description
60	4649	12 41·1	+11 49	9·2	11 Mpc	Vir	Galaxy
61	4303	12 19·4	+ 4 45	9·6	11 Mpc	Vir	Galaxy
62	6266	16 58·1	−30 03	8·9	6·9 kpc	Oph	Globular cluster
63	5055	13 13·6	+42 18	10·1	4 Mpc	CVn	Galaxy
64	4826	12 54·3	+21 57	6·6	6 Mpc	Com	Galaxy
65	3623	11 16·3	+13 22	9·5		Leo	Galaxy
66	3627	11 17·6	+13 16	8·8		Leo	Galaxy
67	2682	8 47·8	+12 00	6·1	830 pc	Cnc	Galactic cluster
68	4590	12 36·8	−26 29	9:	12 kpc	Hya	Globular cluster
69	6637	18 28·1	−32 23	8·9	7·2 kpc	Sgr	Globular cluster
70	6681	18 40·0	−32 21	9·6	20 kpc	Sgr	Globular cluster
71	6838	19 51·5	+18 39	9:	5·5 kpc	Sge	Globular cluster
72	6981	20 50·7	−12 44	9·8	18 kpc	Aqr	Globular cluster
73	6994	20 56·4	−12 50			Aqr	
74	628	1 34·0	+15 32	10·2		Psc	Galaxy
75	6864	20 03·2	−22 04	8·0	24 kpc	Sgr	Globular cluster
76	650	1 38·8	+51 19	12·2	2·5 kpc	Per	Planetary nebula
77	1068	1 40·3	− 0 13	8·9		Cet	Galaxy
78	2068	5 44·2	+ 0 02	8·3	500 pc	Ori	Gaseous nebula
79	1904	5 22·2	−24 34	7·9	13 kpc	Lep	Globular cluster
80	6093	16 14·1	−22 52	7·7	11 kpc	Sco	Globular cluster
81	3031	9 51·5	+69 18	7·9	3·0 Mpc	UMa	Galaxy
82	3034	9 51·9	+69 56	8·8	3·0 Mpc	UMa	Galaxy
83	5236	13 34·2	−29 37	10·1	4 Mpc	Hya	Galaxy
84	4374	12 22·5	+13 10	9·3	11 Mpc	Vir	Galaxy
85	4382	12 22·9	+18 28	9·3	11 Mpc	Com	Galaxy
86	4406	12 23·7	+13 13	9·7	11 Mpc	Vir	Galaxy
87	4486	12 28·3	+12 40	9·2	11 Mpc	Vir	Galaxy
88	4501	12 29·5	+14 42	10·2	11 Mpc	Com	Galaxy
89	4552	12 33·1	+12 50	9·5	11 Mpc	Vir	Galaxy
90	4569	12 34·3	+13 26	10·0	11 Mpc	Vir	Galaxy
91	—						
92	6341	17 15·6	+43 12	6·1	11 kpc	Her	Globular cluster
93	2447	7 42·4	−23 45	6·0	1·1 kpc	Pup	Galactic cluster
94	4736	12 48·5	+41 24	7·9	6 Mpc	CVn	Galaxy
95	3351	10 41·3	+11 58	10·4		Leo	Galaxy
96	3368	10 44·1	+12 05	9·1		Leo	Galaxy
97	3587	11 12·0	+55 18	12·0	800 pc	UMa	Planetary nebula
98	4192	12 11·3	+15 11	10·7	11 Mpc	Com	Galaxy
99	4254	12 16·3	+14 42	10·1	11 Mpc	Com	Galaxy
100	4321	12 20·4	+16 06	10·6	11 Mpc	Com	Galaxy
101	5457	14 01·4	+54 35	9·6	3 Mpc	UMa	Galaxy
102	—						
103	581	1 29·9	+60 27	7·4	2·6 kpc	Cas	Galactic cluster
104	4594	12 37·4	−11 21	8·7	4·4 Mpc	Vir	Galaxy

89

THE PLEIADES

Stars, within 1° of Alcyone, brighter than magnitude 7·6

Hz II	HD	R.A. 1950·0 (h m s)	Dec. (° ′ ″)	V	B−V	U−B	Sp.	Notes
1432	23630	3 44 30·4	+23 57 8	2·87	−0·09	−0·34	B7 III	Alcyone = η Tau
2168	23850	3 46 11·0	+23 54 7	3·64	−0·08	−0·36	B8 III	Atlas = 27 Tau
468	23302	3 41 54·1	+23 57 28	3·71	−0·11	−0·41	B6 III	Electra = 17 Tau
785	23408	3 42 50·8	+24 12 47	3·88	−0·07	−0·40	B7 III	Maia = 20 Tau
980	23480	3 43 21·2	+23 47 39	4·18	−0·06	−0·43	B6 IV	Merope = 23 Tau
563	23338	3 42 13·6	+24 18 43	4·31	−0·11	−0·46	B6 V	Taygeta = 19 Tau
2181	23862	3 46 12·4	+23 59 7	5·09	−0·08	−0·28	B8 pec	Pleione = 28 Tau
1823	23753	3 45 22·9	+23 16 9	5·45	−0·07	−0·32	B8 V	HR 1172
447	23288	3 41 49·5	+24 8 1	5·46	−0·04	−0·33	B7 IV	Celaeno = 16 Tau
541	23324	3 42 10·4	+24 41 2	5·65	−0·07	−0·36	B8 V	18 Tau
817	23432	3 42 55·4	+24 24 0	5·76	−0·04	−0·23	B8 V	Asterope = 21 Tau
2425	23923	3 46 45·2	+23 33 40	6·17	−0·05	−0·19	B9 V	HR 1183
1375	23629	3 44 22·4	+23 57 47	6·29	+0·02	−0·02	A0 V	24 Tau. Sp. Bin.
859	23441	3 43 3·9	+24 22 24	6·43	−0·02	−0·15	B9 V	22 Tau
1705*	23712	3 45 7·0	+24 50 9	6·46	+1·70	+2·07	K5	
2263	23873	3 46 22·6	+24 13 47	6·60	−0·03	−0·12	B9·5 V	
2507	23964	3 46 59·6	+23 41 53	6·74	+0·06	−0·06	A0 V	ADS 2795. Sp. Bin?
1431	23642	3 44 30·6	+24 8 8	6·81	+0·06	+0·02	A0 V	Sp. Bin.
1234	23568	3 44 0·3	+24 22 0	6·82	+0·02	−0·07	B9·5 V	
801	23410	3 42 51·5	+22 59 32	6·85	+0·04	+0·01	A0 V	ADS 2748
2866	24076	3 47 53·7	+23 48 44	6·93	+0·09	+0·03	A2 V	
1876	23763	3 45 31·1	+24 11 36	6·95	+0·12	+0·09	A1 V	
1380	23632	3 44 22·7	+23 39 2	6·99	+0·03	+0·05	A1 V	
717	23387	3 42 39·0	+24 10 51	7·18	+0·16	+0·08	A1 V	
1397	23631	3 44 25·9	+23 45 42	7·26	+0·05	+0·12	A2 V	ADS 2767
1028	23489	3 43 28·5	+24 6 4	7·35	+0·10	+0·12	A2 V	
2690*	24013	3 47 28·8	+24 20 42	7·42	+0·13	+0·12	A2	
153	23155	3 40 43·6	+24 55 28	7·51	+0·15	+0·10	A2	Sp. Bin?
2220	23872	3 46 17·6	+24 14 43	7·52	+0·10	+0·11	A2 V	
2488	23948	3 46 57·5	+24 11 54	7·54	+0·18	+0·08	A2 V	

*These two stars are not members of the Pleiades cluster (proper motion evidence).

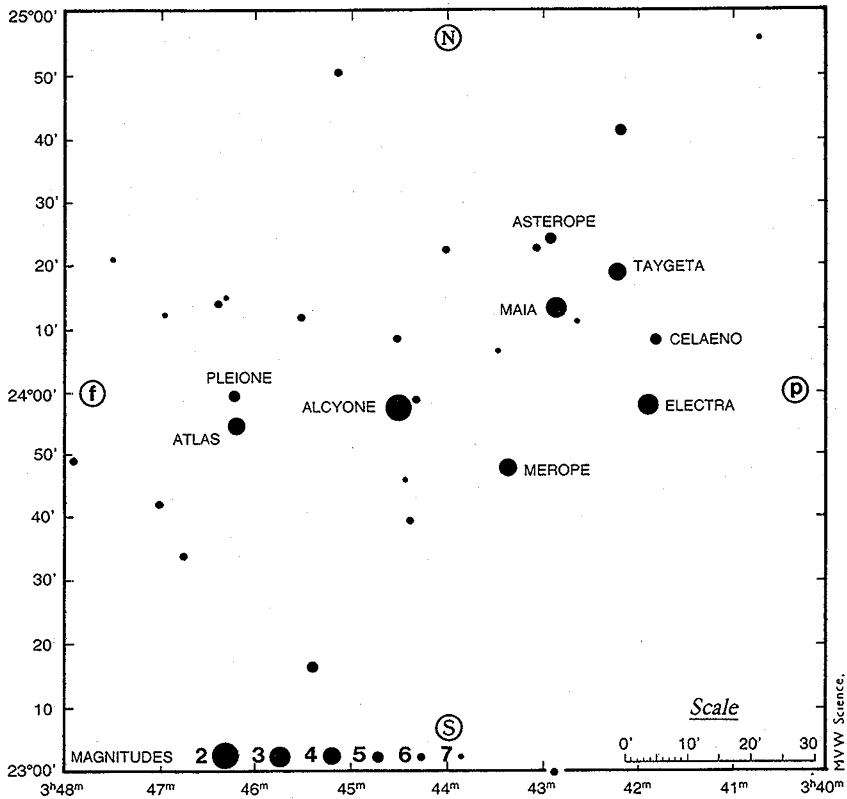
Sources of Data

Positions—Boss *General Catalogue*; *Yale Obs. Trans.* **25**.
Magnitudes and colours—H. L. Johnson and R. I. Mitchell, *Ap. J.*, **128,** 31, 1958.
Spectral types—E. E. Mendoza, *Ap. J.*, **123,** 54, 1956; Henry Draper Catalogue.
Star numbers—E. Herstzprung, *Ann. Leiden Obs.*, **19,** Part 1a, 1947.
Double stars—R. J. Trumpler, *Lick Obs. Bull.*, **10,** 110, 1921; R. G. Aitken, *New General Catalogue*; B. Smith and O. Struve, *Ap. J.*, **100,** 360, 1944; J. A. Pearce, *Pub. D.A.O. Victoria*, **10,** 435, 1958.
Distance and age—R. I. Mitchell and H. L. Johnson, *Ap. J.*, **125,** 414, 1957.
Proper motion and radial velocities—Boss *General Catalogue*; B. Smith and O. Struve, *Ap. J.*, **100,** 360, 1944.

Double stars—ADS 2748 (11^m at 339°, 3″·7); ADS 2767 (10^m at 266°, 5″·6); ADS 2795 (10^m at 239°, 3″·1; 11^m at 236°, 10″).

90

THE PLEIADES



This galactic cluster, M45, is best seen with low power. Its distance is 127 (± 6) parsecs and it is believed to have an age of 150 million years. The cluster as a whole has annual proper motion $\mu_a = +0^s{\cdot}0015$, $\mu\delta = -0''{\cdot}045$ and radial velocity 5 km/sec. Velocities of individual stars relative to the cluster are of order 1 km/sec. The Table and chart show the 30 brightest stars within 1° of Alcyone, 28 of these being physical members of the cluster. Outside this distance 8 physical members are known with visual magnitudes in the range V = 6·07 to 7·6. Eight visual binaries, one visual triple star and at least seven spectroscopic binaries are known in the cluster; two visual binaries, the triple star and two certain and two probable spectroscopic binaries are included in the Table and chart. HD 23642 is the only two-lined spectroscopic binary in the Pleiades. *U, B, V* are the ultraviolet, blue and visual magnitudes; *Hz II* the star number in Hertzsprung's 1947 catalogue; *Sp.* the spectral type, and luminosity class if available.

91

GREEK ALPHABET

Α	α	Alpha	Ι	ι	Iota	Ρ	ϱ	Rho
Β	β	Beta	Κ	ϰ	Kappa	Σ	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	Τ	τ	Tau
Δ	δ	Delta	Μ	μ	Mu	Υ	υ	Upsilon
Ε	ε	Epsilon	Ν	ν	Nu	Φ	ϕ	Phi
Ζ	ζ	Zeta	Ξ	ξ	Xi	Χ	χ	Chi
Η	η	Eta	Ο	ο	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

STANDARD NOTATION FOR LARGE AND SMALL QUANTITIES

The standard notation allows large and small quantities to be written in a form which eliminates the need for inserting numerous 'zeros' which are required to locate the position of the decimal point. It consists of the product of two numbers, the first of which is a number lying between 1 and 10 and the second of which is a power of 10.

Examples: (1) 1234·86 is written $1{\cdot}23486\times1000$
$= 1{\cdot}23486\times10^3$

(2) 0·0067 is written $6{\cdot}7\div1000$
$= 6{\cdot}7\times10^{-3}$

MULTIPLES AND SUB-MULTIPLES OF THE BASIC UNITS USED IN THE METRIC SYSTEM

10^{-1}	deci	d	10	deca	da
10^{-2}	centi	c	10^2	hecto	h
10^{-3}	milli	m	10^3	kilo	k
10^{-6}	micro	μ	10^6	mega	M
10^{-9}	nano	n	10^9	giga	g
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a	10^{18}	exa	E

Other units commonly used in astronomical literature include the following:

micron (μ) = 10^{-6} metres   Ångström (Å) = 10^{-10} metres

92