31. COMMISSION DE L'HEURE

PRÉSIDENT: Sir Harold Spencer Jones, Astronomer Royal, Royal Greenwich Observatory, Herstmonceux, Sussex, England.

DIRECTEUR DU BUREAU: M. Danjon.

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During the period since the Eighth General Assembly of the Union there have been further improvements in the precision of time determinations at many observatories, while the wider use of quartz crystal clocks has resulted in a higher accuracy in time keeping and in the more accurate prediction of clock errors in connexion with the emission of time signals. Several observatories are in process of installing, or have plans to install, quartz crystal clocks, photographic zenith tubes or impersonal prismatic astrolabes for determining and maintaining time with greater accuracy. In connexion with the forthcoming International Geophysical Year (July 1957–December 1958, inclusive), a world-wide programme of determinations of longitude and latitude is being planned by the Special Committee for the International Geophysical Year (C.S.A.G.I.); it is most desirable that observatories should endeavour to complete these improvements or additions to their equipment before the commencement of this extensive programme of observations.

INSTRUMENTS

Small transit instruments, provided with impersonal travelling-wire micrometer, and reversible during the observation of each star-transit so as to eliminate collimation error, continue to be the standard instruments for time determination at most observatories. The standard error of a single time determination (10 to 12 stars) ranges from about 10 to 25 msec., the higher accuracy being generally attained when the travelling wire is motor driven.

The personal equations of observers using the travelling-wire micrometer are in general not greater than 10 msec., but exceptionally they may be as large as 20 to 30 msec. The usual practice at most observatories is to determine the relative personalities from the intercomparison of the results of different observers. Personal equation machines, for the determination of absolute personal equations, are in use at a minority of observatories. The personal equations tend to be somewhat variable and there is some evidence that there are personal errors in the reading of levels as well as in the observations of transits. Corrections are normally applied for the larger and well-established personal equations, but not in general for those that are small.

Variable systematic differences between results given by different instruments may be caused by bad design of the instrument pavilions, by their proximity to buildings or by other unsuitable siting, and by errors in the figures of the pivots. Careful consideration should be given to the siting of transit instruments and to the design of their housing.

Photo-electric recording, for the elimination of personalities, is at present little used, but experimental work is in progress at several observatories. At the Pulkovo Observatory, small transit instruments with a photo-electric device for the registration of star transits are used regularly. The Russian experience is that photo-electric recording not only eliminates personality effects but has reduced the mean square error of a determination of clock corrections, with the same instrument, from 25 to 15 min. The method is that described by N. N. Pavlov (*Pulkovo Observations*, 2nd ser., vol. **59**, 1946) and improved by V. E. Brandt (*Proceedings of the Tenth Astrometrical Conference, Leningrad*, 1954).

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The photo-electric observations are subject to the disadvantage that a long integration time is needed for the observation of faint stars, with the result that the photo-electric signals have a slow rise to maximum; though this does not necessarily reduce the accuracy of measurement, it has the inconvenience that a much longer time is required for the measurement of chronograph tapes. The split-beam technique has advantages, but its use is limited to the brighter stars.

The impersonal prismatic astrolabe, designed by Danjon, appears from the observations made at the Paris Observatory to be sensibly free from personal equations; the standard error for a single determination of time (about 20 stars) with this instrument does not exceed 10 msec. It has the advantage that the same observations determine both latitude and time. The use of these instruments for determining time and latitude during the International Geophysical Year is strongly recommended. The astrolabes are not yet in commercial production, however, and unfortunately it seems doubtful whether the makers (Optique Précision de Levallois) will be able to meet all requirements in time for the 1957–58 programme.

Photographic zenith tubes are coming into wider use. The Washington (with Richmond, Florida), Ottawa, Tokyo, Neuchâtel, and Greenwich Observatories have installed instruments of this type, though there are differences in the details of their designs. The Commonwealth Observatory (Mount Stromlo), the Mizusawa Observatory and the Deutsches Hydrographisches Institut have instruments under construction or approved to be constructed. The Union Observatory (Johannesburg) has plans for the installation of a P.Z.T. These instruments undoubtedly give the highest precision in time determinations, when the star places have been smoothed by observation. The probable error of a single determination of time at Washington and Florida is found to be only $2\frac{1}{2}$ msec. (the corresponding figure for a single star is 7 msec.). The positions of the stars on the observing programmes with P.Z.T.s require to be determined in the fundamental system FK3 by meridian observations, the individual star places then being smoothed by the routine observations.

Clocks

The following observatories base their time service entirely upon clocks of the quartz crystal type, though they may have pendulum or other types of clocks in use: Greenwich, Paris, Uccle, Deutsches Hydrographisches Institut, Torino, Neuchâtel, Washington, Ottawa, Johannesburg (Union Observatory), Mount Stromlo and Tokyo.

Pulkovo, Nikolaev, Sternberg, Poznan and Rio de Janeiro use both quartz and pendulum clocks. Belgrade, Bucarest and San Fernando are planning to install quartz crystal clocks.

In the European observatories (with the exception of Greenwich) the oscillating element is in the form of a bar of square cross-section. At other observatories, plates (GT-cut) or Essen rings (supported on pins or suspended by silk suspensions) are generally used. The experience at Greenwich is that the silk-suspended rings give the best performance on the whole, and that the rings are less troubled by ageing effects and settle down to a satisfactory performance sooner than GT plates.

Whichever form of crystal is used, some are found to give a more consistent performance than others. The design of the drive circuit, the amplitude of oscillation of the crystal, and the accuracy of its temperature control are factors that affect the performance of a given crystal.

At Greenwich the quality of the clock performance is assessed by adopting the mean absolute second difference of the monthly values of the rate of the clock as a numerical criterion. The criterion is expressed in milliseconds per day per month per month. The lowest criterion amongst the clocks whose times are used at Greenwich is 0·06 and the highest is about 0·5. These criteria may be compared with values of 3·4 for Leroy 1372 at Paris (which has given a particularly good performance for a pendulum clock), 10 for a good average pendulum clock and 50 or over for a poor pendulum clock. The superiority of the quartz crystal clocks is at once apparent from these figures. It is suggested that other observatories should express the performance of their clocks numerically by the same criterion to make available information about the accuracy of which different types and designs are capable.

Revision of FK3 System

By resolution of the International Astronomical Union, time determinations are based on the positions of stars in the FK3 system, so that comparisons between time determinations at different observatories should not be complicated by systematic differences between different systems of star places. The mean epoch of the star places of the FK3 system is approximately 1900, and after the lapse of some 50 years the uncertainties in many of the individual star positions have appreciably increased because of the probable errors of the proper motions. It is a common experience that certain stars give systematically large residuals in the reduction of observations for the determination of time. There is need for the correction of the star places within the system and for the revision of the star system itself. The N30 catalogue prepared by H. R. Morgan, though not a fundamental catalogue, has provided evidence that the FK3 system, particularly in certain zones of declination, is not free from errors of the $\Delta\alpha_\alpha$ type. Determinations of time with small transit instruments are normally made in the early evening; errors of this type will then give rise to an apparent seasonal variation in the rate of rotation of the Earth. Observations with the prismatic astrolabe will be less affected by such errors, as the time determinations are then based upon stars differing widely in right ascension. Observations with photographic zenith tubes will also be less affected because the positions of the stars are smoothed by the observations. In consequence, observations with different types of instruments may no longer be directly comparable and, in particular, the derived values of the seasonal variations in the Earth's rotation will be discordant. Investigations at Greenwich have, in fact, shown that the seasonal variations in the Earth's rotation derived from observations at Washington, Greenwich and Mount Stromlo are in better agreement when referred to the N30 system than when referred to the FK3 system. The Pulkovo Observatory reports that investigations made there during 1948–50 indicate that large corrections (up to 15 msec.) are required to the FK3 system in the zone of declination around 60°, and that these corrections agree relatively well with those indicated by the N30 catalogue.

The revision of the FK3 system is now in progress at the Astronomisches Rechen-Institut. Present information is that the revision should be completed during 1958. It is most important, however, that the positions in the revised system should be available not later than the beginning of the International Geophysical Year (1957·5), so that all observations during that period for the determination of time and longitude can be reduced using the revised star places. It is therefore hoped that every effort will be made by the Astronomisches Rechen-Institut to complete the revision before the beginning of the International Geophysical Year.

Time Signals and Standard Frequency Transmissions

The commission recommended at its meeting in Rome in 1952 that radio time-signals should be reduced to the three systems: O.N.O.G.O., rhythmic and the English system of mean time signals. This recommendation was not brought before the General Assembly for approval, but this will be done in Dublin. Geodesists and surveyors have been interested in the retention of the rhythmic signals. At the meeting of the International Association of Geodesy in Rome, in September 1954, a communication was presented by MM. Tardi and Duhamel in which it was shown how the error of a mean time chronometer can be accurately determined by a coincidence method using mean time signals, with the aid of a simple chronoscope, designed in France by the Institut Géographique National, or by a still simpler form of chronoscope described by the authors, or by the use of a second chronometer, adjusted to a gaining rate of 24 min. a day. These methods avoid the need for a registering chronograph, which is inconvenient in field work, and have the advantage over the rhythmic signals method that the error of the chronometer can be determined at any convenient time during the day, by using one of the standard frequency transmissions, such as WWV.

It is to be hoped that geodesists and surveyors will adopt one or other of the suggested methods for determining the error of a chronometer, thereby making it possible for rhythmic signals eventually to be discontinued.

Standard frequency transmissions, with superimposed time signals, have the advantage that they enable both frequency and time to be checked without waiting for the fixed hours at which radio time signals of the standard types are transmitted. The principal characteristics of the various frequency transmissions are given in Appendix A (prepared by M. Boella). With the exception of WWV these transmissions are all at present regarded as experimental. The International Administrative Radio Conference of 1947 allocated frequencies of 2·5, 5, 10, 15, 20, 25 Mc./sec. for such transmissions; these frequencies have been adhered to, though the JJY transmissions are made also on frequencies of 4 and 8 Mc./sec.

In addition to the transmissions listed in the Appendix (p. 453), the Chief of the Time Service of the Central Research Institute of Radio Measurements, Moscow, reports that transmissions of the standard frequency of 1000 c./sec. are carried out by the modulation of the carrier of the broadcasting station, working on the wave-length of 1500 m. from 14.40 to 14.55, Moscow time, daily, except Sundays, holidays and the days of the technical inspection of the transmitter. Relative error of the transmitted standard frequency did not exceed $\pm 2 \times 10^{-8}$. Standard frequencies of 10 and 15 Mc./sec. are transmitted by the short-wave transmitter from 10.15 to 10.45, Moscow time, daily, except Sundays and holidays. On the even dates of the month the frequency of 10 Mc./sec. is transmitted; on the odd dates—the frequency of 15 Mc./sec. The first three minutes of the transmission and the last two minutes the carrier is manipulated by time signals. The standard frequencies are transmitted from one of the quartz oscillators which constitute the group frequency standard or from individual quartz oscillators.

The number of standard frequency transmissions is certain to increase. The Physikalisch-Technische Bundesanstalt, Braunschweig, has announced that it will commence the transmission of standard frequencies during 1955, with time signals from the Deutsches Hydrographisches Institut superimposed (night time only).

Unless some system of time-sharing can be agreed, the use of common frequencies will result in annoying interference between different transmissions, particularly in the zones between adjacent transmitting stations. Interference between different transmissions is already troublesome and will inevitably become worse as the number of transmitting stations increases. By a mutual time-sharing arrangement, with each station transmitting for several hours daily but at different periods of the day, the interference could be kept within tolerable limits, while leaving adequate latitude for users of the transmissions to check their frequency and time standards.

The Bureau de l'Heure has the responsibility of receiving and inter-comparing the many time signals transmitted from various observatories. The distribution of these signals throughout the 24 hours of U.T. is very uneven; the majority of the signals are transmitted at the even hours. The Bureau has suggested for consideration whether the times of transmission of some of the signals can be changed so as to give a more uniform distribution through the 24 hours. Such redistribution would facilitate the work of the Bureau and would be advantageous in addition to the users of the time signals.

The time signals superimposed on standard frequency transmissions are checked by different observatories at any times that happen to be convenient, so that the results are not directly comparable. It is for consideration whether mutually agreed hours for checking these time signals can be arranged; each observatory would retain its freedom to check the signals at other hours of the day in addition, if so desired.

Astronomical and Ephemeris Time

The rotation of the Earth is known to be subject to secular, irregular and seasonal changes. The precision of modern frequency standards is such that the seasonal changes have become of practical importance. If a perfect standard were checked against time determined by the rotation of the Earth, it would appear to have seasonal changes in frequency, of magnitude large enough to be detectable.

The seasonal changes in the rate of rotation of the Earth have been explained as the result of the seasonal variation in the angular momentum of the winds. Such an effect, of meteorological origin, may be expected to vary in magnitude and phase from year to year. M. and Mme Stoyko have communicated the results of the analysis of time determination for the derivation of the seasonal variation for each year from 1940 to 1952. They find a large variation from year to year in both amplitude and phase, with an extreme ratio in amplitude (1941–49) of 9·4. They find also some evidence of a 14-monthly variation which, when allowed for, reduces the extreme ratio in amplitude to 4·2. These results are not confirmed by the analysis of the Greenwich observations which agree, however, in indicating some reduction in amplitude subsequent to 1948 as compared with earlier years (in which the data were less reliable because the clocks then in use were of lower precision). The results for individual years are considered to be too variable for any definite conclusions to be drawn about the existence of a 14-monthly term in the Earth's rotation.

Non-uniformity in time determinations is also caused by the polar motion, which requires the position of the actual meridian to be corrected to that of the meridian through the mean position of the pole. Different procedures have been adopted by different observatories in the endeavour to provide a quasi-uniform time for the convenience of those who use the time signals for checking precision frequency standards. Some correct for the polar motion; Greenwich corrects both for polar motion and for the seasonal variation in the rotation of the Earth; others apply no corrections. Corrections applied for polar motion and for the seasonal variation of the rotation are necessarily of a provisional nature, being based on extrapolated values. The corrections applied should be explicitly stated in the time circulars distributed by the observatories, so that the actual observed times are available. Proposals by the U.S. Naval Observatory for ensuring that corrections are applied in a uniform manner by all observatories are given below for discussion by the commission in Dublin.

The corrections to be applied to astronomical time to obtain the uniform time designated as ephemeris time can be best derived from observations of the Moon. These corrections can be derived a few years in arrears from observations of occultations of stars by the Moon and from meridian observations of the Moon. The dual-rate Moon position camera, developed by Markowitz at the U.S. Naval Observatory, provides the most convenient method of deriving the corrections accurately and promptly. A programme has been prepared in which some twenty of these cameras, distributed about the world, will be in use during the International Geophysical Year and will provide important data for the determination of changes in the rate of rotation of the Earth during that period, for correlation with the extensive meteorological data about the circulation of the atmosphere and the data about ocean currents and changes in sea level that will be obtained. After the completion of this programme it is planned to have the observations with the special Moon cameras continued on a permanent basis at about four observatories.

International Geophysical Year

A world-wide programme of determination of longitudes and latitudes has been included, as already mentioned, in the programme of observations to be undertaken during the International Geophysical Year. A series of recommendations, prepared by the Working Group on Longitudes and Latitudes, was approved and adopted by C.S.A.G.I. at its meeting in Rome, 29 September to 3 October 1954. These resolutions are primarily the concern of Commission 18 (Geographical Positions), but are of interest also to Commission 31, as all observatories concerned with the determination of time will naturally participate in this programme which, inter alia, will provide valuable information about the speed of travel of long and short radio-waves and about the dependence of the speeds of travel upon ionospheric conditions. The general programme will enable a more detailed investigation to be made of the causes of the seasonal variations in the rate of rotation of the Earth than has hitherto been possible. The attention of all observatories concerned with the determination of time is called to these recommendations.

Definition of the Unit of Time

The General Assembly in Rome in 1952 adopted the recommendation that 'dans tous les cas où l'on juge que la variabilité de la seconde de temps solaire moyen s'oppose à son emploie comme unité de temps, l'année sidérale pour 1900.0 soit adoptée comme unité de temps'.

It was subsequently pointed out by Danjon that the tropical year is more fundamental than the sidereal year. The length of the tropical year is derived from Newcomb's tables of the Sun, whereas the length of the sidereal year depends upon the adopted value of the precession. The tropical year should therefore be substituted for the sidereal year in the resolution above.

The Conférence Général des Poids et Mesures, at its meeting in September 1954, proposed the following definition of the fundamental and invariable unit of time:

'The second is the fraction 1:31 556 925·975 of the tropical year for 1900.0.'

In connexion with this definition Danjon comments as follows:

1. Conformément à la résolution 3 de la Conférence sur les Constantes fundamentales de l'astronomie, réunie à Paris en 1950, aucune modification ne sera apportée désormais à l'expression numérique de la longitude tropique du soleil donnée par Newcomb:

$$L = L_0 + 129\,768''\!.13T + 1''\!.089T^2,$$

T étant le nombre de siècles juliens de 36525 jours, comptés à partir du 1^er^ janvier 1900 a midi T.U.

Le coefficient de T dans cette expression devient ainsi une constante absolue, non sujette à revision, et dont la valeur doit être considérée comme rigoureusement donnée (en d'autres termes, on peut supposer les chiffres à droite suivi d'un nombre illimité de zéros).

Cette décision impose le choix de l'année *tropique* comme étalon naturel de temps.

2. On déduit de cette expression la durée de l'année tropique pour le 1er janvier 1900 à midi T.U. (ce n'est pas la durée de l'année qui commence à cette date, mais celle de l'année dont le milieu tombe à cette date). On a, pour le temps T,

$$365^{j}\!\cdot242\,198\,781\,17 - 0^{j}\!\cdot000\,006\,138T,$$

ou

$$31\,556\,925^{s}\!\cdot974\,74 - 0^{s}\!\cdot5303T.$$

Proposals for Discussion

The following proposals have been received from M. Stoyko:

1. Il est désirable que les observatoires participant au service horaire international reçoivent, en plus des signaux émis par les stations rapprochées, les émissions des stations éloignées. Par exemple, il est souhaitable que les observatoires d'Amérique du Nord reçoivent les signaux européens, pour qu'on puisse faire la liaison bilatérale entre l'Europe et l'Amérique et de déterminer régulièrement la vitesse apparente de propagation des ondes radioélectriques.

2. Il est désirable qu'il n'existe pas une accumulation des très nombreuses émissions horaires scientifiques au même moment. Cette accumulation est très grande surtout aux

heures paires (0^h, 2^h, 4^h, ..., T.U.). A 12^h T.U. on a 33 émissions commandées par 8 services horaires. Il faut poser la question de la meilleure distribution dans le temps des émissions de signaux horaires.

3. Les résolutions qui ont été prises par la Commission 31 de l'U.A.I. les 8 et 10 Septembre 1952 n'ont pas été votées par l'Assemblée Générale pour avoir l'effet légal. Il faut les faire voter par l'Assemblée Générale de Dublin.

(i) La Commission exprime le vœu que l'U.A.I. accepte de soutenir, par une appréciation favorable, les Comités Nationaux des Pays d'Europe Occidentale dans l'effort que certains d'entre eux envisagent d'entreprendre en vue d'obtenir de leur gouvernement respectif la participation à la création, en commun, en Europe ou en Afrique, d'un centre de recherches dont le programme comprendrait l'étude et la construction d'étalons de fréquence de haute précision.

(ii) La Commission adopte, pour l'unification d'émission des signaux horaires, de maintenir seulement trois types de signaux horaires radio-électriques: O.N.O.G.O., rythmés et le système anglais.

(iii) Que toutes les modifications dans le programme d'émission des signaux horaires soient communiquées au Bureau Central des Télégrammes Astronomiques de Copenhague, pour que l'annonce de ces modifications puisse être connue par tous.

(iv) Il est recommandé que les observatoires ayant un service horaire ne modifient pas la longitude conventionnelle qu'ils ont adoptée. Ils modifieraient, ainsi, l'homogénéité des résultats et ces changements sont trop petits vis-à-vis de la dispersion des résultats.

(v) Il est recommandé que les longitudes conventionnelles se rapportent à un point fixe dans l'Observatoire. Il arrive que les longitudes données se rapportent à un instrument. Si cet instrument change de place, la valeur de la longitude conventionnelle change aussi et souvent on ne sait pas, si un changement de la longitude est due au déplacement de l'instrument, ou à une autre cause. Il faut communiquer tous les changements au B.I.H.

(vi) La correction, que l'on doit appliquer au Temps Universel pour obtenir le Temps Quasi-Uniforme, devrait être publiée comme une correction additionelle dans les publications de corrections de l'heure.

(vii) La Commission estime qu'il serait hautement désirable de voir un service de l'heure de haute précision fonctionner dans une région équatoriale.

The following proposals have been received from Dr Markowitz:

The introduction of corrections for polar variation and for annual fluctuation allows a quasi-uniform time to be determined. The corrections applied by various observatories are not on the same system, however. It is proposed that the corrections be applied in a uniform manner, so that the improvements in time-keeping may be obtained without having a multiplicity of time systems. Several years may elapse, it is realized, before the proposals may be put in effect. The proposals are:

1. The Central Bureau of the I.L.S. shall furnish preliminary values of the polar variation to the B.I.H. These values may be based on the results obtained with instruments in addition to those of the I.L.S.

2. The B.I.H. shall use these values of the P.V. to compute the corrections in time due to P.V. for several months in advance, by extrapolation, for the various observatories which determine time.

3. The annual fluctuation in the Earth's speed of rotation shall be studied further. If the fluctuation appears to be sensibly the same from year to year, a correction for fluctuation shall be adopted which will be used by all observatories. The correction may be changed from year to year, but shall be published in advance by the B.I.H.

4. The bulletins published by the various time services shall give for each 5 days the quantities to be *added* to the times of reception to remove the correction for P.V. and the correction for annual fluctuation.

H. Spencer Jones
President of the Commission

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CARACTERISTIQUES PRINCIPALES DES STATIONS DE FREQUENCES ETALON ET DE SIGNAUX HORAIRES

Stations	Hawaii	Johannesburg[e]	Rugby	Tokyo	Torino	Uccle[v]	Washington
Indicatifs	WWVH	ZUO	MSF	JJY	IBF	—	WWV
Service	Expérimental	Expérimental	Expérimental	Expérimental	Expérimental	Expérimental	Régulier
Puissance de l'onde porteuse (kW.)	2[a]	0,1	0,5	1	0,3	0,02	10[a]
Type d'aérien	Dipôle vertical	*L* renversé	Dipôle vertical	Dipôle vertical	Dipôle horizontal[r]	—	Dipôle vertical
Nombre d'émissions simultanées	3	1	3	1	1	1	6
Nombre de fréquences utilisées	3	1	3	3	1	1	6
Emissions							
Jours par semaine	7	7	7	7−2[l]	1[s]	7	7
Heures par jour	22	24[f]	24[i]	24	6[t]	22	24
Fréquences étalon utilisés							
Porteuses (Mc./sec.)	5; 10; 15	5	2,5; 5; 10[j]	2,5[m]; 5[n]; 10[o, p]	5	2,5	Toutes
Modulations (c./sec.)	1[b]; 440; 600	1[g]	1[b]; 1000	1[q]; 1000	1[b]; 440; 1000	Néant	1[b]; 440; 600
Durée de la modulation audible (min.)	4 sur 5[c]	—	5 sur 15	9 sur 20	5 sur 10[u]	—	4 sur 5[c]
Exactitude des fréquences (10^{-8})	±2	±2[h]	±2	±2	±2	±1	±2
Dérive max. mensuelle de l'oscillateur (10^{-8})	+2	+4	+0,5	+1	+4	—	+1
Valeur maximum des bonds de réglage de fréquence (10^{-8})	1	2	2	2	2	—	1
Durée de transmission des signaux horaires (min.)	Continus	Continus	5 sur 15	Continus	5 sur 10	Néant	Continus
Exactitude des intervalles de temps	$\pm 2 \times 10^{-8}$ ± 1 µsec.	$\pm 2 \times 10^{-8}$ ± 10 µsec.	$\pm 2 \times 10^{-8}$ ± 1 µsec.	$\pm 2 \times 10^{-8}$ ± 1 µsec.	$\pm 2 \times 10^{-8}$ ± 1 µsec.	—	$\pm 2 \times 10^{-8}$ ± 1 µsec.
Méthode de réglage des signaux horaires	Par la fréquence[d]	Par la fréquence[d]	Par bonds de 50 m.sec.[k]	Réglés sur une moyenne de signaux horaires	Par la fréquence[d]	—	Par la fréquence[d]

[a] Valeurs maximum; une puissance réduite est utilisée sur certaines fréquences et à certains jours.
[b] Impulsions de 5 cycles de modulation à 1000 c./sec.
[c] 440 et 600 c./sec. alternativement.
[d] Aucun ajustement de phase sur les signaux eux-mêmes.
[e] L'émission est assurée par l'Observatoire de l'Union (Union de l'Afrique du Sud).
[f] Interruptions pendant de courts intervalles.
[g] Impulsions de 100 cycles de modulation à 1000 c./sec.
[h] Par rapport à WWV.
[i] Interruption de l'émission de la minute 15 à la minute 20 de chaque heure.
[j] Des émissions sont faites également sur 60 kc./sec.
[k] Le 1er du mois si cela est nécessaire.
[l] Voir fréquences porteuses.
[m] de 7^h à 23^h T.U.
[n] Le lundi.
[o] Le mercredi.
[p] Des émissions sont faites également sur 4 et 8 Mc./sec.
[q] Interruptions de l'émission pendant 20 msec.
[r] Direction de rayonnement maximum: N.O.–S.E.
[s] Le mardi.
[t] De 8 h. à 11 h. et de 13 h. à 16 h. T.U.
[u] 440 et 1000 c./sec. alternativement.
[v] L'émission est assurée par l'observatoire Royal de Belgique.

Report of Meeting. Thursday, 1 September 1955, 9 a.m.

PRESIDENT: Sir Harold Spencer Jones.

SECRETARY: H. M. Smith.

The President proposed the adoption of the Draft Report which was approved subject to the correction of minor printing errors and a few amendments. (These have been incorporated in the report as printed on pp. 446–53.)

Prof. Danjon, Director of the Bureau International de l'Heure presented his report for the period 1952–54 (see Appendix I). The President complimented Prof. Danjon and M. Stoyko on the work of the Bureau and the report was adopted.

The President informed the Commission that the Secretary of the I.A.U. had received a letter from the President and Secretary of the Comité International des Poids et Mesures asking the approval of the I.A.U. to the following definition of the Unit of Time: 'The second is the fraction:

1: 31 556 925·975 of the tropical year for 1900·0.

Prof. Danjon outlined the various stages in the formation and consideration of this definition. The present legal unit, based on the mean solar day, was not uniform and was unsatisfactory to astronomers and physicists. The proposed unit had, in effect, been agreed at the Rome meeting of the I.A.U. and all that was now needed was a minor correction by the substitution of 'tropical year' for 'sidereal year'. The Comité International had been authorized by the Conférence Générale des Poids et Mesures to adopt this definition of the second if the amendment was acceptable to the I.A.U.

M. Barrell considered that recent developments in the precise measurement of atomic and molecular frequencies would lead in the next few years to a strong demand by physicists for a new definition of the unit of time, but pointed out that the second of the proposed definition would not be immediately available. Prof. Danjon said that to reject the new definition would involve the retention of a unit of time which was known to be subject to serious variation. The President remarked that physicists were concerned to know how the second of today, or of any other epoch, was to be related to the legal second if the new definition were adopted.

He proposed the adoption of the definition and the preparation of an explanatory memorandum.

M. Sadler inquired if an infinite number of noughts should be added to the coefficient of T in the Newcomb expression for the longitude of the Sun, or to the denominator of the fraction expressing the second in terms of the tropical year for 1900·0. Prof. Danjon replied that the Newcomb coefficient must be regarded as exact, and that the fraction of the tropical year, though quoted with adequate accuracy for a legal definition, must be regarded as an approximation: at present the fraction was 1: 31 556 925·974 74. . . .

M. Clemence explained that the Commission were being asked to choose between the mean solar second, which was readily accessible but subject to variation, and the proposed new second which was invariable but less readily accessible.

On the motion of the President, the new definition was adopted. A sub-committee under the chairmanship of Prof. Danjon was set up to prepare an explanatory memorandum which would be submitted to the next meeting of Commission 31, and if approved, attached to the reply to be sent by the I.A.U. to the Comité International des Poids et Mesures. The following were appointed members of the sub-committee:

Danjon (*Chairman*)	Markowitz
Brouwer	Sadler
Clemence	Subbotin
Essen	Smith (*Secretary*)

M. Essen then gave a brief account of the atomic frequency standard at the National Physical Laboratory. He stressed that in this development full use had been made of the pioneer work carried out in the U.S.A. The standard depended on the transition between the two ground state energy levels of the caesium atom. In one of these states the atom possessed a positive magnetic moment, and in the other a negative magnetic moment; and this made it possible to detect the transitions by the Rabi atomic beam technique. The advantages of this technique were that the usual causes of the broadening of spectral lines were all avoided and the line-width depended simply on the time spent by the atoms in the exciting magnetic field. A beam of atoms was evaporated from an oven and focused by means of two magnets on to a detector. In between the focusing magnets it passed through two cavity resonators coupled to a stable microwave oscillator. The frequency of oscillation was varied and when it corresponded to the transition frequency the atoms changed from one state to the other with a reversal of the sign of their magnetic moment, so that they were deflected away from the detector. Alternatively, the magnets could be arranged so that the atoms were deflected on to the detector when transitions occurred. The frequency could be set with a precision of 1 part in 10^9 and the value in terms of the present adopted unit of time was:

$$9\,192\,631\,830 \pm 10 \text{ c./s.}$$

The experimental model of the apparatus had been constructed in such a way as to enable the effects of varying the many design parameters to be studied. This work would take some time, but it had already been established that most of these variations had a negligible effect on the line frequency. When the astronomical data became available the result would be expressed in terms of the new unit now being adopted; and when the relationship had been established the atomic standard would be used to extrapolate beyond the astronomical observations and to make the new unit currently available to the physicist and radio engineer.

Prof. Danjon drew attention to the fact that M. Essen had quoted the observed caesium resonance frequency to an accuracy which exceeded the precision with which the second had been defined.

M. Clemence remarked that it would be of considerable theoretical interest to discover if the astronomical and atomic time-scales are in agreement.

The President emphasized the importance of progress in microwave spectroscopy and referred to the work of Prof. Townes at Columbia, where two ammonia oscillators had been found to agree over many weeks to a few parts in 10^{16}. He then read the following concluding paragraph from a letter by Sir Edward Bullard in *Nature* (13 August 1955):

> It is possible that the new accuracy in the measurement of frequency will reveal some unexpected phenomena. It is not self-evident that the times shown by atomic and astronomical clocks will keep in step indefinitely. In fact, Dirac, Milne, Jordan and others have suggested that what are usually regarded as the 'constants of physics' may change by amounts of the order of $1/T$ per year, where T is the 'age of the universe' in years. If T is about 4×10^9 years, changes of this order may soon be measurable over intervals of a few years. This is a matter that can only be settled by experiment and gives an added interest to the development of methods of precise time-keeping.

As the next meeting of the I.A.U. would not take place until after the I.G.Y. programme was in full operation, the President suggested that members of Commission 31 might wish to have some information concerning the astronomical and radio equipment for the longitude programme. M. Decaux distributed copies of the draft memorandum on radio reception and measurement techniques which had been prepared by a subcommittee of C.S.A.G.I. under his chairmanship: it is proposed that the final memorandum should be in two parts, one to be published soon and the other to be delayed until shortly before the commencement of the I.G.Y. so that the latest information might be included. M. Smith gave a brief account of tests at the Royal Greenwich Observatory with 'inclined-V' aerial and suggested that it might be employed with advantage in radio time signal reception.

Prof. Danjon reported that the final prototype astrolabe was approaching completion at the O.P.L. factory, and that establishments requiring instruments for the I.G.Y. should place orders as soon as possible. The exact price was not known, but would be about 5 million French francs. A report was in preparation and would be available soon.

M. Decaux drew attention to the possibility of making precise trans-Atlantic measures of radio travel times and their variations if the long-wave NSS transmitter were re-started in the U.S.A. M. Markowitz said that this was not a question for the U.S. Naval Observatory, but for the Director of U.S. Naval Communications. M. Clemence suggested that an approach should be made to the U.S. National Committee through the Special Committee of the I.G.Y. The President and Prof. Danjon, who are members of this Committee, agreed to pass this request forward at the forthcoming Brussels meeting.

M. Stoyko then outlined the reasons for his proposal (1) on p. 451. In particular he recommended that European radio time signals should be measured regularly in U.S.A. and Australia.

M. Markowitz said that the U.S. Naval Observatory received a number of overseas time signals, and that in cases where it was justifiable, the measurements were published in units of 0·1 msecs. He urged that a short list be prepared of radio time signals which were recommended for world-wide intercomparisons.

The President said that the B.I.H. and all time-keeping observatories would warmly welcome such a list. Prof. Danjon said that a list had been prepared by C.S.A.G.I. and would be published in *Information Bulletin*, no. 4.

M. Stoyko's proposition was agreed for transmission to the General Assembly (Resolution 2).

Report of Meeting. 3 September 1955

At the invitation of the President, Prof. Danjon presented the report of the sub-committee appointed to prepare an explanatory statement in clarification of the definition of the unit of time (Appendix II). It was agreed that this statement should be attached to the Definition of Time (Resolution 1) and forwarded to the General Assembly for transmission to the Comité International des Poids et Mesures.

M. Markowitz was then asked to present his proposals 1 and 2 (p. 452). As the acting chairman of Commission 19, he described the scheme which had been adopted for the prompt determination of the polar motion, using data from observatories equipped with modern instruments such as the P.Z.T., the Danjon astrolabe and the new Russian instruments. The latitude observations were to be communicated each week by the observatories concerned to the Central Bureau of the International Latitude Service, where they would be combined and smoothed to provide current values of the co-ordinates of the pole. M. Markowitz then proposed that these figures should be transmitted to the B.I.H., where they would be employed for the calculation of longitude corrections to be communicated to all observatories co-operating in the international time service. These corrections, based on the current observations, would be tabulated at ten-day intervals, and distributed every forty days: it was recommended that they should be used in all time service publications in place of the provisional results used at some observatories hitherto. M. Smith requested that the co-ordinates x and y, used in the determination of the longitude corrections, should also be included in the figures to be published by the B.I.H. M. Danjon emphasized the desirability of all time service stations employing corrections computed on the same basis. M. Stoyko suggested that a trial should be made to determine the period for which extrapolation could safely be made: the period should not be specified at this stage.

M. Federov proposed that 'the Central Bureau of the International Latitude Service be requested to publish as soon as possible the method to be used for the determination of the polar co-ordinates on the basis of observations at all stations, both adhering to the I.L.S. and individual'. The President stated that this was not a matter for Commission 31, but could be taken up by M. Federov as the new President of Commission 19. M. Markowitz's proposals were then put to the meeting and adopted (Resolution 6).

M. Smith proposed that, to facilitate inter-comparisons between timekeeping establishments, data tabulated at intervals of five days, ten days, and so on, should be given for days on which the number of Julian days elapsed at Greenwich noon is divisible by the tabular intervals. This system had been employed at the Royal Greenwich Observatory since 1948. The proposal was adopted (Resolution 9).

The President then invited M. Markowitz to speak on his proposal 3 (p. 452). M. Markowitz explained that this proposal represented a further attempt to achieve homogeneity. A recent analysis of the American P.Z.T. observations for the period 1951–54 indicated that the annual fluctuation in the rotation of the Earth had been sensibly constant during that period: he accordingly proposed that rounded values should be adopted for the amplitude and phase of the annual and semi-annual terms. Corrections for the annual fluctuation should be made available to all time-keeping observatories in a similar manner to that agreed for the correction for the effects of polar motion.

The President expressed some misgivings at the assumption that the annual fluctuation could be regarded as sensibly constant. It had been well established that the fluctuation arose from meteorological causes: even if the amplitude were to remain fairly constant from year to year, changes in phase might introduce substantial divergences at a particular epoch. M. Danjon drew attention to the complications arising from local variations of the vertical. If, however, each observatory were to make experimental determinations and adopt its own value for the annual fluctuation, many difficulties arose in the co-ordination of the results at the B.I.H.

He was therefore prepared to accept M. Markowitz's proposal on the grounds that it envisaged a provisional correction which could be generally adopted.

M. Barrell stressed the importance of the work on atomic standards of frequency in giving further assistance in the evaluation of the annual fluctuation. The President concurred and M. Essen thought that the inclusion in the resolution of a reference to the importance of atomic standards of frequency would serve to encourage progress in this field.

M. Smith reminded members of the commission that time observations made with a conventional transit instrument exhibited an apparent annual fluctuation, which was the sum of the true annual fluctuation in the rotation of the Earth and a spurious fluctuation arising from periodic errors in Star places. Comparisons between the N30 and FK3 star places suggested that star-place errors were more serious in the Southern Hemisphere. P.Z.T. observations, utilizing star places which had been determined by the clocks and P.Z.T. observations alone, and which were related only in the mean to the FK3 system, showed the true annual fluctuation. R. Markowitz's proposal would help to secure uniformity among observatories employing P.Z.T. instruments, but the adopted fluctuation might not be directly applicable to observations obtained with transit instruments. M. Danjon added that the advantages of the P.Z.T. in this respect were shared by the Danjon astrolabe, in which $\Delta\alpha_\alpha$ errors were smoothed.

In answer to a question by the President, M. Markowitz explained that the B.I.H. should be responsible for the preparation and publication of the adopted values, and that the scheme should be inaugurated from January 1956. The commission agreed (Resolution 7).

The fourth proposal by M. Markowitz (p. 452) was next considered. M. Danjon referred to the difficulties now experienced by the B.I.H. and M. Markowitz agreed to give full details of all the corrections employed in the published results of the U.S. Naval Observatory. The draft proposal was slightly modified, and then adopted (Resolution 8).

M. Stoyko was invited to give further details of his draft proposal 2 (p. 451). He explained that the present concentration of radio time signals at particular times made

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it quite impossible for the B.I.H. to maintain proper comparisons with some observatories. M. Danjon suggested that this was not so much a matter for a formal resolution, but for the consideration of all members of the commission. The President said that it was clearly desirable to establish a rational programme, involving the least possible alteration in individual schedules. The following resolution, proposed by the President, was unanimously approved:

The B.I.H. is instructed to consider how the times of transmission of radio time signals could be modified to facilitate as far as possible the reception of near and distant stations, and to report at the next meeting of the Union.

M. Danjon introduced the third proposal put forward by M. Stoyko (p. 452) which had been agreed at the 1952 meetings of Commission 31, but had not been confirmed at the General Assembly.

The proposals were dealt with as follows:

3 (i) deleted as no longer required
3 (ii) adopted as modified (Resolution 3)
3 (iii) adopted as modified (Resolution 4)
3 (iv), 3 (v) combined and modified: adopted (Resolution 5)
3 (vi) deleted, as already dealt with (Resolution 8)
3 (vii) adopted as modified (Resolution 10)

M. Smith referred to the high precision which had been achieved in frequency and time comparisons by means of low-frequency radio transmissions. The use of very stable low-carrier frequencies such as 16 kc./s. (GBR) and 60 kc./s. (MSF) ensured good reception and measurement over a wide area at all times of the day: no difficulties arise on account of skip area, and there is relative freedom from Doppler effects. Using methods described by Pierce and others ('World-wide frequency and time comparisons by means of radio transmissions', J. A. Pierce, H. T. Mitchell and L. Essen, *Nature*, **174**, 922, 13 Nov. 1954) frequency comparisons had been made to better than 1 in 10^9 and phase comparisons to 10–20 micro-seconds in trans-Atlantic comparisons: it had also been possible to study diurnal phase variations. Similar equipment was under development at the Royal Greenwich Observatory. M. Smith proposed that the I.A.U. should support the continuation and extension of standard frequency transmissions on low frequencies, and drew attention to the value of two-way transmissions.

The President stated that any resolution passed by the I.A.U. in this matter could be transmitted to C.C.I.R. to support claims for frequency allocations. M. Decaux supported the proposal. As President of the C.C.I.R. Commission on time and frequency he would welcome the support of I.A.U., and he stressed the value of low-frequency standard frequency transmissions in radio research. M. Essen also indicated his support, and the proposal was adopted (Resolution 11).

This concluded the business, and the President closed the meeting.

Resolutions

1. The General Assembly of the I.A.U. approve the definition of the second proposed by the Comité International des Poids et Mesures, as follows:

The second is the fraction 1:31 556 925·975* of the length of the tropical year for 1900.0.

2. It is urged that observatories co-operating in the international time service should receive transmissions of radio time signals from distant stations in addition to those from

* The more precise value required for exact agreement with Newcomb's Tables of the Sun is: 1: 31 556 925·974 74.

near stations in order to facilitate determination of the apparent speed of propagation of radio waves.

3. The I.A.U., considering the inconvenience arising from the use of many different types of radio time signals, recommends for permanent retention only the English system: the use of the three systems, American, O.N.O.G.O. and rhythmic, may be continued for a provisional period.

4. The I.A.U. recommends that all modifications in the programme of radio time signal transmissions should be communicated to the Central Bureau of Astronomical Telegrams in Copenhagen and published in the circulars issued by the Bureau.

5. The I.A.U. recommends that observatories co-operating in the international time service should not change their conventional adopted longitudes: such changes impair the homogeneity of the international results.

It is further recommended that the adopted longitude should refer to a fixed point in the observatory, and that any changes in the positions of instruments used for determination of time should be communicated to the Bureau International de l'Heure.

6. The I.A.U. instructs the B.I.H. to compute for the various observatories co-operating in the international time service the longitude corrections due to the motion of the pole, using for this purpose the values of the polar motion supplied by the Central Bureau of the International Latitude Service: extrapolated corrections for several months in advance shall be provided for current use. The x and y component of the polar motion used for the computation of these corrections should also be published in the Bulletin Horaire.

7. The B.I.H. shall adopt and shall publish in advance each year corrections for annual fluctuation in the speed of rotation of the Earth. These corrections shall be used by all observatories in the determination of Universal Time. Studies of the annual fluctuations shall be continued, especially with the aid of atomic standards of frequency.

8. The I.A.U. recommends that the bulletins published by observatories co-operating in the international time service should contain the quantities to be added to the times of reception of radio time signals tabulated in U.T. to allow for the effects of polar motion and the annual fluctuation in the rotation of the Earth.

9. The I.A.U. recommends that, to facilitate intercomparisons between time-keeping establishments, data tabulated at intervals of five days, ten days, and so on, should be given for days on which the number of Julian days elapsed at Greenwich noon is divisible by the tabular interval.

10. The I.A.U. draws attention to the importance of the establishment of time services of high precision in equatorial regions.

11. In view of the high precision which has been achieved in intercomparisons of time and frequency, and in the measurement of variations in propagation time, by means of the experimental frequency transmissions on a frequency of 60 kc./s., which precision is not attainable on any of the frequencies allocated by the C.C.I.R. for standard frequency transmission, the I.A.U. desired to draw the attention of the C.C.I.R. to the importance of frequencies being allocated for the continuation and extension of standard frequency transmissions on frequencies below 100 kc./s.

APPENDIX I

Rapport sur l'Activité du Bureau International de l'Heure au Cours de la Période 1952–54

La période 1952–54 a marqué un progrès très important de l'activité du B.I.H. par rapport à la période précédente. Le nombre des réceptions de signaux horaires a augmenté de 43% en moyenne et celui des observations astronomiques de 26%; comme on peut voir d'après le tableau ci-dessous.

Années	1949	1950	1951	1952	1953	1954
Rec. sign.	14592	18802	23061	24893	27121	28553
Obs. astr.	404	470	500	458	595	672

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Par rapport à la période 1946–48, le nombre des réceptions de signaux horaires, ainsi que celui des observations astronomiques a plus que doublé.

Le Bulletin Horaire a paru régulièrement. Il a donné les heures demi-définitives de toutes les émissions reçues au B.I.H. Il a publié, de plus, les heures définitives de 1950 d'après 21 observatoires, de 1951 et 1952 d'après 24 observatoires, de 1953 et 1954 d'après 27 observatoires.

Le calcul de l'heure définitive pour la première partie de l'année 1954 a demandé l'exploitation de 514 réceptions journalières. On publie l'heure définitive pour 259 émissions journalières et, de plus, les corrections journalières pour 27 observatoires, ce qui exige un travail considérable. Comme on le voit, le nombre des émissions de signaux horaires à exploiter augmente sans cesse et leur réduction à un système homogène reste indispensable.

Le B.I.H. commande depuis le 1er janvier 1953 sept fois par jour (au lieu de 4) des émissions de signaux horaires automatiques ou anglais suivis de signaux horaires scientifiques (rythmés) sur différentes longueurs d'onde. La réception de ces signaux et des signaux extérieurs se fait sur des chronographes Belin à gros cylindre (1 seconde = 500 mm.). Les pendules à pression et à température constantes et les horloges à quartz et à diapason sont comparées, en permanence, avec les horloges à quartz du Laboratoire National de Radioélectricité à Bagneux, sur un chronographe Belin.

Les observations astronomiques ont été faites régulièrement en utilisant deux lunettes de passage (Gautier, no. 381 et Bouty) et un astrolabe à prisme impersonnel de M. A. Danjon.

Pendant la période écoulée on a étudié au B.I.H. la précision des garde-temps (pendules et horloges à quartz), la propagation des ondes radio-électriques, la précision des services horaires, les erreurs expérimentales, les longitudes mondiales, les fluctuations de la rotation de la Terre et les tremblements de Terre.

Pendant la même période, les appareils suivants sont entrés en service:

(1) un appareil fournissant automatiquement la moyenne des fréquences de trois horloges à quartz 1000 c./s. (Decaux, L.N.R.);

(2) trois horloges à quartz (Belin);

(3) un nouvel émetteur des signaux horaires (Belin);

(4) une horloge synchrone à contacts multiples pour la synchronisation de chronographes (Belin);

(5) un amplificateur pour l'enregistrement du contact de la pendule Shortt (Bernier);

(6) un amplificateur pour les contacts de l'horloge synchrone 61:60 et 60:60 (Bernier).

Tous ces appareils appartiennent à l'Observatoire de Paris.

(Sgd.) (Professor) A. DANJON
Directeur

APPENDIX II

EXPLICATION

Le Temps solaire, moyen ou Universel, fourni par la rotation de la Terre est déduit en pratique de l'observation des étoiles.

Le Temps des Ephémérides, variable fondamentalement indépendante des équations du mouvement des corps célestes, est l'argument des ephémérides astronomiques.

La seconde de Temps des Ephémérides est l'unité de temps définie par la Résolution 1.

La comparaison des positions tabulaires de corps célestes convenablement choisis, et des positions observées en Temps Universel donne la différence Δt, Temps des Ephémérides *moins* Temps Universel.

En pratique, le Temps des Ephémérides est le temps pour lequel la position observée de la lune coïncide avec la position tirée de l'éphéméride calculée dans la même échelle de temps que l'éphéméride solaire conforme aux décisions internationales. Pour les années 1952–59 cette éphéméride est publiée dans le volume *Improved Lunar Ephemeris, 1952–59*; à partir de 1960 elle sera publiée annuellement dans les Ephémérides nationales.

Pour obtenir une fréquence ν_E correspondant à l'unité invariable definie dans la resolution 1, la marche est la suivante:

(*a*) La fréquence ν_U est obtenue en utilisant comme unité de temps la seconde de Temps Universel fournie par les signaux horaires radio-télégraphiques émis par les services horaires nationaux.

(*b*) Les corrections de ces signaux, déduites ultérieurement de l'observation des étoiles, sont publiées régulièrement par les services horaires. Le Bureau International de l'Heure publie annuellement les corrections définitives des signaux horaires émis par les divers observatoires.

(*c*) Les différences Δt: Temps des Ephémérides *moins* Temps Universel, correspondant au milieu de chaque année, sont publiées actuellement dans un délai de deux ou trois ans. Elles sont déduites d'occultations d'étoiles par la lune et d'observations méridiennes de la Lune. On espère que dans un programme d'observations avec les 'dual-rate Moon position Cameras', développé par Markowitz au U.S. Naval Observatory, assurera la détermination de la différence Δt plus rapidement et avec plus de précision.

(*d*) Soit $D\ \Delta t$ la variation annuelle de Δt, déduite d'une suite de valeurs annuelles de Δt au moyen d'une formule convenable de différentiation numérique.

Si Δt est exprimé en secondes, la frequence ν_E qui correspond à la définition de la seconde contenue dans la Résolution 1 est donnée par:

$$\nu_E = \nu_U \left(1 - \frac{D\ \Delta t}{31,556,925\cdot975}\right)$$
$$= \nu_U\ (1 - 3\cdot1689 \times 10^{-8}\ D\ \Delta t).$$

(*e*) Lorsque la fréquence d'un étalon atomique aura été rapportée avec une précision suffisante à la seconde de la résolution 1, l'étalon atomique pourra fournir immédiatement la seconde.

Remarques

Les déterminations astronomiques de temps sont affectées par les variations saisonnières de la rotation de la terre et par le mouvement du pôle. Ces causes entraîent des discordances dans les déterminations de temps des divers observatoires. Actuellement, ces effets ne peuvent être corrigées d'une manière définitive qu'après plusieurs années. Cependant, des corrections provisoires peuvent être immédiatement appliquées, l'incertitude qui en résulte sur le Temps Universel étant au plus de l'ordre de grandeur de l'incertitude sur les valeurs annuelles de Δt.

Les déterminations de fréquence correspondant à la seconde de Temps Universel, variable, faites au laboratoire, contribueront efficacement à l'étude des variations saisonnières de la rotation de la Terre.

Clarification

Mean solar or Universal Time, based on the rotation of the Earth, is obtained in practice from observations of stars.

Ephemeris Time, basically the independent variable of the equations of motion of celestial bodies, is the time argument of astronomical ephemerides.

The second of Ephemeris Time is the unit of time defined in Resolution 1.

The comparison of ephemeris positions of suitable celestial bodies with observations recorded in Universal Time serves to obtain the difference Δt, Ephemeris Time *minus* Universal Time.

In practice, Ephemeris Time is determined as the time at which an observation of the Moon is in agreement with the lunar ephemeris constructed in conformity with the internationally adopted solar ephemeris. For the years 1952–59 this lunar ephemeris is published in the volume *Improved Lunar Ephemeris, 1952–59*; from 1960 onward it will be published annually in the National Ephemerides.

In order to obtain a frequency ν_E corresponding to the invariable unit of time defined in Resolution 1, the following steps are required:

(*a*) The frequency ν_U is obtained by using as unit of time the second of Universal Time provided by radio time signals transmitted by the national time services.

(*b*) Corrections to these time signals, subsequently obtained from observations of stars, are published regularly by the time services. Definitive corrections to the time signals transmitted by the various observatories are published annually by the Bureau International de l'Heure.

(*c*) Values of the difference Δt, Ephemeris Time *minus* Universal Time, applicable to the middle of each year, are being published with a lag of from two to three years. They are at present derived from observations of occultations of stars by the Moon, and meridian observations of the Moon. It is expected that in the near future a programme of observations with dual-rate Moon position cameras, developed by Markowitz at the U.S. Naval Observatory, will provide a method of deriving the difference Δt more accurately and more promptly.

(*d*) Let $D\,\Delta t$ designate the change per annum in the value of Δt, derived by a suitable formula for numerical differentiation from a sequence of annual values of Δt. If Δt is expressed in seconds, the frequency ν_E corresponding to the second defined in Resolution 1 is then obtained by:

$$\nu_E = \nu_U \left(1 - \frac{D\,\Delta t}{31,556,925\cdot975}\right)$$

$$= \nu_U \,(1 - 3\cdot1689 \times 10^{-8}\, D\,\Delta t).$$

(*e*) After the frequency of an atomic frequency standard has been determined to sufficient accuracy, with respect to the second of Resolution 1, the atomic standard may be used to make the second immediately available.

Further Comments

The astronomical determinations of time are complicated by seasonal variations in the rate of rotation of the Earth as well as by the polar motion. These causes contribute to the discordances among the determinations of time at various observatories. Definitive corrections for these effects can at present be effected only with a lag of several years. Provisional corrections can, however, be applied at once, with a resulting uncertainty in Universal Time at most of the same order as the uncertainty in the annual values of Δt.

Laboratory determinations of frequencies corresponding to the varying second of Universal Time may aid importantly in the study of the seasonal variations in the Earth's rate of rotation.