While the 1961 results listed in Table 1 seem to have a much greater weight than the earlier Venus echo determinations in 1958 and 1959, these previous derivations claim to be of very high precision, too, and agree surprisingly well with each other. The discrepancies are rather puzzling and suggest the involvement of some yet unknown systematic source of error. It is of some interest that the only dynamical determination, from Pioneer V, is in fair agreement with the comparable results from Eros.

The discrepancies exhibited in Table 1 not withstanding, one may yet expect to find either their explanation, or new and better results finally converging towards some definite value in the not too distant future. As soon as this is achieved and astronomers can agree on a solar parallax secured to the fourth significant figure, the ephemeris requirements postulated above can be satisfied, as far as the mass of Earth + Moon is involved. A still higher accuracy remains desirable, of course, for the conversion of distances from astronomical into terrestrial units.

Once the solar parallax and the mass of the Moon have been secured to a higher degree of precision from the various new methods now available, related constants such as that of the lunar equation and the constant of aberration may also be established more accurately. This short discussion does not attempt to exhaust all the aspects and all the constants involved. It seems justified, however, to conclude that space probes and the modern methods of radio astronomy will soon provide us with rather accurate values of some of those fundamental constants, which in turn will justify and require the construction of planetary theories and ephemerides of highest precision. Especially better theories of the Earth and of Venus, to be preceded perhaps by more rapidly obtainable numerical integrations of high internal accuracy, appear as some of the most urgent tasks and challenges now confronting celestial mechanics. It goes without saying that the availability of such precise ephemerides would in turn facilitate the determination of improved constants by means of conventional methods, such as a fuller utilization of all the observations of Eros, of Mars, and of Venus in corresponding differential corrections.

REFERENCES

1. Krotkov, R. and Dicke, R. H. *A.J.* **64**, 157, 1959.
2. Clemence, G. M. *A.J.* **65**, 21, 1960.
3. Clemence, G. M. *Astr. Pap. Wash.* **11**, Part 2, 1949.

9. ASTRONOMICAL AND ATOMIC TIME INVOLVED IN THE OBSERVATION OF ARTIFICIAL SATELLITES

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The independent variable, t, in the orbit and in the ephemeris of a planet or satellite, natural or artificial, is Ephemeris Time. The term 'Ephemeris Time' is used in astronomy in two senses:

(*a*) In the general sense, as the independent variable of dynamical astronomy.

(*b*) As a specific measure of time, defined by a resolution adopted by the IAU.

The definition of E.T. in the sense of (*b*) is contained in a resolution adopted jointly by Commissions 4 and 31 at the tenth General Assembly (1). The basis of the measure of E.T. is the orbital motion of the Earth about the Sun. For the purpose of obtaining Ephemeris Time rapidly, other orbital motions may be used. Specific recommendations concerning the determination of Ephemeris Time from the motion of the Moon were made by Commission 31 at the ninth General Assembly (2). Observations of the Moon are the principal means of determining Ephemeris Time at present. It should be realized, however, that the ephemeris of the Moon must be brought into accordance with the ephemeris of the Sun from time to time and that it is the motion of the Sun which provides the fundamental definition of Ephemeris Time.

When the equations of motion of celestial mechanics are written down, the independent variable is Ephemeris Time. When the equations are solved an orbit is obtained, from which there is prepared an ephemeris. The independent variable in the orbit and in the ephemeris is E.T. Thus, the preparation of an ephemeris imposes no requirement on celestial mechanics in order that the ephemerides shall have Ephemeris Time in the general sense as the independent variable.

An observation of a planet or satellite, denoted J, for which an ephemeris has been prepared will provide a value of E.T. for the epoch of observation. A series of such values may be compared with the value of E.T. obtained from observations of the Sun. In general, the two will differ. If this is so, the orbital constants of J have to be revised if the two are to be equivalent. Such comparisons, however, are made on only few occasions, as when deriving the theory of a planet or satellite based upon centuries of observation. Hence, there appears to be no immediate requirement for having values of E.T. from the Sun available with high precision at all times.

The question arises whether we can find an object which is superior to the Sun as the basis for the definition of E.T. The Moon is not a satisfactory object because of uncertainties in the effect of tidal friction upon its orbital motion. An artificial satellite might be used, but this seems doubtful. Artificial satellites will be affected by non-gravitational forces whose effects probably cannot be calculated with sufficient rigour for thousands of years. Thus, it does not appear likely that in the foreseeable future an artificial satellite will replace the Sun as the fundamental measure of E.T.

Artificial satellites, however, can be useful in the solution of certain problems, for example, in studying whether the gravitational and atomic time scales are equivalent. Any satellite which can provide E.T. proportional to E.T. from the Sun with high precision will suffice.

Ephemeris Time cannot be obtained readily with high precision from observation, and Atomic Time may be used as a substitute. It has been found that the frequency of the cesium beam atomic oscillator is 9 192 631 770 cycles per second of Ephemeris Time, as determined through observations of the Moon (3). This value serves as the basis of the system of Atomic Time denoted A. 1, which is based on the operation of a number of cesium beam oscillators, located in various countries. The system A.1 provides intervals of Atomic Time with a precision of about 5 parts in 10^{11}, approximately 1 millisecond per year. Any possible divergence between gravitational time and Atomic Time may be ignored in reducing satellite observations extending over a few years, except when this divergence itself is being studied.

The apparent position of an artificial satellite as observed from the surface of the Earth depends upon both its orbital position and the location of the observer. The latter depends upon the rotational position of the Earth, which is given by U.T. 1. Hence, both Atomic Time and U.T. 1 are required for reducing observations of satellites and for predicting apparent positions.

Observations are recorded with respect to U.T. 2, generally with respect to some particular time signal transmission. Preliminary times of emission of signals with respect to U.T. 1, U.T. 2, and A. 1 are distributed weekly by several observatories. These quantities vary slowly, and the reduction of satellite observations at a central location may be made with sufficient precision by use of these values.

REFERENCES

1. *Trans. IAU* **10**, 72, 1958.
2. *Trans. IAU* **9**, 460 and 461, 1955.
3. Markowitz, W., Hall, R. G., Essen, L. and Parry, J. V. L. "Frequency of Cesium in Terms of Ephemeris Time", *Phys. Rev. Letters* **1**, 105, 1958.

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