REPORT OF THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS OF THE PLANETS AND SATELLITES: 1982

M. E. DAVIES*
The Rand Corporation, Santa Monica, California, U.S.A.
V. K. ABALAKIN
Institute for Theoretical Astronomy, Leningrad, U.S.S.R.
J. H. LIESKE
Jet Propulsion Laboratory, Pasadena, California, U.S.A.
P. K. SEIDELMANN
U.S. Naval Observatory, Washington, D.C., U.S.A.
A. T. SINCLAIR
Royal Greenwich Observatory, Sussex, England
A. M. SINZI
Maritime Aafety Agency, Tokyo, Japan
B. A. SMITH
University of Arizona, Tucson, Arizona, U.S.A.
and
Y. S. TJUFLIN**
Central Research Institute of Geodesy, Air Survey, and Mapping (TsNIIGAik), Moscow, U.S.S.R.

(Received 1 November, 1982)

Abstract. This paper contains the report of the IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites as presented at the XVIII General Assembly held at Patras, Greece, 1982. Tables give the recommended values for the direction of the north poles of rotation and the prime meridians of the planets and satellites referred to both the B1950 and J2000 standard coordinate systems. Reference surfaces for mapping these bodies are described. An appendix discusses the principal changes to the tables since 1979.

1. Introduction

The IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites was established as a consequence of resolutions adopted by Commissions 4 and 16 at the IAU General Assembly at Grenoble in 1976. The first report of the Working Group was presented to the General Assembly at Montreal in 1979 and published in the *Trans. IAU* **17B,** pp. 72–79, 1980. The report with appendices was published in *Celest. Mech.* **22** (1980), pp. 205–230. The guiding principles

* Chairman.
** Consultant.

Celestial Mechanics **29** (1983) 309–321. 0008-8714/83/0294-0309 $01.95.

and conventions that were adopted by the Group and the rationale for their acceptance are presented in that report and its appendices and will not be reviewed here.

This report will incorporate changes in the tables giving the directions of the north poles of rotation and the prime meridians of the planets and satellites expressed in standard equatorial coordinates of 1950.0. New tables give these same parameters with respect to the standard equator and equinox of J2000. The tables giving the sizes and shapes of the planets and satellites have also been revised.

2. Definition of Rotational Elements

The north pole is that pole of rotation which lies on the north side of the invariable plane of the solar system. At this time, two standard coordinate systems are in common use; they are designated B1950 and J2000. B1950 is defined with respect to the fundamental FK4 catalog and J2000 is defined with respect to the new FK5 catalog. B1950 has the standard epoch (J1950) of 1950 January 1.0, ET(JED 2433282.5) and J2000 has the standard epoch (J2000) of 2000 January 1.5 (JD 2451545.0), TDB. The variable quantities are expressed in units of days (86400 SI seconds) or Julian centuries of 36525 days.

The direction of the north pole is specified by the value of its right ascension α_0 and declination δ_0, whereas the orientation of the prime meridian is specified by the angle W that is measured *along* the planet's equator in the positive sense with respect to the planet's north pole (i.e., in an easterly direction on the planet's surface) *from* the ascending node of the planet's equator on the standard equator *to* the point where the prime meridian crosses the planet's equator. Because the prime meridian is assumed to rotate uniformly with the planet, W accordingly varies linearly with time. In addition, α_0, δ_0, and W may vary with time due to a precession of the axis of rotation of the planet (or satellite). If W increases with time, the planet has a *direct* (or prograde) rotation relative to the invariable plane; if W decreases with time, the rotation is said to be *retrograde*.

In the absence of other information, the axis of rotation is assumed to be normal to the mean orbital plane; Mercury and most of the satellites are in this category. For many of the satellites, it is assumed that the rotation rate is equal to the mean orbital period.

The angle W specifies the ephemeris position of the prime meridian, and for planets or satellites without any accurately observable fixed surface features the adopted expression for W defines the prime meridian and is not subject to correction. Where possible, however, the cartographic position of the prime meridian is defined by a suitable observable feature and so the constants in the expression $W = W_0 + \dot{W}d$, where d is the interval in days from the standard epoch, are chosen so that the ephemeris position follows the motion of the cartographic position as closely as possible; in these cases the expression for W may require emendation in the future.

Recommended values of the constants in the expressions for α_0, δ_0, and W are

TABLE I

Recommended values for the direction of the north pole of rotation and the prime meridian of the Sun and planets (1982)

α_0, δ_0 are standard equatorial coordinates with equinox B1950 at epoch J1950. Approximate coordinates of the north pole of the invariable plane are $\alpha_0 = 272^\circ.40$, $\delta_0 = +66^\circ.99$.
T = interval in Julian ephemeris centuries (of 36525 days) from the standard epoch.
d = interval in ephemeris days from the standard epoch.
The standard epoch is 1950 January 1.0 ET, i.e., JED 2433282.5.

Sun	$\alpha_0 = 285^\circ.90$	
	$\delta_0 = 63.90$	
	$W = 240.90 + 14^\circ.1844000\ d$	
Mercury	$\alpha_0 = 280.90 - 0.033\ T$	
	$\delta_0 = 61.40 - 0.005\ T$	
	$W = 184.74 + 6.1385025\ d$	(a)
Venus	$\alpha_0 = 272.80$	
	$\delta_0 = 67.20$	
	$W = 213.63 - 1.4814205\ d$	
Earth	$\alpha_0 = 0.00 - 0.640\ T$	
	$\delta_0 = 90.00 - 0.557\ T$	
	$W = 99.87 + 360.9856123\ d$	(b)
Mars	$\alpha_0 = 317.342 - 0.108\ T$	
	$\delta_0 = 52.711 - 0.061\ T$	
	$W = 11.504 + 350.8919830\ d$	(c)
Jupiter	$\alpha_0 = 268.00 - 0.008\ T$	
	$\delta_0 = 64.50 + 0.003\ T$	
	$W = 80.60 + 870.5360000\ d$	(d)
Saturn	$\alpha_0 = 38.50 - 0.034\ T$	
	$\delta_0 = 83.31 - 0.004\ T$	
	$W = 76.81 + 810.7939024\ d$	(d)
Uranus	$\alpha_0 = 256.72$	
	$\delta_0 = -15.04$	
	$W = 360.00 - 554.9130000\ d$	
Neptune	$\alpha_0 = 294.91$	
	$\delta_0 = 40.53$	
	$W = 360.00 + 468.7500000\ d$	
Pluto	$\alpha_0 = 311.00$	
	$\delta_0 = 4.00$	
	$W = 360.00 - 56.3640000\ d$	

Note: (a) The 20° meridian is defined by the crater Hun Kal.
(b) The 0° meridian is defined by the transit circle at Greenwich, England.
(c) The 0° meridian is defined by the crater Airy-0.
(d) The equations for W for Jupiter and Saturn refer to the rotation of their magnetic fields (System III). On Jupiter, System I ($W_I = 17^\circ.7 + 877^\circ.900\ d$) refers to the mean atmospheric equatorial rotation; System II ($W_{II} = 16^\circ.8 + 870^\circ.270\ d$) refers to the mean atmospheric rotation north of the south component of the north equatorial belt, and south of the north component of the south equatorial belt.

TABLE II

Recommended values for the direction of the north pole of rotation and the prime meridian of the satellites (1982)

α_0, δ_0, T, and d have the same meanings as in Table I (epoch 1950 January 1.0 ET, i.e., JED 2433282.5)

Planet	Satellite	Elements	Note
Earth:	Moon	$\alpha_0 = 270^\circ.000 - 3^\circ.878 \sin E1 - 0^\circ.120 \sin E2 + 0.070 \sin E3 - 0.017 \sin E4$	
		$\delta_0 = 66.534 + 1.543 \cos E1 + 0.024 \cos E2 - 0.028 \cos E3 + 0.007 \cos E4$	
		$W = 244.375 + 13.1763581\ d + 3.558 \sin E1 + 0.121 \sin E2 - 0.064 \sin E3 + 0.016 \sin E4 + 0.025 \sin E5$	
	where	$E1 = 12^\circ.112 - 0^\circ.052992\ d$, $E2 = 24^\circ.224 - 0^\circ.105984\ d$, $E3 = 227.645 - 13.012000\ d$, $E4 = 261.105 + 13.340716\ d$, $E5 = 358.000 - 0.985600\ d$,	
Mars:	Phobos	$\alpha_0 = 317^\circ.31 - 0^\circ.108\ T + 1^\circ.79 \sin M_1$	
		$\delta_0 = 52.70 - 0.061\ T - 1.08 \cos M_1$	
		$W = 270.23 + 1128.8444790\ d + 0.66 \times 10^{-8}\ d^2 - 1.42 \sin M_1 - 2.31 \sin M_2$	
	Deimos	$\alpha_0 = 316.29 - 0.108\ T + 2.98 \sin M_1$	
		$\delta_0 = 53.33 - 0.061\ T - 1.78 \cos M_1$	
		$W = 69.97 + 285.1619030\ d - 0.4 \times 10^{-9}\ d^2 - 2.66 \sin M_1$	
	where	$M_1 = 207^\circ.34 - 0^\circ.435764\ d$ $M_2 = 88^\circ.80 + 1128^\circ.409670\ d + 0.66 \times 10^{-8}\ d^2$	
Jupiter:	Amalthea	$\alpha_0 = 268^\circ.00 - 0^\circ.008\ T$	
		$\delta_0 = 64.50 + 0.003\ T$	
		$W = 50.20 + 722.6303746\ d$	
	Io	$\alpha_0 = 268^\circ.00 - 0^\circ.008\ T + 0^\circ.094 \sin J1 + 0^\circ.024 \sin J2$	
		$\delta_0 = 64.50 + 0.003\ T + 0.040 \cos J1 + 0.011 \cos J2$	
		$W = 262.72 + 203.4889538\ d - 0.085 \sin J1 - 0.022 \sin J2$	
	Europa	$\alpha_0 = 268.03 - 0.008\ T + 1.086 \sin J2 + 0.060 \sin J3 + 0.015 \sin J4 + 0.009 \sin J5$	
		$\delta_0 = 64.52 + 0.003\ T + 0.468 \cos J2 + 0.026 \cos J3 + 0.007 \cos J4 + 0.002 \cos J5$	
		$W = 158.44 + 101.3747235\ d - 0.980 \sin J2 - 0.054 \sin J3 - 0.014 \sin J4 - 0.008 \sin J5$	(a)
	Ganymede	$\alpha_0 = 268.15 - 0.008\ T - 0.037 \sin J2 + 0.431 \sin J3 + 0.091 \sin J4$	
		$\delta_0 = 64.57 + 0.003\ T - 0.016 \cos J2 + 0.186 \cos J3 + 0.039 \cos J4$	
		$W = 196.82 + 50.3176081\ d + 0.033 \sin J2 - 0.389 \sin J3 - 0.082 \sin J4$	(b)
	Callisto	$\alpha_0 = 268.68 - 0.008\ T - 0.068 \sin J3 + 0.590 \sin J4 + 0.010 \sin J6$	
		$\delta_0 = 64.83 + 0.003\ T - 0.029 \cos J3 + 0.254 \cos J4 - 0.004 \cos J6$	
		$W = 157.55 + 21.5710715\ d + 0.061 \sin J3 - 0.533 \sin J4 - 0.009 \sin J6$	(c)
	where	$J1 = 19^\circ.20 + 4850^\circ.7\ T$, $J2 = 120^\circ.80 + 1191.3\ T$, $J3 = 349^\circ.50 + 262^\circ.1\ T$, $J4 = 198.30 + 64.3\ T$, $J5 = 241.60 + 2382.6\ T$, $J6 = 317.70 + 6070.0\ T$	

Table II (continued)

Saturn:	Mimas	$\alpha_0 =$	$38\overset{\circ}{.}50 - 0\overset{\circ}{.}034\,T + 13\overset{\circ}{.}13 \sin S1$	
		$\delta_0 =$	$83.31 - 0.004\,T - 1.53 \cos S1$	
		$W =$	$246.80 + 381.9945550\,d - 13.04 \sin S1 - 43\overset{\circ}{.}41 \sin S6$	(d)
	Enceladus	$\alpha_0 =$	$38.50 - 0.034\,T$	
		$\delta_0 =$	$83.31 - 0.004\,T$	
		$W =$	$301.41 + 262.7318996\,d$	(e)
	Tethys	$\alpha_0 =$	$38.50 - 0.034\,T + 9.36 \sin S2$	
		$\delta_0 =$	$83.31 - 0.004\,T - 1.09 \cos S2$	
		$W =$	$31.76 + 190.6979085\,d - 9.29 \sin S2 + 2.16 \sin S6$	(f)
	Dione	$\alpha_0 =$	$38.50 - 0.034\,T$	
		$\delta_0 =$	$83.31 - 0.004\,T$	
		$W =$	$121.54 + 131.5349316\,d$	(g)
	Rhea	$\alpha_0 =$	$38.22 - 0.034\,T + 3.00 \sin S3$	
		$\delta_0 =$	$83.34 - 0.004\,T - 0.35 \cos S3$	
		$W =$	$14.52 + 79.6900478\,d - 2.98 \sin S3$	(h)
	Titan	$\alpha_0 =$	$34.30 - 0.034\,T + 2.58 \sin S4$	
		$\delta_0 =$	$83.71 - 0.004\,T - 0.30 \cos S4$	
		$W =$	$79.10 + 22.5769768\,d - 2.56 \sin S4$	
	Hyperion	$\alpha_0 =$	$33.42 - 0.034\,T + 4.89 \sin S5 + 2.75 \sin S4$	
		$\delta_0 =$	$83.80 - 0.004\,T - 0.57 \cos S5 - 0.32 \cos S4$	
		$W =$	$344.75 + 16.9199514\,d - 4.86 \sin S5 - 2.73 \sin S4 + 9.09 \sin S7$	(i)
	Iapetus	$\alpha_0 =$	$289\overset{\circ}{.}26$	
		$\delta_0 =$	78.73	
		$W =$	$275.36 + 4.5379571\,d$	(j)

where $S1 = 68\overset{\circ}{.}60 - 36505\overset{\circ}{.}5\,T$, $S2 = 314\overset{\circ}{.}50 - 7225\overset{\circ}{.}9\,T$, $S3 = 134\overset{\circ}{.}90 - 1016\overset{\circ}{.}3\,T$,
$S4 = 57.40 - 52.1\,T$, $S5 = 22.60 - 239.2\,T$, $S6 = 64.90 + 506.2\,T$,
$S7 = 277.40 + 20528.5\,T$

Uranus:	Miranda	$\alpha_0 =$	$256\overset{\circ}{.}72$	
		$\delta_0 =$	-15.04	
		$W =$	$59.20 - 254\overset{\circ}{.}5968883\,d$	
	Ariel	$\alpha_0 =$	256.72	
		$\delta_0 =$	-15.04	
		$W =$	$47.30 - 142.8356047\,d$	
	Umbriel	$\alpha_0 =$	256.72	
		$\delta_0 =$	-15.04	
		$W =$	$146.40 - 86.8688136\,d$	
	Titania	$\alpha_0 =$	256.72	
		$\delta_0 =$	-15.04	
		$W =$	$202.00 - 41.3513623\,d$	
	Oberon	$\alpha_0 =$	256.72	
		$\delta_0 =$	-15.04	
		$W =$	$3.20 - 26.7394375\,d$	
Neptune:	Triton	$\alpha_0 =$	$294\overset{\circ}{.}89 - 20\overset{\circ}{.}09 \sin N$	
		$\delta_0 =$	$36.93 + 15.26 \cos N$	
		$W =$	$132.30 - 61.2575147\,d + 10\overset{\circ}{.}52 \sin N$	

where $N = 158\overset{\circ}{.}34 + 62\overset{\circ}{.}0\,T$

Table II (continued)

Pluto:	Charon	$\alpha_0 = 311°.00$ $\delta_0 = 4.00$ $W = 133.00 - 56°.3640000\,d$

Note: (a) The 182° meridian is defined by the crater Cilix.
(b) The 128° meridian is defined by the crater Anat.
(c) The 326° meridian is defined by the crater Saga.
(d) The 162° meridian is defined by the crater Palomides.
(e) The 5° meridian is defined by the crater Salih.
(f) The 299° meridian is defined by the crater Arete.
(g) The 63° meridian is defined by the crater Palinurus.
(h) The 340° meridian is defined by the crater Tore.
(i) The 196° meridian is defined by the crater Bahloo.
(j) The 276° meridian is defined by the crater Almeric.

TABLE III

Recommended values for the direction of the north pole of rotation and the prime meridian of the Sun and planets (1982)

α_0, δ_0 are standard equatorial coordinates with equinox J2000 at epoch J2000. Approximate coordinates of the north pole of the invariable plane are $\alpha_0 = 272°.38$, $\delta_0 = +66°.99$.
T = interval in Julian centuries (of 36525 days) from the standard epoch.
d = interval in days from the standard epoch.
The standard epoch is 2000 January 1.5, i.e., JD 2451545.0 TDB.

Sun	$\alpha_0 = 285°.96$	
	$\delta_0 = 63°.96$	
	$W = 84.11 + 14°.1844000\,d$	
Mercury	$\alpha_0 = 281.02 - 0.033\,T$	
	$\delta_0 = 61.45 - 0.005\,T$	
	$W = 329.71 + 6.1385025\,d$	(a)
Venus	$\alpha_0 = 272.78$	
	$\delta_0 = 67.21$	
	$W = 159.91 - 1.4814205\,d$	
Earth	$\alpha_0 = 0.00 - 0.641\,T$	
	$\delta_0 = 90.00 - 0.557\,T$	
	$W = 100.21 + 360.9856123\,d$	(b)
Mars	$\alpha_0 = 317.681 - 0.108\,T$	
	$\delta_0 = 52.886 - 0.061\,T$	
	$W = 176.655 + 350.8919830\,d$	(c)
Jupiter	$\alpha_0 = 268.05 - 0.009\,T$	
	$\delta_0 = 64.49 + 0.003\,T$	
	$W = 284.95 + 870.5360000\,d$	(d)
Saturn	$\alpha_0 = 40.66 - 0.036\,T$	
	$\delta_0 = 83.52 - 0.004\,T$	
	$W = 38.90 + 810.7939024\,d$	(d)

Table III (continued)

Uranus	$\alpha_0 =$	257°.43
	$\delta_0 =$	−15.10
	$W =$	261.62 − 554°.9130000 d
Neptune	$\alpha_0 =$	295.33
	$\delta_0 =$	40.65
	$W =$	107.21 + 468.7500000 d
Pluto	$\alpha_0 =$	311.63
	$\delta_0 =$	4.18
	$W =$	252.66 − 56.3640000 d

Note: (a) The 20° meridian is defined by the crater Hun Kal.
(b) The 0° meridian is defined by the transit circle at Greenwich, England.
(c) The 0° meridian is defined by the crater Airy-0.
(d) The equations for W for Jupiter and Saturn refer to the rotation of their magnetic fields (System III). On Jupiter, System I ($W_{\mathrm{I}} = 67°.1 + 877°.900$ d) refers to the mean atmospheric equatorial rotation; System II ($W_{\mathrm{II}} = 43°.3 + 870°.270$ d) refers to the mean atmospheric rotation north of the south component of the north equatorial belt, and south of the north component of the south equatorial belt.

TABLE IV

Recommended values for the direction of the north pole of rotation and the prime meridian of the satellites (1982)

α_0, δ_0, T, and d have the same meanings as in Table III (epoch 2000 January 1.5, i.e., JD 2451545.0 TDB)

Earth:	Moon	$\alpha_0 =$	270°.000 − 3°.878 sin E1 − 0°.120 sin E2
			+ 0.070 sin E3 − 0.017 sin E4
		$\delta_0 =$	66.534 + 1.543 cos E1 + 0.024 cos E2
			− 0.028 cos E3 + 0.007 cos E4
		$W =$	38.314 + 13.1763581 d + 3.558 sin E1
			+ 0.121 sin E2 − 0.064 sin E3
			+ 0.016 sin E4 + 0.025 sin E5
	where		E1 = 125°.045 − 0°.052992 d, E2 = 249°.390 − 0°.105984 d,
			E3 = 196.694 − 13.012000 d, E4 = 176.630 + 13.340716 d,
			E5 = 358.219 − 0.985600 d
Mars:	Phobos	$\alpha_0 =$	317°.65 − 0°.108 T + 1°.80 sin M_1
		$\delta_0 =$	52.87 − 0.061 T − 1.08 cos M_1
		$W =$	32.84 + 1128.8444790 d + 0.66 × 10^{-8} d^2
			− 1.43 sin M_1 − 2.32 sin M_2
	Deimos	$\alpha_0 =$	316.62 − 0.108 T + 3.00 sin M_1
		$\delta_0 =$	53.50 − 0.061 T − 1.78 cos M_1
		$W =$	79.55 + 285.1619030 d − 0.4 × 10^{-9} d^2 − 2.68 sin M_1
	where		M_1 = 169°.51 − 0°.435764 d, M_2 = 190°.71 + 1128°.409670 d + 0.66 × 10^{-8} d^2
Jupiter:	Amalthea	$\alpha_0 =$	268°.05 − 0°.009 T
		$\delta_0 =$	64.49 + 0.003 T
		$W =$	208.06 + 722°.6303746 d

Table IV (continued)

	Io	$\alpha_0 =$	$268\overset{\circ}{.}05 - 0\overset{\circ}{.}009\,T$	$+\ 0\overset{\circ}{.}094 \sin J1 + 0\overset{\circ}{.}024 \sin J2$	
		$\delta_0 =$	$64.50 + 0.003\,T$	$+\ 0.040 \cos J1 + 0.011 \cos J2$	
		$W =$	$200.39 + 203.4889538\,d$	$-\ 0.085 \sin J1 - 0.022 \sin J2$	
	Europa	$\alpha_0 =$	$268.08 - 0.009\,T$	$+\ 1.086 \sin J2 + 0.060 \sin J3$	
				$+\ 0.015 \sin J4 + 0.009 \sin J5$	
		$\delta_0 =$	$64.51 + 0.003\,T$	$+\ 0.468 \cos J2 + 0.026 \cos J3$	
				$+\ 0.007 \cos J4 + 0.002 \cos J5$	
		$W =$	$34.97 + 101.3747235\,d$	$-\ 0.980 \sin J2 - 0.054 \sin J3$	(a)
				$-\ 0.014 \sin J4 - 0.008 \sin J5$	
	Ganymede	$\alpha_0 =$	$268.20 - 0.009\,T$	$-\ 0.037 \sin J2 + 0.431 \sin J3$	
				$+\ 0.091 \sin J4$	
		$\delta_0 =$	$64.57 + 0.003\,T$	$-\ 0.016 \cos J2 + 0.186 \cos J3$	
				$+\ 0.039 \cos J4$	
		$W =$	$42.79 + 50.3176081\,d$	$+\ 0.033 \sin J2 - 0.389 \sin J3$	(b)
				$-\ 0.082 \sin J4$	
	Callisto	$\alpha_0 =$	$268.72 - 0.009\,T$	$-\ 0.068 \sin J3 + 0.590 \sin J4$	
				$+\ 0.010 \sin J6$	
		$\delta_0 =$	$64.83 + 0.003\,T$	$-\ 0.029 \cos J3 + 0.254 \cos J4$	
				$-\ 0.004 \cos J6$	
		$W =$	$259.90 + 21.5710715\,d$	$+\ 0.061 \sin J3 - 0.533 \sin J4$	(c)
				$-\ 0.009 \sin J6$	

where $J1 = 283\overset{\circ}{.}90 + 4850\overset{\circ}{.}7\,T$, $J2 = 355\overset{\circ}{.}80 + 1191\overset{\circ}{.}3\,T$, $J3 = 119\overset{\circ}{.}90 + 262\overset{\circ}{.}1\,T$,
$J4 = 229\overset{\circ}{.}80 + 64.3\,T$, $J5 = 352\overset{\circ}{.}25 + 2382.6\,T$, $J6 = 113\overset{\circ}{.}35 + 6070.0\,T$

Saturn:	Mimas	$\alpha_0 =$	$40\overset{\circ}{.}66 - 0\overset{\circ}{.}036\,T$	$+\ 13\overset{\circ}{.}56 \sin S1$	
		$\delta_0 =$	$83.52 - 0.004\,T$	$-\ 1.53 \cos S1$	
		$W =$	$340.81 + 381.9945550\,d$	$-\ 13.48 \sin S1 - 44.85 \sin S6$	(d)
	Enceladus	$\alpha_0 =$	$40.66 - 0.036\,T$		
		$\delta_0 =$	$83.52 - 0.004\,T$		
		$W =$	$1.18 + 262.7318996\,d$		(e)
	Tethys	$\alpha_0 =$	$40.66 - 0.036\,T$	$+\ 9.66 \sin S2$	
		$\delta_0 =$	$83.52 - 0.004\,T$	$-\ 1.09 \cos S2$	
		$W =$	$10.77 + 190.6979085\,d$	$-\ 9.60 \sin S2 + 2.23 \sin S6$	(f)
	Dione	$\alpha_0 =$	$40.66 - 0.036\,T$		
		$\delta_0 =$	$83.52 - 0.004\,T$		
		$W =$	$356.68 + 131.5349316\,d$		(g)
	Rhea	$\alpha_0 =$	$40.38 - 0.036\,T$	$+\ 3.10 \sin S3$	
		$\delta_0 =$	$83.55 - 0.004\,T$	$-\ 0.35 \cos S3$	
		$W =$	$232.47 + 79.6900478\,d$	$-\ 3.08 \sin S3$	(h)
	Titan	$\alpha_0 =$	$36.41 - 0.036\,T$	$+\ 2.66 \sin S4$	
		$\delta_0 =$	$83.94 - 0.004\,T$	$-\ 0.30 \cos S4$	
		$W =$	$189.64 + 22.5769768\,d$	$-\ 2.64 \sin S4$	
	Hyperion	$\alpha_0 =$	$35.52 - 0.036\,T$	$+\ 5.05 \sin S5 + 2.84 \sin S4$	
		$\delta_0 =$	$84.03 - 0.004\,T$	$-\ 0.57 \cos S5 - 0.32 \cos S4$	
		$W =$	$103.88 + 16.9199514\,d$	$-\ 5.02 \sin S5 - 2.82 \sin S4$	
				$+\ 9.39 \sin S7$	(i)

Table IV (continued)

	Iapetus	$\alpha_0 =$	$288^{\circ}.57$
		$\delta_0 =$	78.82
		$W =$	$351.15 + 4^{\circ}.5379571\,d$ (j)
	where		$S1 = 177^{\circ}.40 - 36505^{\circ}.5\,T$, $S2 = 300^{\circ}.00 - 7225^{\circ}.9\,T$, $S3 = 345^{\circ}.20 - 1016^{\circ}.3\,T$, $S4 = 29^{\circ}.80 - 52.1\,T$, $S5 = 261^{\circ}.45 - 239.2\,T$, $S6 = 316^{\circ}.45 + 506.2\,T$, $S7 = 100.10 + 20528.5\,T$
Uranus:	Miranda	$\alpha_0 =$	$257^{\circ}.43$
		$\delta_0 =$	-15.10
		$W =$	$243.81 - 254^{\circ}.5968883\,d$
	Ariel	$\alpha_0 =$	257.43
		$\delta_0 =$	-15.10
		$W =$	$72.35 - 142.8356047\,d$
	Umbriel	$\alpha_0 =$	257.43
		$\delta_0 =$	-15.10
		$W =$	$224.97 - 86.8688136\,d$
	Titania	$\alpha_0 =$	257.43
		$\delta_0 =$	-15.10
		$W =$	$303.03 - 41.3513623\,d$
	Oberon	$\alpha_0 =$	257.43
		$\delta_0 =$	-15.10
		$W =$	$194.50 - 26.7394375\,d$
Neptune:	Triton	$\alpha_0 =$	$295.34 - 20.12 \sin N$
		$\delta_0 =$	$37.05 + 15.26 \cos N$
		$W =$	$297.25 - 61.2575147\,d + 10^{\circ}.56 \sin N$
	where		$N = 189^{\circ}.66 + 62^{\circ}.0\,T$
Pluto:	Charon	$\alpha_0 =$	311.63
		$\delta_0 =$	4.18
		$W =$	$25.66 - 56.3640000\,d$

Note: (a) The 182° meridian is defined by the crater Cilix.
(b) The 128° meridian is defined by the crater Anat.
(c) The 326° meridian is defined by the crater Saga.
(d) The 162° meridian is defined by the crater Palomides.
(e) The 5° meridian is defined by the crater Salih.
(f) The 299° meridian is defined by the crater Arete.
(g) The 63° meridian is defined by the crater Palinurus.
(h) The 340° meridian is defined by the crater Tore.
(i) The 196° meridian is defined by the crater Bahloo.
(j) The 276° meridian is defined by the crater Almeric.

given for the planets and satellites in Tables I and II for the standard equatorial coordinates with equinox B1950 at epoch J1950 and for the planets and satellites in Tables III and IV for the standard equatorial coordinates with equinox J2000 at epoch J2000. In general these expressions should be accurate to one-tenth of a degree; however, two decimal places are given to assure consistency when changing coordinate systems. Zeros are added to rate values ($\dot{W}$) for computational consistency and are not an indication of significant accuracy. Three decimal places are given in the expressions for the Moon and Mars, reflecting the greater confidence in their accuracy. Expressions for the Sun and Earth are given to a similar precision as those of the other bodies of the solar system for comparative purposes only.

3. Definition of Cartographic Coordinate Systems

Both planetocentric and planetographic systems of coordinates are used in the study of the planets and satellites. Both systems are based on the same fundamental reference axis but differ, as explained below, in the definitions of latitude and longitude. Planetocentric coordinates are used for general purposes and are based on a right-handed system of axes, whereas planetographic coordinates are used for cartographic purposes and depend on the adoption of additional parameters to define a reference surface, usually a spheroid, that approximates an equipotential surface of the planet.

For both systems, the fundamental reference z-axis is the mean axis of rotation and the planetary equator is the plane that is normal to this axis and passes through the center of mass of the planet. The x-axis is defined by the intersection of the equatorial plane with the plane of the prime meridian, whose position is defined in an arbitrary manner. The y-axis of planetocentric rectangular coordinates is defined so as to form a right-handed system.

Latitude is measured north and south of the equator; north latitudes are designated as positive. The planeto*centric* latitude (ϕ) of a point is the angle between the equatorial plane and the line connecting the point to the center of mass. The planeto*graphic* latitude (ϕ') of a point on the reference surface is the angle between the equatorial plane and the normal to the reference surface at the point.

Longitude is measured around the equatorial plane from the prime meridian from from $0°$ to $360°$. Planeto*centric* longitudes (λ) are measured positively to the east, whereas planeto*graphic* longitudes (λ') are measured in the direction opposite to the rotation, i.e., positively to the west in the case of direct rotation. Planetocentric longitudes are measured from the ephemeris position of the prime meridian as defined by the rotational elements, whereas planetographic longitudes are measured from the cartographic position of the prime meridian as defined by the adopted longitude of some clearly observable surface feature. These two positions may normally be assumed to coincide, but it is conceivable that errors in the rotational elements may cause the cartographic position to drift away from the ephemeris position by a small amount ΔW, where ΔW is measured positively to the east of the ephemeris position.

Planetocentric *radius* (R) is measured from the center of mass to the point concerned. In the planetographic system the position of a point (P) not on the reference surface is specified by the planetographic longitude and latitude of the point (P') on the reference surface at which the normal passes through P and by the *height* (h) of P above P'.

The reference surfaces for most of the planets are spheroids for which the radius of the equator (A) is larger than the polar semiaxis (C). For some planets and most satellites the reference surface is a sphere ($A = C$), and the planetocentric and planetographic latitudes are then numerically the same. The polar axis of each reference surface is assumed to be the mean axis of rotation as defined by the adopted rotational

TABLE V
Recommended reference spheroids for mapping the planets and major satellites (1982)

Planet	Satellite	Equatorial radius (km)	Flattening
Mercury		2 439	0
Venus		6 051	0
Earth		6 378.140	0.003 352 81
	Moon	1 738	0
Mars		3 393.4	0.005 186 5
Jupiter		71 398	0.064 808 8
	Io	1 815	0
	Europa	1 569	0
	Ganymede	2 631	0
	Callisto	2 400	0
Saturn		60 000	0.107 620 9
	Mimas	198	0.019
	Enceladus	253	0.020
	Tethys	525	0
	Dione	560	0
	Rhea	765	0
	Titan	2 575	0
	Iapetus	725	0
	Phoebe	110	0
Uranus		25 400	0.030
	Ariel	400	0
	Umbriel	275	0
	Titania	500	0
	Oberon	450	0
	Miranda	150	0
Neptune		24 300	0.025 9
	Triton	1 600	0
Pluto		1 500	0
	Charon	600	0

Note: The equatorial radii for Mercury, Venus, Moon, Mars, Io, Europa, Ganymede, Callisto, Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus are used in current mapping programs, and those for Jupiter and Saturn are used in sequencing and analyzing data from current flight missions. The values for Mars and Pluto differ from those recommended by the IAU in 1976 (*Trans. IAU* **16B,** p. 60). The reference spheroid for Mars (3393.4 km radius) has been used in all mapping programs since 1973, although the IAU 1976 radius (3397.2 km) is probably a better value. In 1976 Pluto's satellite, Charon, had not been discovered.

TABLE VI
Recommended reference shapes for mapping irregular satellites (1982)

Planet	Satellite	Equatorial radius, A (km)	Equatorial radius, B (km)	Polar radius, C (km)
Mars	Phobos	13.5	10.7	9.6
	Deimos	7.5	6.0	5.5
Jupiter	Amalthea	140	105	80
Saturn	Hyperion	200	125	110
	Janus	110	95	80
	Epimetheus	70	57	50

elements since the accuracy of measurement cannot, at present, observe a motion of the axis of rotation with respect to the axis of figure.

The recommended values of the parameters for the reference surfaces for planets and satellites are given in Table V. Radii for irregular-shaped satellites are given in Table VI.

It should be noted that east longitude on the Sun, Earth, and Moon is commonly considered to be in the positive direction and that longitudes are usually measured 0° to 180° east and west.

Appendix

The principal changes to the tables since 1979 concern Saturn and its satellites and result from the large influx of new data acquired by the Voyager spacecraft as they flew by the planet. The rotation period of Saturn's magnetic field (system III) was measured by Desch and Kaiser (1981) and a longitude system was proposed. Their longitude definition was adopted; however, the sidereal rotation period was modified to $10^h39^m22.4^s$ by letter (Kaiser, 1982). The longitude systems I and II of Jupiter were moved to a footnote as most atmospheric studies of the circulation of Jupiter and Saturn use the system III rotation.

A small change was made in the direction of the axis of rotation of the Sun based on the work of Stark and Wöhl (1981). The equations for Pluto and Charon were updated by Harrington and Christy. New expressions for Phobos and Deimos were derived by Duxbury and Callahan (1981).

Craters on Europa, Ganymede, and Callisto have been chosen for the definition of the longitude system (Davies and Katayama, 1981). Craters have also been identified for this purpose on Mimas, Enceladus, Tethys, Dione, Rhea, Hyperion, and Iapetus, and the expressions given in the tables are those currently in use by Davies and Katayama (for example, see Davies and Katayama, 1982). The radii for the Galilean satellites come from Davies and Katayama (1981), those of Mimas and Enceladus from Davies and Katayama (1982), and those of Hyperion, Janus, and Epimetheus from Thomas *et al.* (1982).

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