4. EPHEMERIDES (ÉPHÉMÉRIDES)

PRESIDENT: A M Sinzi.
VICE-PRESIDENT: T Lederle.
ORGANIZING COMMITTEE: V K Abalakin, S Aoki, R L Duncombe, J H Lieske, B L Morando, A Orte, P K Seidelmann, G A Wilkins, B D Yallop.

I. INTRODUCTION

Because of unforeseen difficulties, Dr Sinzi, President of the Commission, was not able to prepare this Report. It was then too late for asking the Directors of the almanac offices and the other Members of the Commission for informations. This Report is therefore based on the material just available, and it must be apologized for some lack from which it necessarily suffers. If possible, any omitted facts which appear to be serious, may be included in the Report for the following triennium.

II. INTERNATIONAL AND NATIONAL EPHEMERIDES

We are still in a period of development, and the problems to be resolved during the next few years may be characterized as follows:

(a) Basic Changes to be introduced by the new System of Constants, the improved fundamental catalogue, and the new theories on which the ephemerides are based. Difficulties will arise by the requirements of continuity and consistency and of best fitting the most recent observations. Compromises have to be searched in order to find optimal solutions.

(b) Modifications in the presentation which result from re-considering the real needs of the users of the almanacs. In view of their different aspects some variety between the almanacs should be quite desirable.

(c) Improvement of the content and rationalization in the production of the almanacs by making use of best computation facilities and modern printing techniques.

The general aspects of these developments are described in detail by P K Seidelmann in (25.047.022). Some particular informations are given in the following survey.

HM Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux, UK, and the Nautical Almanac Office, US Naval Observatory, Washington, USA, have continued to cooperate in the production and publication of three unified almanacs, namely the Astronomical Almanac (previously the Astronomical Ephemeris/American Ephemeris), the Nautical Almanac, and the Air Almanac, and of the Astronomical Phenomena. Data for other major almanacs and special purposes has been supplied on request. The almanacs for 1984 onwards will be based on new heliocentric ephemerides of the planets and of the Moon supplied by the US Naval Observatory; the geocentric ephemerides being prepared by HM Nautical Almanac Office will take into account the changes in the IAU system of astronomical constants adopted in 1976 and at subsequent meetings. The preparation of Planetary and Lunar Coordinates for 1984-2000 is in progress. The Almanac for Computers, published by the Nautical Almanac Office, Washington, annually since 1977, contains polynomial coefficients which provide the means for computing the positions of the Sun, Moon and planets to the accuracy desired for any time during the year. It also includes star coefficients in order to provide mean or apparent places of stars to the desired levels of accuracy and also a list of useful formulas for performing special computations (G A Wilkins / P K Seidelmann).

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During the period under review three issues of the Astronomical Almanac of the USSR for the years 1982, 1983, 1984 have been published by the Institute for Theoretical Astronomy, Leningrad, USSR, the fundamental ephemerides of the Sun, Moon, and major planets being computed on the classical theoretical basis. The ephemerides for physical observations of major planets for 1985 will be computed on the basis of the new values of the rotational elements and cartographic coordinates as it was recommended in the Report prepared by the IAU Joint Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites. The ephemeris of the lunar crater Mösting A, which is regularly published in the Astronomical Almanac of the USSR will be based from 1985 onwards on the new set of the Moon's physical libration parameters as given by K Koziel in 1964 and on the Moon's physical libration series defined by D H Eckhardt's theory in 1970 (V K Abalakin).

The Connaissance des Temps, which is published annually by the Bureau des Longitudes, Paris, France, uses developments of the coordinates into Chebychev polynomials. Bureau des Longitudes published also supplements to Connaissance des Temps for 1981 and 1982 giving the phenomena and configurations of the satellites of Jupiter and another supplement entitled "Ephemeris of the faint Satellites of Jupiter and Saturn for 1981, 1982, 1983" where the Chebychev polynomials developments of the coordinates of those bodies are given (B L Morando).

L'Instituto y Observatorio de Marina, San Fernando, Espagne, a commencé à faire une revision progressive dans le contenu des Efemérides Astronômicas. Cette revision est demarée avec le volume 1981 et doit être finie avec celui du 1984 dans lequel les Recommendations UAI de Grenoble sur les Constantes Astronomiques, Equinoxes, etc., seront appliqués. Etant donné le tirage limité de nos "Efemérides" et la varieté du public auquel elles sont destinées, on a decidé de ne pas faire des reformes radicales. On est arrivé à conserver la même disposition des differents tableaux, mais en éliminant certaines colonnes qu'on peut obtenir sans peine. Les coordonnées de la lune α, δ et π sont données journalièrement sous la forme de coefficients de Tchebychev. La Explicaciôn qui apparaît à la fin des "Efemérides" va être simultanément racourcie et les concepts seront revisés, bien dans la publication même, ou bien dans une brochure à part, comme supplement dans certaines années. On fait des efforts pour arriver à mecaniser le plus que possible le tirage des "Efemérides". Pour satisfaire certaines demandes on distribue aussi depuis 1979, une petite brochure à titre experimental nommé Almanaque Náutico Reducido pour les calculs du bord avec des petites calculatrices (A Orte).

The Chinese Astronomical Ephemeris is published by the Academia Sinica, Purple Mountain Observatory, Nanking, China, every year since 1955. On the proposal by surveyors, the apparent positions of stars are given for 0^h UT at intervals of 10 days (N-y Li).

During the time period of this survey the Indian Ephemeris, prepared by the Positional Astronomy Centre, Calcutta, India, has been published for the years 1980, 1981 and 1982 (A Bandyopadhyay).

The Japanese Ephemeris, the Nautical Almanac, the Abridged Nautical Almanac and the Polaris Almanac for Azimuth Determination have continued to be published by the Hydrographic Department of Japan, Tokyo, Japan. From the volume for 1980, the fundamental ephemerides of the Sun, the Moon and the planets in the Japanese Ephemeris are computed at the Department, being rigorously based on the respective basic data on which the Astronomical Ephemeris had been based. The Japanese Ephemeris for 1980 to 1982 contain predictions of the solar eclipses in 1981-1985, 1986-1990 and 1991-1995, respectively, as a supplement. This series will be concluded in the volume for 1983. Also, trigonometric series or basic values for approximate positions of the Sun, the Moon, the planets and some stars are supplemented to the Nautical Almanac and the Abridged Nautical Almanac since the volume for 1978, together with a series of formulae for obtaining the apparent places (S Aoki).

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In the preparation of the annual volumes of the Apparent Places of Fundamental Stars from 1981 onwards, the Astronomisches Rechen-Institut, Heidelberg, F. R. Germany, has transcribed the computed data on magnetic tape with all necessary printing instructions such that the volumes are now being printed automatically by a photo-composing method. Beginning with the volume for the year 1984, the computations will be based on the IAU (1976) System of Astronomical Constants and related IAU recommendations. It will not be possible to include already in the volume for 1984 the star positions on the basis of the FK5. As soon as the FK5 will be completed the A.P.F.S. will be based on the FK5, and corrections will be given for the star places published for 1984 and possibly also for 1985. The equinox correction, however, namely

$$\Delta\alpha = 0\overset{s}{.}0775 + 0\overset{s}{.}085\ T\ ,$$

where T is counted in Julian centuries from J2000.0, will be included in all right ascensions in the 1984 and following volumes. For the status of FK5, reference should be made to the Report of Commission 8 (W Fricke).

III. THEORY OF NUTATION

The XVIIth General Assembly of the IAU at Montreal in 1979 has adopted the "1979 IAU Theory of Nutation" (Trans. IAU XVIIB pp 80-83) upon recommendation of the IAU Working Group on Nutation. Subsequently the IUGG passed a resolution requesting that this action be reconsidered in favor of a theory based on a different Earth model. After wide discussions, also at the IAU Colloquium in September 1980, the Working Group proposed a revised nutation series, labeled "1980 IAU Theory of Nutation". By mail votes of the members of Commissions 4, 7, 8, 19, 24 and 31, the majority agreed that the theory adopted at Montreal should be replaced by the revised version. The complete "Final Report of the IAU Working Group on Nutation" will be printed in 'Celestial Mechanics'; it seems, however, useful to publish the Summary of it in the APPENDIX to this Commission Report.

IV. RELATIONSHIP BETWEEN UNIVERSAL AND SIDEREAL TIME

The IAU (1976) System of Astronomical Constants, adopted at the XVIth General Assembly of the IAU at Grenoble in 1976, contained a Recommendation {3(c)} saying that "the expression for Greenwich mean sidereal time at 0^h UT shall be amended ..... in order to avoid a discontinuity in UT" (Trans. IAU XVIB p 59). In 1979 at Montreal a Resolution was adopted by which the "relationship between mean sidereal time and UT1 be modified so that there is no change in either value or rate of UT1" (Trans. IAU XVIIB pp 41 and 66-67). That modification, however, was not sufficient to maintain the continuity of UT1 because it considered the equinox correction only. But one would have to take into account also the change of the precessional quantities (other, smaller effects can be compensated for by corrections to the longitudes of the instrument by which UT0 is being determined). In connection with the discussions for a revised expression to be proposed for adoption in 1982, two controversial points of view concerning definitorial questions became involved. Communications will be available in two papers: (a) S Aoki, B Guinot, G H Kaplan, H Kinoshita, D D McCarthy, P K Seidelmann: 'The New Definition of Universal Time' (A & A, in press); (b) S Aoki, H Kinoshita: 'Note on the Relation between the Equinox and Guinot's Non-rotating Origin' (Celestial Mechanics, in press).

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V. LUNAR, PLANETARY AND SATELLITE RESEARCH

Dr Seidelmann reports: "Planetary ephemerides using the IAU 1976 system of Astronomical Constants and the equator and equinox of the FK5 (J2000.0) have been developed by G H Kaplan, K F Pulkkinen, E J Santoro, T C Van Flandern and P K Seidelmann. This activity has been in cooperation with work being done by E M Standish and J G Williams at the Jet Propulsion Laboratory and C Oesterwinter at the Naval Surface Weapons Center, Dahlgren, Virginia. This effort along with the work of R S Harrington, has indicated the presence of systematic errors between the observations and the ephemerides of some of the outer planets. One of the hypotheses being investigated would be another planet beyond Pluto. L E Doggett has successfully developed a means of calculating planetary ephemerides by means of Chebychev polynomials to accuracy limited only by the computer precision.

"T C Van Flandern and M R Lukac have analyzed occultation timings covering the period 1820 to 1979 to determine the difference between dynamical and universal time. This history of the variation of the Earth rotation rate discloses an especially large change in 1896.

"Some investigators have suggested that the radius of the Sun may be changing significantly over a long period of time. This was based on a long series of transit records. As a result of this, A D Fiala entered into collaboration with S Sophia of NASA/GSFC and D W Dunham of Computer Science Corp. to study the use of solar eclipse observations to detect changes in the solar radius. This program requires the timings of eclipse phenomena near the edges of the central path.

"D Pascu has made photographic observations of the Galilean moons of Jupiter and Saturn satellites I-VIII with the 26-inch refractor. In March 1980, D Pascu and P K Seidelmann participated with W A Baum of Lowell Observatory and D Currie of the University of Maryland in an observing program on the 61-inch telescope at Flagstaff, Arizona; using the 500 x 500 pixel charge coupled device (CCD) ground camera of the Space Telescope Widefield/Planetary camera team. Observations were made of the Saturn system during the crossing of the Saturn ring plane by the Earth. This observing program resulted in the detection of the E ring of Saturn and a number of observations of satellite images. From 30 April to 8 May 1981 further CCD camera observations were made with the 61-inch telescope. During this period, an 800 x 800 pixel Texas Instrument CCD was installed in the camera. T C Van Flandern and K F Pulkkinen have analyzed the astrometric observations of Pluto to determine the orbital period of Charon and carried out similar analysis on observations of Neptune to determine the orbital period of Triton."

Dr Morando writes: "New theories for the motion of the planets and the Moon will be used in the Connaissance des Temps from 1984 onwards. The theories for the Sun and inferior planets which will replace the old ones, were made by P Bretagnon, the theory for Jupiter, Saturn, Uranus and Neptune by P Bretagnon and J L Simon. The theory of the motion of the Moon, which will replace the ILE, was made by M Chapront-Touzê and J Chapront; this theory is called ELP2000-82. When building up those theories, the authors have chosen to use, as often as possible, the IAU System of Astronomical Constants (IAU-76), namely: the masses of the planets, the geocentric constant of gravitation, the harmonics of the gravity field of the Earth. The theories have been adjusted to observations via numerical integrations of the NWL and JPL, mainly through DE102 for the planets and LE51 for the Moon."

From the report of Dr Abalakin: "M D Kislik et al. have constructed a numerical theory of Mars motion based on 2654 radar measurements and 4465 optical observations, the parameters being fitted over the interval of 1964-1971. This work has been extended further on on other inner planets being based on 3768 radar measurements (1962-1980) and on 7193 positional observations (1960-1976). The residuals do not exceed 6 km for Venus and 10 km for Mars. The similar theories for the inner planets' motions have been constructed by E L Akim et al. as well as by G A Krasinski et al.. M D Kislik has also investigated the relativistic effects influenc-

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ing the planetary orbits determinations when making use of radar measurements, the necessary corrections to radar observations being thoroughly studied. The numerical approach to the study of all major planets' motions has been chosen by V P Dolgachyov et al. on the time interval of 1950-2150, and the secular variations of the longitudes of perihelia of Mercury's and Mars' orbits as well as of the longitude of the ascending node of Venus' orbit have been determined. The same authors have determined the values of time derivatives of ϖ and Ω for the inner planets making use of numerical integration of the differential equations of planetary motions in the gravitation field of the ellipsoidal Sun, its flattening ε being equal to 5 parts in 10^4. The results are found to be in fairly good agreement with observations. V A Izvekov has continued and completed his work on refinement of orbital parameters of Venus by use of radar and optical observations. Yu V Barkin has studied periodic perturbations in the translational motion and in the rotation of the Moon and Mercury. He has also investigated the perturbations in the Moon's orbital motion arising from the third and higher harmonics of the force function expansion for the Moon. N I Kolosnitsyn and A V Osipova have studied the perturbations in the heliocentric radii-vectors of Venus and Mars as well as in the geocentric radius-vector of the Moon due to violation of the equivalence principle.

"A series of papers by V V Beletsky et al. was concerned with the problem of the resonances in the Venus' rotation. The value of the inclination of the Venus' equator to the plane of its orbit is found to be equal to 51' with the mean error of $\pm$17'. D Z Koenov has estimated the magnitude of periodic perturbations in the Earth's diurnal rotation due to the Moon's influence the period of these perturbations being found to be equal to 9000 ys. The shortening of the length of the day in 1979 was equal to 4 parts in 10^4 in seconds per day. Yu G Markov has applied the Poincaré's theory of periodic solutions to investigations of the Moon's rotation making use of osculating canonical Andoyer's elements. The resonant libration of the Moon arising from the 2-term has been investigated by A S Dubrovsky and K S Shakirov; they have also found the most probable value of the Moon's physical constant f. The parameter f has been also considered by Yu A Chikanov and K S Shakirov.

"The motion of distant satellites of a major planet has been studied by N B Batuyeva on the basis of the generalized Hill's problem. I G Chugunov has considered the perturbed motion of Saturn's satellites, the theoretical results being compared against observations. He has also studied the mutual perturbations of Saturn's satellites. A A Orlov and V M Chepurova have investigated solar short-periodic perturbations of the fourth order in the motions of satellites of major planets.

"D P Duma et al. have corrected the zero-points of the FK4 fundamental system on the basis of analysis of 2441 Mercury optical observations made in 1929-1971, 6957 Venus positional observations (1929-1971), 1834 Mars observations (1941-1971) as well as observations of Ceres, Pallas, Juno, and Vesta. The similar investigations have been made by V I Orelskaya who had used observations of the selected minor planets. The dependence of computed ephemerides positions of planets on errors in orientation of coordinate systems of star catalogues has been investigated and analyzed by D P Duma et al. By D D Polozhentsev have been determined the parameters of the Sun's space motion and of the Galaxy's rotation as well as the correction to the precession constant, the work being done on the basis of the analysis of the proper motions system in right ascension of the general star catalogue compiled for the southern sky hemisphere.

"Yu S Yatskiv has given a review of the recent version of the theory of the astronomical nutation in connection with the new IAU system of astronomical constants. The IAU system of astronomical constants (1976, 1979) has been also reviewed by V K Abalakin. New rotational parameters for major planets and their satellites as well as the parameters defining new systems of planetographic (or cartographic) coordinates which were recommended in 1979 by the IAU Joint Working Group have been considered by Yu S Tyuflin and V K Abalakin. V K Abalakin has outlined the intrinsic ties connecting the Ephemeris astronomy with celestial mechanics and Astrometry.

"The algorithms for representing the fundamental precise ephemerides data by means of Chebyshev's polynomials have been worked out by M A Fursenko, the corresponding FORTRAN IV procedures being also developed. The same problem for rectan-

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gular planets' coordinates has been approached by E Z Khotimskaya. V N L'vov and S V Serova have constructed the algorithm for computation of stars' apparent ephemerides in the rectangular coordinates based on the recommendations of the XVIIth IAU General Assembly concerned with the reduction techniques and the IAU system of astronomical constants, the accuracy of $\pm 0''.001$ being secured. V N L'vov has compiled also a package of routines designed for ephemerides computation for radio astronomical observations of quasars and radio emitting objects within the Solar systems.

"M L Sveshnikov has compared the Sun's positional observations made in 1911-1970 at the USNO, Washington, with Newcomb's theory. Further developments of numerical integration methods with regularization based on Taylor type expansions (the Taylor-Steffensen methods) have been continued by V F Myachin and O A Sizova. V A Brumberg et al. have treated the problem dealing with comparison of a theory with observations and accounting for the relativity effects. V A Izvekov has investigated the ephemerides computation process for the case where the ill-conditioned systems of normal equations must be solved."

Dr Aoki writes: "A second-order theory of the motion of Mars has been constructed at the Tokyo Astronomical Observatory and is found to be slightly better than the theory by G M Clemence. A third-order theory is necessary for achievement of $''.01$ accuracy. Planetary ephemerides, VSOP80, have been compared with numerical integration over 35 years at the Tokyo Astronomical Observatory. They achieve $''.01$ accuracy (RMS residuals) for inner planets and $''.1$ accuracy for outer planets. Lunar ephemerides, ELP2000 and SALE2000, have been compared with numerical integration. As for as the main problem is concerned, ELP2000 has 1.2 cm accuracy (RMS residuals) over one year in the distance (H Kinoshita).

"H Niimi found the set of orbital elements of Mars in Clemence's theory without empirical secular term and the equator and equinox corrections to FK4 system from meridian observations, covering the period from 1935 to 1976; the equator and equinox corrections are $-0''.08$ and $+0^{s}.042$, respectively. He found that there still remain systematic trends in the residuals, even after an improvement of orbital elements. The systematic trends seem to be due to the unaccounted phase effect."

Report on ephemeris efforts at the Jet Propulsion Laboratory (Dr Lieske): "During the past three years efforts have continued at JPL to produce highly accurate planetary, lunar, and satellite ephemerides for use in the NASA space program and for international investigations which require high accuracy. Investigations and cooperative efforts with other scientists have been undertaken to more clearly understand the similarities and differences between JPL ephemerides and the classical ephemerides of Newcomb, as well as for obtaining a greater understanding of the underlying astronomical constants. Cooperative investigations have been made with Bretagnon and Chapront at the Bureau des Longitudes, with Stumpff in Bonn, with Schubart and Fricke in Heidelberg, and with the USNO, Washington. Efforts have also continued for the development and production of highly accurate satellite ephemerides for the Voyager and Galileo NASA missions. Several thousand 17th and 18th century eclipse observations of the Galilean satellites have been discovered which should lead to a better understanding of the variations in ΔT, as well as possible evolution of the Laplacian commensurability for the Galilean satellites. The planetary and lunar ephemeris recommended for the MERIT campaign is Development Ephemeris Number DE200/LE200. It has been produced at the Jet Propulsion Laboratory in collaboration with members of the United States Naval Observatory. It will form the basis of the Astronomical Almanac starting in 1984 and most likely will be adopted by other national almanac offices as well. The ephemerides provide, by themselves, a dynamically consistent system whose reference frame has been accurately adjusted to the dynamical equinox of J2000.0. Furthermore, the relative positions and velocities of the four inner planets and moon are well-determined and their mean motions are accurately represented with respect to inertial space.

"With such an accurately determined system (positions, velocities, inertial mean motions, masses, and true obliquity), it has been possible to locate the actual dynamical equinox of DE200/LE200 at the origin of the reference system. This was done through a detailed analysis of the Earth-Moon barycenter's orbital motion and a subsequent adjustment of the coordinate axis. An independent determination by Bretagnon and Chapront indicates that this procedure is accurate to at least 0".001.

"One may note that the reference frame of the ephemerides will not strictly coincide with the origin of the FK5 catalog system. The difference will be the amount by which the origin of the FK5 itself fails to coincide with the dynamical equinox of J2000.0. However, the ephemeris-FK5 difference should actually be much smaller than it would be if an attempt were made to align the ephemeris system directly to the FK5 through the use of optical planetary observations. As such, the above procedure for orienting the planetary ephemeris to the dynamical equinox of J2000.0 is strongly justified. In actuality, the adjustment angle used in DE200/LE200 of 0".53087 is surprisingly close to that of 0".525 which will be used by Fricke for the FK5."

VI. MISCELLANEOUS

(a) Lunar occultations. The Hydrographic Department of Japan took over the services of the International Lunar Occultation Centre (ILOC) from the Nautical Almanac Office of the Royal Greenwich Observatory on 1981 January 1, in accordance with the resolution of Commission 4 at the IAU XVIIth General Assembly held in Montreal. Since then, timing data of lunar occultations are collected and some predictions are provided by the new ILOC. The reduction system is also being developed at the Centre. HM Nautical Almanac Office, Herstmonceux, continues to provide predictions of occultations by minor planets and satellites.

(b) Astronomical Constants. At its XVIIth General Assembly at Canberra in December 1979 the IUGG has adopted a new "Geodetic Reference System 1980" (Bull. Géod. 54, p 370). Note that the numerical value for the equatorial radius of the Earth is there 6 378 137 m (compared with 6 378 140 m in the IAU (1976) System of Constants).

T. LEDERLE
Vice-President of the Commission

APPENDIX

SUMMARY OF 1980 IAU THEORY OF NUTATION

(Final Report of the IAU Working Group on Nutation)

1. The President of IAU Commission 4, Dr. V K Abalakin, established the Working Group on Nutation at the request of IAU Symposium No. 78 on Nutation and the Earth's Rotation, held at Kiev in May 1977. The final membership of the Working Group comprise the authors of this report.

2. The theory of nutation currently in use is due to E W Woolard (Astr. Papers Amer. Ephemeris XV, Pt. I, 1953) and has the following characteristics:
   - (a) It is based on a rigid model of the Earth with dynamical axisymmetry (A=B).
   - (b) The "constant of nutation" is an empirical value and is not consistent with other adopted astronomical constants.
   - (c) Eulerian motion and forced nearly-diurnal polar motion are not included in the current theory of nutation, but are assumed to be part of polar motion.
   - (d) The pole of reference is the instantaneous celestial rotation pole.

3. Modern theoretical and observational developments of various types have revealed the following problems with the current theory of nutation:
   - (a) The Earth is not a rigid body and the effects of non-rigidity can be observationally significant.
   - (b) Determinations of UT1 and polar motion using optical observations of stars, Doppler and laser range tracking of satellites, laser ranges to the Moon, and radio interferometric measurements are sufficiently accurate that their usefulness can be degraded by use of the present theory of nutation in the data reduction process.
   - (c) As Jeffreys and Atkinson pointed out, the instantaneous axis of rotation as defined by Woolard rotates relative to an Earth-fixed coordinate system with a quasi-diurnal period. For accurate observation reduction, this rotation cannot be ignored and a resolution was passed at the Sixteenth General Assembly of the IAU in 1976 in Grenoble to adopt a different pole of reference.
   - (d) Observational data indicate that with the current (Woolard) theory of nutation and a redefined pole of reference, a body-fixed coordinate system would still rotate with respect to the reference pole; therefore, the theory of nutation should be revised.

In proposing a theory of nutation to the Montreal IAU General Assembly in 1979, the Working Group sought to present a numerical expression that represented nutation with an accuracy better than existing astronomical observations. Two series were considered; both based upon Kinoshita's rigid-body calculations but differing slightly in how the effects of the Earth's deformability were accommodated. The first series was prepared by Kinoshita and co-workers and used the well-known results given by Molodensky in 1961. The other series, due to Wahr, had become available to the Working Group only a few months before the IAU meeting; it had not yet been published and, hence was not widely known. Furthermore, it was clear that for any known astronomical application, the differences between the series were not currently detectable. Thus, both series satisfied the Working Group's requirements for a theory of nutation for astronomical observations.

4. In August 1979, the General Assembly of the IAU at the recommendation of the Working Group adopted the 1979 IAU Theory of Nutation, which was based on the

rigid-body theory of Kinoshita and the deformable theory for Earth model No. 2 by Molodensky. At that time it was emphasized that this action was the adoption of a set of nutation coefficients and not the endorsement of a particular Earth model.

In December 1979 the International Union of Geodesy and Geophysics (IUGG) adopted a resolution requesting that the IAU reconsider its choice of a nutation series. The IUGG objection to the IAU resolution was not based on a criticism of the numerical values of the coefficients of the nutation theory, but rather on their interpretation that the IAU had implicitly endorsed the Molodensky Earth model 2, which was no longer judged adequate on geophysical grounds. Wahr's results, on the other hand, were obtained using a representative model available in 1979.

The IAU has avoided this misunderstanding by accepting the IUGG suggestion. The IUGG believes that the model on which Wahr's computations are based (the model 1066A of Gilbert and Dziewonski) is the best Earth model presently available and that observed geophysical constraints are such that any modern Earth model would have to be very similar. This implies that the observational residuals that result from the use of the Wahr nutation series will be more meaningful, geophysically.

On the other hand, since the IUGG objections were predicated on the question of the choice of Earth model, changing to the Wahr series implies at least an indirect endorsement by the IAU of the IUGG's preferred Earth model. This is not necessarily bad, especially in view of the belief that future models will not differ appreciably so far as nutation is concerned, but it must be clear that the nutation series will not be changed in the near future in response to shifts in the Earth model preferred by the IUGG.

After considerable correspondence and a discussion at IAU Colloquium 56 in September 1980 in Warsaw, Poland, the process of changing to the 1980 IAU Theory of Nutation was initiated. Clearly the situation has changed since the General Assembly in Montreal and it is advisable to make any adjustments before the 1979 theory has been introduced into wide spread use. Therefore, with the approval of the General Secretary the IAU Commissions involved voted by mail to adopt the 1980 Theory of Nutation.

5. The goal of this report is the adoption of a set of nutation coefficients which will provide an adequate working standard for determination of UT1 and polar motion, the reduction of optical observations of stars, Doppler or laser range tracking of satellites, laser ranges to the Moon, radio interferometric measurements and other high precision requirements.

6. Therefore, the proposed solution incorporates the following changes:
   - (a) A non-rigid model of the Earth without axial symmetry is used. This model of the Earth is subject to tidal distortions, has a solid inner core, fluid outer core, but no oceans.
   - (b) The constants are consistent with the 1976 IAU System of Astronomical Constants and are in agreement with available observational data of various types.
   - (c) The reference pole is selected so that there are no diurnal or quasi-diurnal motions of this pole with respect to either a space-fixed or Earth-fixed coordinate system. The phenomenon of dynamical variation of latitude, otherwise known as forced diurnal polar motion, is included implicitly in the new nutation theory. The new nutation theory thus includes externally-forced motions of the Earth's rotation axis, but does not include free motions or such complex phenomena as ocean tides, atmospheric winds, and currents in the oceans or core. The new reference pole shall be referred to as the "Celestial Ephemeris Pole" (CEP).

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7. The new nutation theory, incorporating the above changes, is given in Table I and shall be referred to as the "1980 IAU Theory of Nutation". This nutation theory was developed by Wahr (29.081.005) based on previous work by H Kinoshita (20.042.046) and F Gilbert and A M Dziewonski (Phil. Trans. R. Soc. London A 278, 187, 1975). The fundamental arguments for the nutation theory are given in Table II.

P K Seidelmann, Chairman

V K Abalakin, C A Murray, J G Williams

H Kinoshita, M L Smith, Ya S Yatskiv

J Kovalevsky, R O Vicente

TABLE I

Nutation in Longitude and Obliquity
referred to mean ecliptic of date

Epoch J2000.0 (JD 2451545.0 TDB)
T in Julian Centuries

	Argument					Period	Longitude		Obliquity	
	l	*l'*	*F*	*D*	Ω	(days)	(″0001)		(″0001)	
1	0	0	0	0	1	6798.4	-171996	-174.2T	92025	8.9T
2	0	0	0	0	2	3399.2	2062	.2T	-895	.5T
3	-2	0	2	0	1	1305.5	46	0.0T	-24	0.0T
4	2	0	-2	0	0	1095.2	11	0.0T	0	0.0T
5	-2	0	2	0	2	1615.7	-3	0.0T	1	0.0T
6	1	-1	0	-1	0	3232.9	-3	0.0T	0	0.0T
7	0	-2	2	-2	1	6786.3	-2	0.0T	1	0.0T
8	2	0	-2	0	1	943.2	1	0.0T	0	0.0T
9	0	0	2	-2	2	182.6	-13187	-1.6T	5736	-3.1T
10	0	1	0	0	0	365.3	1426	-3.4T	54	-.1T
11	0	1	2	-2	2	121.7	-517	1.2T	224	-.6T
12	0	-1	2	-2	2	365.2	217	-.5T	-95	.3T
13	0	0	2	-2	1	177.8	129	.1T	-70	0.0T
14	2	0	0	-2	0	205.9	48	0.0T	1	0.0T
15	0	0	2	-2	0	173.3	-22	0.0T	0	0.0T
16	0	2	0	0	0	182.6	17	-.1T	0	0.0T
17	0	1	0	0	1	386.0	-15	0.0T	9	0.0T
18	0	2	2	-2	2	91.3	-16	.1T	7	0.0T
19	0	-1	0	0	1	346.6	-12	0.0T	6	0.0T
20	-2	0	0	2	1	199.8	-6	0.0T	3	0.0T
21	0	-1	2	-2	1	346.6	-5	0.0T	3	0.0T
22	2	0	0	-2	1	212.3	4	0.0T	-2	0.0T
23	0	1	2	-2	1	119.6	4	0.0T	-2	0.0T
24	1	0	0	-1	0	411.8	-4	0.0T	0	0.0T
25	2	1	0	-2	0	131.7	1	0.0T	0	0.0T

TABLE I (continued)

Nutation in Longitude and Obliquity
referred to mean ecliptic of date

Epoch J2000.0 (JD 2451545.0 TDB)
T in Julian Centuries

	Argument *l*	*l'*	*F*	*D*	Ω	Period (days)	Longitude (″0001)		Obliquity (″0001)	
26	0	0	-2	2	1	169.0	1	0.0T	0	0.0T
27	0	1	-2	2	0	329.8	-1	0.0T	0	0.0T
28	0	1	0	0	2	409.2	1	0.0T	0	0.0T
29	-1	0	0	1	1	388.3	1	0.0T	0	0.0T
30	0	1	2	-2	0	117.5	-1	0.0T	0	0.0T
31	0	0	2	0	2	13.7	-2274	-.2T	977	-.5T
32	1	0	0	0	0	27.6	712	.1T	-7	0.0T
33	0	0	2	0	1	13.6	-386	-.4T	200	0.0T
34	1	0	2	0	2	9.1	-301	0.0T	129	-.1T
35	1	0	0	-2	0	31.8	-158	0.0T	-1	0.0T
36	-1	0	2	0	2	27.1	123	0.0T	-53	0.0T
37	0	0	0	2	0	14.8	63	0.0T	-2	0.0T
38	1	0	0	0	1	27.7	63	.1T	-33	0.0T
39	-1	0	0	0	1	27.4	-58	-.1T	32	0.0T
40	-1	0	2	2	2	9.6	-59	0.0T	26	0.0T
41	1	0	2	0	1	9.1	-51	0.0T	27	0.0T
42	0	0	2	2	2	7.1	-38	0.0T	16	0.0T
43	2	0	0	0	0	13.8	29	0.0T	-1	0.0T
44	1	0	2	-2	2	23.9	29	0.0T	-12	0.0T
45	2	0	2	0	2	6.9	-31	0.0T	13	0.0T
46	0	0	2	0	0	13.6	26	0.0T	-1	0.0T
47	-1	0	2	0	1	27.0	21	0.0T	-10	0.0T
48	-1	0	0	2	1	32.0	16	0.0T	-8	0.0T
49	1	0	0	-2	1	31.7	-13	0.0T	7	0.0T
50	-1	0	2	2	1	9.5	-10	0.0T	5	0.0T
51	1	1	0	-2	0	34.8	-7	0.0T	0	0.0T
52	0	1	2	0	2	13.2	7	0.0T	-3	0.0T
53	0	-1	2	0	2	14.2	-7	0.0T	3	0.0T
54	1	0	2	2	2	5.6	-8	0.0T	3	0.0T
55	1	0	0	2	0	9.6	6	0.0T	0	0.0T
56	2	0	2	-2	2	12.8	6	0.0T	-3	0.0T
57	0	0	0	2	1	14.8	-6	0.0T	3	0.0T
58	0	0	2	2	1	7.1	-7	0.0T	3	0.0T
59	1	0	2	-2	1	23.9	6	0.0T	-3	0.0T
60	0	0	0	-2	1	14.7	-5	0.0T	3	0.0T
61	1	-1	0	0	0	29.8	5	0.0T	0	0.0T
62	2	0	2	0	1	6.9	-5	0.0T	3	0.0T
63	0	1	0	-2	0	15.4	-4	0.0T	0	0.0T
64	1	0	-2	0	0	26.9	4	0.0T	0	0.0T
65	0	0	0	1	0	29.5	-4	0.0T	0	0.0T
66	1	1	0	0	0	25.6	-3	0.0T	0	0.0T
67	1	0	2	0	0	9.1	3	0.0T	0	0.0T

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TABLE I (continued)

Nutation in Longitude and Obliquity
referred to mean ecliptic of date

Epoch J2000.0 (JD 2451545.0 TDB)
T in Julian Centuries

	Argument					Period	Longitude		Obliquity	
	l	*l'*	*F*	*D*	Ω	(days)	(″0001)		(″0001)	
68	1	-1	2	0	2	9.4	-3	0.0T	1	0.0T
69	-1	-1	2	2	2	9.8	-3	0.0T	1	0.0T
70	-2	0	0	0	1	13.7	-2	0.0T	1	0.0T
71	3	0	2	0	2	5.5	-3	0.0T	1	0.0T
72	0	-1	2	2	2	7.2	-3	0.0T	1	0.0T
73	1	1	2	0	2	8.9	2	0.0T	-1	0.0T
74	-1	0	2	-2	1	32.6	-2	0.0T	1	0.0T
75	2	0	0	0	1	13.8	2	0.0T	-1	0.0T
76	1	0	0	0	2	27.8	-2	0.0T	1	0.0T
77	3	0	0	0	0	9.2	2	0.0T	0	0.0T
78	0	0	2	1	2	9.3	2	0.0T	-1	0.0T
79	-1	0	0	0	2	27.3	1	0.0T	-1	0.0T
80	1	0	0	-4	0	10.1	-1	0.0T	0	0.0T
81	-2	0	2	2	2	14.6	1	0.0T	-1	0.0T
82	-1	0	2	4	2	5.8	-2	0.0T	1	0.0T
83	2	0	0	-4	0	15.9	-1	0.0T	0	0.0T
84	1	1	2	-2	2	22.5	1	0.0T	-1	0.0T
85	1	0	2	2	1	5.6	-1	0.0T	1	0.0T
86	-2	0	2	4	2	7.3	-1	0.0T	1	0.0T
87	-1	0	4	0	2	9.1	1	0.0T	0	0.0T
88	1	-1	0	-2	0	29.3	1	0.0T	0	0.0T
89	2	0	2	-2	1	12.8	1	0.0T	-1	0.0T
90	2	0	2	2	2	4.7	-1	0.0T	0	0.0T
91	1	0	0	2	1	9.6	-1	0.0T	0	0.0T
92	0	0	4	-2	2	12.7	1	0.0T	0	0.0T
93	3	0	2	-2	2	8.7	1	0.0T	0	0.0T
94	1	0	2	-2	0	23.8	-1	0.0T	0	0.0T
95	0	1	2	0	1	13.1	1	0.0T	0	0.0T
96	-1	-1	0	2	1	35.0	1	0.0T	0	0.0T
97	0	0	-2	0	1	13.6	-1	0.0T	0	0.0T
98	0	0	2	-1	2	25.4	-1	0.0T	0	0.0T
99	0	1	0	2	0	14.2	-1	0.0T	0	0.0T
100	1	0	-2	-2	0	9.5	-1	0.0T	0	0.0T
101	0	-1	2	0	1	14.2	-1	0.0T	0	0.0T
102	1	1	0	-2	1	34.7	-1	0.0T	0	0.0T
103	1	0	-2	2	0	32.8	-1	0.0T	0	0.0T
104	2	0	0	2	0	7.1	1	0.0T	0	0.0T
105	0	0	2	4	2	4.8	-1	0.0T	0	0.0T
106	0	1	0	1	0	27.3	1	0.0T	0	0.0T

$\varepsilon_{J2000} = 23°26'21''.448$

$\sin \varepsilon_{J2000} = .39777716$

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TABLE II

Fundamental Arguments

The fundamental arguments in the FK5 reference system are (Van Flandern, Astr J, 1981, in press):

$$l = 134°57'46''.733 + (1325^r + 198°52'02''.633)T + 31''.310T^2 + 0''.064T^3$$

$$l' = 357°31'39''.804 + (99^r + 359°03'01''.224)T - 0''.577T^2 - 0''.012T^3$$

$$F = 93°16'18''.877 + (1342^r + 82°01'03''.137)T - 13''.257T^2 + 0''.011T^3$$

$$D = 297°51'01''.307 + (1236^r + 307°06'41''.328)T - 6''.891T^2 + 0''.019T^3$$

$$\Omega = 125°02'40''.280 - (5^r + 134°08'10''.539)T + 7''.455T^2 + 0''.008T^3$$

where the fundamental epoch is J2000.0 = 2000 January $1^d.5$ TDB = JD 2451545.0 TDB, and

$1^r = 360° = 1296000''.0$,

T is measured in Julian centuries of 36525 days of 86400 seconds of dynamical time each,

l = mean longitude of the Moon minus the mean longitude of the Moon's perigee,

l' = mean longitude of the Sun minus the mean longitude of the Sun's perigee,

F = mean longitude of the Moon minus the mean longitude of the Moon's node,

D = mean elongation of the Moon from the Sun,

Ω = longitude of the mean ascending node of the lunar orbit on the ecliptic, measured from the mean equinox of date.

Note that the fundamental arguments are the best values currently available for the FK5 reference system and the 1976 IAU constants. These values may change slightly based on an improved lunar ephemeris, but the changes will not significantly affect the nutation theory. It is possible that the different expressions should be used for work which depends in a very critical way on the precise solar or lunar theories; however, nutation theory is not in this class of work. Therefore the above expressions, while provisional, are of sufficient accuracy for the evaluation of the nutation theory to 0''.0001.

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