satisfactory discrepancy between theoretical and observed $\bar{H}$-values here pointed out is an additional argument for acceleration of more precise studies of the sort he enumerates in the concluding paragraph of his interesting report.

LINCOLN LAPAZ

Institute of Meteoritics, University of New Mexico, Albuquerque

References

1. R. H. Wilson, Jr., *Science* **130**, 791 (1959).
2. L. LaPaz, *Contribs. Soc. Research Meteorites* **2**, 181 (1940).

19 October 1959

Abstract. Continued numerical improvement of all parts of my previous report, based on later accumulation and rediscussion of data, has revealed several small random adjustments, including the arithmetical correction discussed by LaPaz. The consequent result remains a satisfactory agreement of the ground-observed geomagnetic dipole field with that deduced from rotational retardation of the Vanguard I satellite.

Had his services been available, an independent computer could probably have caught the arithmetical error in the evaluation of the integral of Eq. 15 of my report (*1*) before it crept into print. Fortunately, however, continued accumulation and discussion of new data on this Vanguard I problem have resulted in several mutually compensatory numerical adjustments, which, when generally accounted, as I shall do below, still preserve a good agreement between the magnetic field deduced from satellite rotational damping and that from previous geomagnetic theory.

When my attention was first called to the arithmetical error (*2*), I found among my earlier notes the closed general solution for the definite integral discussed by LaPaz:

$$I = \frac{(1 + e^2/2)\pi}{(1 - e^2)^{5/2}} \quad (1)$$

which I overlooked in the final round-up for publication. My derivation of it consisted simply of direct use of formulas 308 and 300 in Peirce's tables (*3*); thus I arrived by a different route at a result equivalent to that of LaPaz.

Even so, my less elegant approach by numerical integration using Simpson's rule with five points, which, when corrected, gives $\bar{H} = 0.1574$ gauss, seems not altogether inappropriate, since, as stated seven lines above it in my report, the denominator of the integral is only a first approximation. The *exact* geocentric distance is

$$r = a\,(1 - e \cos E) \quad (2)$$

where E is the eccentric anomaly in Kepler's famous transcendental equation

$$M = E - e \sin E \quad (3)$$

so that the approximation shown used only the first-power term in an infinite alternating power series in the eccentricity e. Inclusion of further terms in this series for r (*4*) would render closed integration practically impossible, and such terms should be considered for the level of accuracy discussed by LaPaz. For example, inclusion of the second-power term, so that

$$r = a\left[1 - e \cos M + \frac{e^2}{2}(1 - 2 \cos 2M)\right] \quad (4)$$

in the integral, would give $\bar{H} = 0.1505$ gauss. With this power series the truncation error of the integral is approximately $3(-e)^n\bar{H}/2(n-1)!$, where n is the order of the first omitted term. Hence, using $n = 3$, a final estimate for the integral, using the coefficient given in the report, would be $\bar{H} = 0.1515$ gauss, having an error of less than 0.1 percent.

However, the relevant uncertainties in the data and other physical assumptions of the report are at least as important as the above purely mathematical discussion. For a properly balanced conclusion it is therefore necessary to report here some significant progress on the physical side of the question since the previous article was published. In general these refinements seem to converge toward equalization of the mean magnetic field deduced from rotational damping with that from other means of measurement.

It was suggested by Richard Andryshak of this Center that, although the maximum geomagnetic inclination of the satellite orbit is about 45°, the mean would be the same as the geographical, namely, 34°, so that the latter value should replace $\pi/4$ everywhere in Eq. 14. Carrying out this correction, one obtains $\bar{H}_H = 0.286$ gauss, $\bar{H}_V = 0.175$ gauss, and $\bar{H}_0 = 0.335$ gauss. Substitution of the last number for 0.356 in Eq. 15 yields $\bar{H} = 0.148$ gauss, using the correction discussed by LaPaz, or $\bar{H} = 0.143$ gauss, using the higher order approximation for that integral.

New data on the satellite and its rotation are continually being accumulated, and the reductions correspondingly revised. The 10-day means of rotational speed, as recorded up to 1 December 1959 by the Tracking Systems Division of this Center, continue to waver about a straight line on a semilogarithmic grid, as shown in Fig. 1. However, the mean relaxation time deduced from this extended curve is now 230 days, a 10-percent increase over

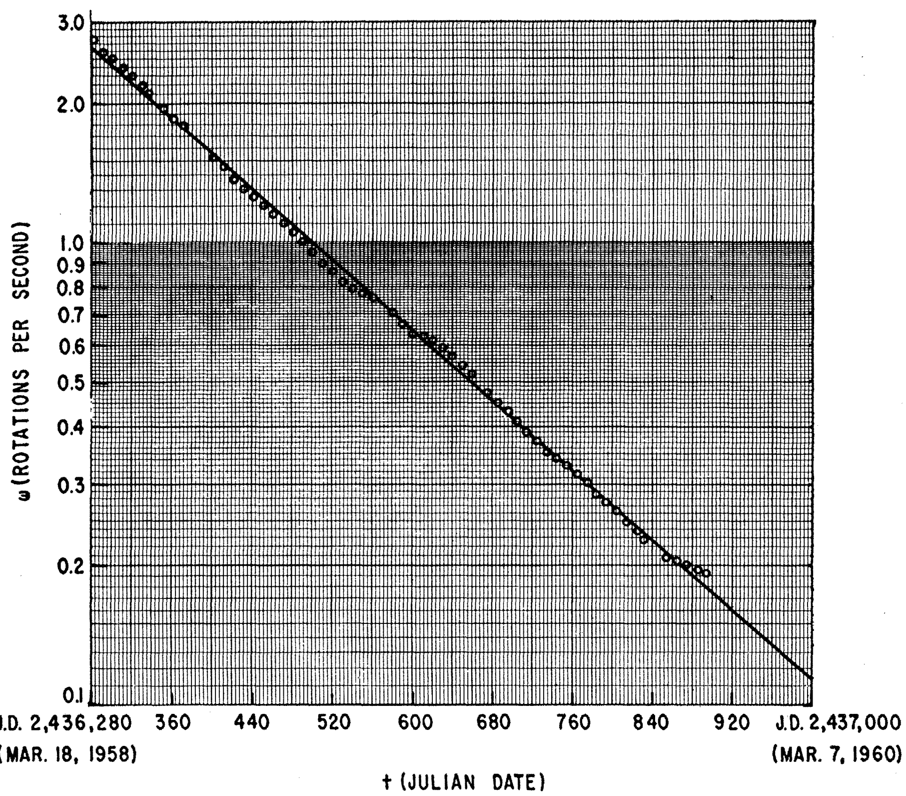

Fig. 1. Observed spin-rate versus time for satellite 1958β2 (Vanguard I), using data to 1 December 1959. The straight line represents exponential decay with a relaxation time of 230 days.

that in the previous report, by including an additional year of observations. That number should replace 210 in Eq. 1 of my report, and consequently 5.03 should replace 5.51 in Eqs. 1a and 3 there. This change would imply a 5-percent decrease in the deduced field, provided that the spin-axis of the satellite has remained fixed in space. However, the spin-axis might be expected theoretically to drift slowly toward parallelism with the magnetic field, thus decreasing the magnetic component normal to the axis and the damping factor resulting therefrom. Such axis drift would produce just such a secular lengthening of the relaxation time, which should be omitted for the present purpose if new orientation data were also available to confirm it. However, without such orientation data we shall need several more months of rotation speed data as a basis for decision about the quantitative importance of spin-axis drift.

Since the steel battery cans have lately been found experimentally to have an effective permeability of only about 2 (almost nonmagnetic) for a field perpendicular to their geometric axes, it seems necessary to abandon the previous assumption that the body-orientation of the spin-axis remained, as at orbital injection, parallel to the geometric axes of the batteries. It is in agreement with mechanical theory, recently confirmed by direct evidence for the analogous case (*5*) of Vanguard II, to expect that the position of the original body-axis, about which the moment of inertia is smaller, would be unstable. Hence, within a short time after its detachment from the launching rocket, the satellite would have slipped to rotation about a stable axis near its original equator, since about this axis the moment of inertia would be a maximum for the satellite. Note that this change of body-orientation of the axis does not necessarily imply any change in its space-orientation. The new corresponding moment of inertia was measured before launching as 69,203 gm-cm², a 2-percent increase which would correspond to a 1-percent increase of the magnetic field. When this number replaces 67,885 as an additional revision of Eq. 3 of the report, the observed total damping coefficient in that equation and the last member of Eq. 7 becomes 0.00348 gm-cm² sec. This change would correspond to a 4-percent decrease in the derived field.

Direct measurements of pertinent physical properties of the satellite materials are being carried out at the National Bureau of Standards, the resistivities under supervision of James Thomas, and magnetic permeabilities under Irvin Cooter. Resulting data for the spherical aluminum shell are changed little: $1/\sigma = 4633$ electromagnetic units (emu) at the measured (*6*) mean temperature 45°C for the satellite 80 percent of the time in sunlight and a mean thermal coefficient 0.004 per degree centigrade. For the seven steel battery cans they found $1/\sigma = 13{,}600$ emu (the previously printed value should have read 78,000 instead of 78), and $\mu = 42$. That latter value is the measured effective initial magnetic permeability of the cylindrical can (which ranged from 65 along its axis down to 2 for a field normal to that line), for the mean field component parallel to its geometrical axis. Owing to the above-discussed 90° shift of body-axis orientation, the revised damping couple on all the cylindrical shells should now be computed using only Eq. 6 of the previous report. The result for the additional couples is 0.39 that due to the spherical shell, so that 1.39 should replace 2, and 2.78 should replace 4 in the second and third members, respectively, of Eq. 7. This change corresponds to a 13-percent increase in *H*.

Using the revised numbers and data in Eqs. 2 and 7, the satellite damping constant $K = 312{,}000$ sec-gauss² $= 3.61$ day-gauss² by Eq. 8. Solving Eq. 7 gives the mean field normal to the spin-axis as $\bar{H}_{\perp} = 0.125$ gauss to replace 0.115 in Eq. 9. This new value is then substituted in Eq. 17, together with the revisions of Eq. 14 discussed above which change Eq. 16 to read: $\bar{H}_V/\bar{H}_H = 175/286 = 0.6119$. The resulting new Eq. 18 for the mean total field deduced from rotational damping is $\bar{H} = 0.144$ gauss, and the agreement with either the approximate solution 0.148 or the more exact 0.143 of Eq. 15 is still satisfactory.

This revised calculation is based entirely on directly measured data, except for spin-axis orientation. Errors of 2 percent in the measured conductivity or about 3 percent in the magnetic permeability would each lead to a 1-percent error in the derived magnetic field.

Owing to the temperature coefficient of conductivity, known to be 0.004 per degree centigrade, an error of only + 5° in the assumed mean temperature 45°C would also cause an error of + 1 percent in the calculated field. For this reason, space "weathering" by pelting meteorites and radiation, by deteriorating the satellite's temperature-controlling silicone coating, could cause the possible secular increase in the rotational relaxation time noted above.

Indeed, the wavelike variations of slope of the spin-rate curve, which correspond to variations in relaxation time between about 210 and 280 days, that is, between 9 percent below and 22 percent above the mean, may thus be fully explained by respective temperature variations of 22° below and 55° above the assumed mean. Observed temperatures (*6*) indicate a possibility of such a range. The minimum slope of the rotation curve occurred around December in both 1958 and 1959, a season when the highest satellite temperatures would be expected (*7*), owing to the annual maximum of both solar and terrestrial heating intensity. The solar maximum then is due to the earth's passing perihelion, and to the extreme solstitial solar declination causing the satellite to be in sunlight 100 percent of the time over a period of 3 weeks. The annual maximum of terrestrial heating at that season would be due to the Southern Hemisphere's being at its hottest, and the Northern, with its dominant land area, at its whitest (*8*).

RAYMOND H. WILSON, JR.
Goddard Space Flight Center, National Aeronautics and Space Administration, Washington, D.C.

References and Notes

1. R. H. Wilson, Jr., *Science* **130**, 791 (1959).
2. By Daniel Levine of Glendale, Arizona, in a private communication dated 24 Oct. 1959.
3. B. O. Peirce, *A Short Table of Integrals* (Ginn, Boston, 1929).
4. D. H. Menzel, Ed., *Fundamental Formulas of Physics* (Prentice-Hall, New York, 1955), p. 685.
5. R. H. Wilson, Jr., *Science* **131**, 223 (1960).
6. R. L. Easton and M. J. Votaw, *Rev. Sci. Instr.* **30**, 72 (1959).
7. R. H. Wilson, Jr., *Science* **127**, 812, and **128**, 209 (1958).
8. It is a pleasure to express my appreciation for the contributions of all persons who, by interest, suggestions, or new data, have enriched the discussion of this subject.

14 December 1959

Induction of Ovulation in Immature Hypophysectomized Rats

Abstract. Immature rats given minute doses of highly purified pituitary gonadotropins (follicle-stimulating hormone and luteinizing hormone) 7 to 100 days after hypophysectomy ovulated and formed corpora lutea. Neither hormone alone was effective. Luteinizing hormone repaired in part the atrophied theca interna and interstitial tissue, and follicle-stimulating hormone stimulated the development of the granulosa cells.

Until the recent availability of highly purified pituitary gonadotropins (follicle-stimulating hormone and luteinizing hormone) (*1*), it was impossible to (i) identify with clarity the real physiological actions of these hormones, (ii) induce ovulation, and (iii) produce corpora lutea in hypophysectomized rats. Up to that time, *all* of the pituitary gonadotropins tested were either too