the revised (2) Eq. 17 in the previous article (1), so that, using $\overline{H} = 0.160$,

$$\overline{H}_{\perp} = \overline{H}/1.15 = 0.139 \text{ gauss} \quad (4)$$

by Bauer's theory (3) based on surface measurements. The value of $\overline{H}_{\perp}$ found by equating the observed total damping couple constant $C/\omega = 0.3205$ gm-cm²/sec to the sum of electromagnetic couples pertaining to the various conducting parts of the Vanguard II satellite should agree with Eq. 4.

The outer cover of Vanguard II is a spherical shell of radius $r = 25.4$ cm and mean thickness $\Delta r = 0.073$ cm, including a very thin inner plating of copper, silver, and gold. It is essentially constructed of a magnesium alloy containing Al (3 percent), Mn (0.2 percent), and Zn (1 percent), for which the electrical resistivity $1/\sigma$ at 40°C is given as 10,000 electromagnetic units (emu) (4) and the magnetic permeability μ is unity. With these data, its resulting couple constant is:

$$C_0/\omega = (2\sigma\pi r^4 \Delta r \mu^2 H^2)/3 = 6.364\, H^2 \text{ gm-cm}^2\text{/sec-gauss}^2 \quad (5)$$

Inside the outer cover is a cylindrical can of the same metal, which contains most of the scientific apparatus. The cylindrical shell has a radius $r = 7.06$ cm, height $h = 33.66$ cm, and mean thickness $\Delta r = 0.10$ cm. Since the geometrical axis of the cylinder is normal to the plane of the antennas, the geomagnetic couple constant will be given by the equation for rotation about an axis perpendicular to it, namely:

$$\frac{C_1}{\omega} = \sigma\pi\, \mu^2 H^2 r^3 \left[\frac{h}{4} + \frac{11r}{24}\right] \Delta r = 0.129 H^2 \text{ gm-cm}^2\text{/sec-gauss}^2 \quad (6)$$

Other inside structural tubing of the same material is equivalent to eight cylinders, each having $h = 25.4$ cm, $r = 0.64$ cm, and $\Delta r = 0.089$ cm. By the same formula these have a total couple constant of $C_2/\omega = 0.001 H^2$ gm-cm²/sec-gauss². This completes the discussion of all satellite parts large enough to experience a perceptible couple, *unless the smaller parts contain iron.* The cylindrical supports of the two "optics" have approximately $h = 5$ cm, $r = 5$ cm, and $\Delta r = 0.01$ cm, and are said to be of stainless steel, but since that material (5) is only very slightly magnetic ($\mu < 2$), the resulting couple constant would probably be no larger than C_2/ω, so it is neglected here.

The theoretical magnetic couple on any part involves the dimensions of this part and is always proportional to its spin rate ω and electrical conductivity σ, as well as to the square of the magnetic

Reports

Geomagnetic Rotational Retardation of Satellite 1959α1 (Vanguard II)

Abstract. Radio observations made during the battery life of Vanguard II showed that the satellite's rotation was being retarded exponentially at a rapid rate. Precise analysis of electromagnetic couples on the conducting and magnetic parts of the satellite indicates a mean ambient geomagnetic field of 0.158 gauss, and confirms the eddy-current theory previously applied to Vanguard I.

During the four weeks of battery life after its launching on 17 Feb. 1959, the time-rate of radio intensity maxima for Vanguard II (1959α1) was observed with Minitrack by the tracking systems division of Goddard Space Flight Center, National Aeronautics and Space Administration. Since the nearly circular uniformity of the intensity pattern of the four antennas in the regular spin equator plane is said to make spin about that axis undetectable, the present observations are assumed to represent only precession of the regular equator, which is equivalent to rotation about an axis within 20° or so of that equator. Three-day means of these spin rates, plotted in Fig. 1 on a logarithmic scale against the date, follow a straight line having a relaxation interval (for rate to be divided by $e = 2.718$) of 72 days. Since the initial rotation rate ω_0 was 0.25 turn per second on Julian Date 2,436,616 (T_0), the smoothed empirical rates are represented by

$$\omega = 0.25 \exp[(616 - T)/72] \quad (1)$$

rotation per second for $T =$ (J.D. $-2{,}436{,}000$) days. Substituting $t = 86{,}400T$, we obtain the equivalent formula

$$\omega = 0.25 \exp[1.62 \times 10^{-7}(t_0 - t)] \quad (1')$$

rotation per second for $(t_0 - t)$ in seconds; this form is better adapted to theoretical study. Since the moment of inertia of the satellite about an axis parallel to the regular spin equator was measured as $I = 1.977 \times 10^6$ gm-cm², comparison of Eq. 1′ with the general equation for damped rotation,

$$\omega = \omega_0 \exp[C(t_0 - t)/I\omega] \quad (2)$$

indicates that $C/\omega = 0.3205$ gm-cm²/sec is the braking couple constant which would have produced the observed retardation. As in the report on the analogous problem of Vanguard I (1), it seems reasonable to assume that practically all of this couple is due to magnetic damping. The following discussion is intended to confirm the previous finding that the mean geomagnetic field deduced from magnetic damping theory agrees with that to be expected from surface measurements.

Since the orbit of Vanguard II is essentially similar to that of Vanguard I, it will be sufficient, in order to find the expected mean total field $\overline{H}$ surrounding Vanguard II, merely to substitute the slightly different values of the mean geocentric distance $a = 1.30$ earth radii and eccentricity $e = 0.166$ into the revised (2) Eq. 15 of that report to find:

$$\overline{H} = \frac{0.335}{2.197\pi} \int_0^{\pi} \frac{dM}{(1 - 0.166 \cos M)^3} = 0.166 \text{ gauss} \quad (3)$$

(more exactly 0.160, by including higher order terms)

Likewise, the launching position and direction were approximately the same for Vanguard II as for Vanguard I, so the space orientation of the predominant spin-axis can be assumed to be the same. Thus, the expected effective mean field $\overline{H}_{\perp}$ (component perpendicular to the rotation axis) is found by applying the same reducing factor 1.15 given by

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* **125**, 16 (1957)].

induction B within the part. Since, for a surrounding field H, $B = \mu H$, where μ is the magnetic permeability of the material of the part, the couple will vary as the square of such permeability. From this arises the important fact that a part made of ferromagnetic material (for which type alone μ differs significantly from unity) may suffer a damping couple millions of times greater than that acting on one of the same size made of nonferrous metal. Thus, in the discussion of Vanguard I, it was found that the magnetic couple exerted on the steel cans of seven small mercury batteries was about half that on the remaining dominant mass of the satellite.

In the case of Vanguard II, the discussion of couples on ferrous material parts is further complicated by the existence in this satellite (*6*) of several permanent magnets: (i) the tape-recorder "record-playback" magnet, (ii) the "erase" magnet, (iii) the "record" motor field magnet, and (iv) the "playback" motor field magnet. Each of these magnets was surrounded in all except one direction by magnetic shielding of "mumetal" or other high-permeability material. Such shielding material would experience an extremely high couple relative to a rotating magnetic field. However, the net secular geomagnetic couple due to these permanent magnets and their shields is believed to be relatively small, and has been neglected here. The reason is that, with a vector **B** having a scalar value thousands of times that inducible by the earth's field, which already nearly saturates these bodies in a direction fixed in them, there would be negligible resultant vector changes $d\mathbf{B}/dt$ by which alone is induced a current producing the opposing (retarding) magnetic field. For instance, in a permanent magnetic field of 1000 gauss the earth's effective field of 0.1 gauss would produce a maximum nutation of the effective field of less than 10^{-4} radian, so that the mean effective couple would be only 10^{-4} that which would be produced if no permanent field were present.

As in Vanguard I there were many cold-rolled nickel-steel battery cans, for which was measured (*2*) a resistivity $1/\sigma = 12{,}500$ emu, and an effective initial (that is, weak field) magnetic permeability μ varying with dimensions and aspects. All cans in Vanguard II were assumed to be cylinders perpendicular to the rotation axis under consideration, so that their couple constants were evaluated according to Eq. 6. Thus, for the three types of Mallory battery: (i) 39 cells of type RM-12-R with mean $\mu = 40$, $r = 0.790$ cm, $h = 4.961$ cm, and $\Delta r = 0.0254$ cm had a total couple constant $C_3/\omega = 0.316H^2$ gm-cm^2/sec-gauss^2; (ii) 23 cells of type RM-502-R with mean $\mu = 48$, $r = 0.674$ cm, $h = 4.935$ cm, and $\Delta r = 0.0254$ cm had a total couple constant $C_4/\omega = 0.160H^2$ gm-cm^2/sec-gauss^2. (iii) 67 cells of type RM-640-R with mean $\mu = 35$, $r = 0.794$ cm, $h = 1.092$ cm, and $\Delta r = 0.0254$ cm had a total couple constant $C_5/\omega = 0.167H^2$ gm-cm^2/sec-gauss^2.

The predominant geomagnetic couple on Vanguard II was due to the iron cores of several transformers, for which the material is, of course, chosen for its high permeability. The two largest of these cores, in type SSO-3 transformers, were of "Double E" form—that is, approximately a double hollow-square laminant having outer width $h = 1.2$ cm, metal width $\Delta r = 0.4$ cm, and laminant thickness $d = 0.7$ cm. The total couple constant for both cores having their rotation-axis perpendicular to d is approximately:

$$\frac{C_6}{\omega} = \sigma\,\mu^2 H^2 d\left[\frac{h^3\Delta r}{2} - \frac{3h^2(\Delta r)^2}{2} + 2h(\Delta r)^3 - (\Delta r)^4\right] = 9.480\,H^2\ \text{gm-cm}^2/\text{sec-gauss}^2 \quad (7)$$

The material of these cores was an iron containing 49 percent nickel, for which was assumed (*7, 8*) a resistivity $1/\sigma = 50{,}000$ emu at 45°C, and permeability $\mu = 2300$ for a very weak field. Four other smaller transformers of DOT type have cores of the same alloy in the form of a torus with mean radius $R = 0.24$ cm and thickness $\Delta r = 0.16$ cm, for which the total couple constant would be given approximately by:

$$\frac{C_7}{\omega} = \sigma\mu^2 H^2 \pi^2 R^3\ (\Delta r)^2 = 0.369H^2\ \text{gm-cm}^2/\text{sec-gauss}^2 \quad (8)$$

The smallest ferromagnetic couples in Vanguard II to be considered here are the cylindrical cores of five relay switches, for which $h = 2.54$ cm, $r = \Delta r = 0.15$ cm, and the axis of rotation is assumed to be perpendicular to the geometrical, so that Eq. 6 may be applied to give $C_8/\omega = 0.023H^2$. For this result the material has been assumed (*9*) to be ordinary "relay steel," a 4-percent silicon iron having resistivity $1/\sigma = 60{,}000$ emu and initial permeability $\mu = 500$.

Collecting all the above theoretical couple constants, and equating the sum to that derived from the observed rotational damping, gives the equation:

$$\sum_{n=0}^{8} \frac{C_n}{\omega} = (6.364 + 0.129 + 0.001 + 0.316 + 0.160 + 0.167 + 9.480 + 0.369 + 0.023)H^2 = 0.3205\ \text{gm-cm}^2/\text{sec} \quad (9)$$

or $17.009H^2 = 0.3205$, so that $H^2 = 0.01884$, and an effective mean field normal to the spin-axis of $\overline{H}_\perp = 0.137$ gauss would theoretically explain the observed retardation. Since the actual values for metallic properties such as magnetic permeability may vary somewhat, the close agreement with Eq. 4 is somewhat fortuitous, but even the same order of magnitude would seem to confirm the geomagnetic theory of observed rotational retardation.

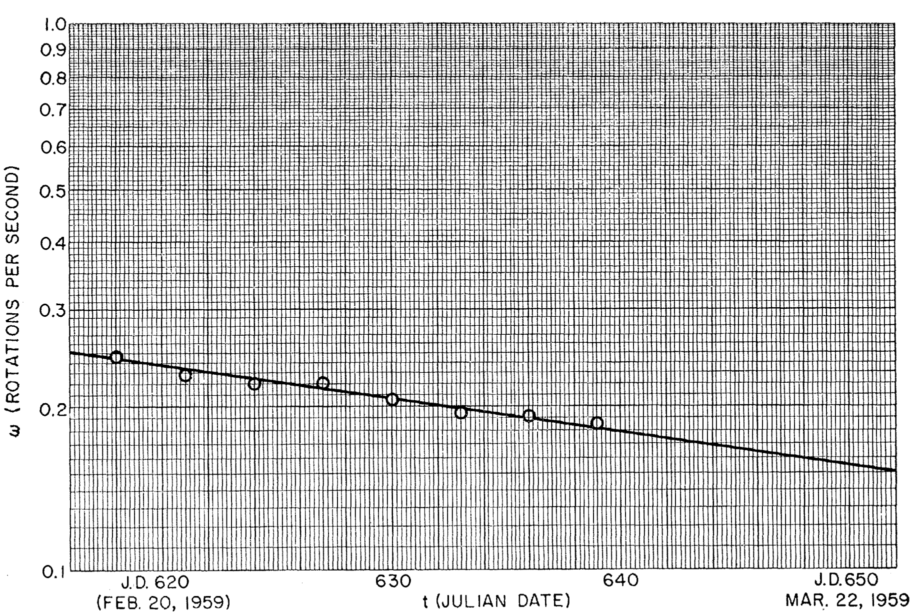

Fig. 1. Observed spin rate versus time for Vanguard II (1959α1). The straight line represents exponential decay with a relaxation time of 72 days.

Although the accuracy of this theoretical value of $\bar{H}_{\perp}$ has been increased by direct measurements of electrical and magnetic properties of some pertinent parts, which must be as near as possible like those in Vanguard II, there is little hope for such exact magnetometry as in the case of Vanguard I. For this scientific purpose Vanguard I has the relative advantages of magnetic simplicity, as well as continuing rotation observations, both radio and optical. The practically uniform specular surface of Vanguard II would seem to preclude any rotational observations after the battery life limit shown in Fig. 1.

For future practical considerations, it is interesting to note that, if the magnetic shields used in Vanguard II (of "mumetal," a favorite material for such purposes, since $\mu > 20{,}000$) had not been well saturated by interior permanent magnets, the damping couple would have been thousands of times greater than that deduced here, and the relaxation time shorter by the same factor. In this case the entire magnetic evolution of the artificial rotational motion—damping, precession, and nutation—would have been completed in about a day, and thereafter any such motion would merely follow the local vagaries of the earth's magnetic and gravitational fields.

This remarkable sensitivity of highly permeable magnetic material to its ambient field suggests its possible exploitation for orientation control of space vehicles. The present investigation indicates, by Eqs. 2 and 5, that, if the outer shell had been of mumetal, the satellite would have become directionally "locked" in the earth's field within a second of time. Could not properly designed and oriented rings of mumetal be used as rudders to supplement more complicated gyroscopic devices for direction control of space observatories?

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2 October 1959

Potential Genetic Variability of Wild Pairs of Drosophila melanogaster

Abstract. Eleven of 21 wild pairs of *Drosophila melanogaster* tested gave rise to at least 1 fly with crossvein defects out of 1000 F_2 progeny. Considered in the light of additional information, the results support the idea that an individual possesses to a large degree the potential variability of the population of which he is a member.

Any ordinary sexual population, if allowed to reproduce maximally, would soon give rise to a vast array of variant individuals (*1*). Even the descendants of only one pair, under similar conditions, would give rise to a great number of variant individuals. Just how the potential genetic variability of a pair compares with that of a whole population is a question that the experiment reported here was designed to approach.

Rather than attempt the impossible task of cataloging the variation produced in each case, I have taken a single example of phenotypic variation and investigated the proportion of individual wild pairs capable of giving rise to such a variant in the F_2 generation.

In wild populations of *D. melanogaster*, on the order of 1 in 1000 individuals has defective posterior crossveins. This trait has been found in *Drosophila* all over the world, and it is controlled (with rare exceptions) by a number of polygenes, probably about five, found on all three major chromosomes and studied by several workers (*2*). The rare but ubiquitous crossveinless phenodeviants (*3*) are flies in which rather common genes occur in rare combination—a situation rather analogous to that in which a spade is drawn out of a full deck of cards seven times out of ten.

If indeed the genes are so common, it follows that a large fraction of all wild pairs have the potential for producing offspring that include at least a tiny proportion of crossveinless flies. The experiment under discussion was set up to determine whether this is actually the case.

Twenty-one wild inseminated females were collected in their natural habitat, five grocery stores in Ann Arbor, Mich. Such females can be treated as wild pairs. All proved to be fertile. The 21 groups of F_1 flies were then inbred to produce 1000 F_2 flies each for analysis. The number of crossveinless flies in the F_2 generation was noted, each fly being rated as to the degree of crossvein defect, from 0 (normal) to 12 (posterior crossvein completely absent). This procedure involved two departures from natural conditions. First, as stated, the F_1 flies were inbred. Second, the flies were raised at a temperature of 18° ± 1°C. The inbreeding caused an increase in the total number of crossveinless (*cve*) flies observed but probably did not markedly alter the number of pairs giving rise to at least one crossveinless fly. Also, the *cve* genes are better expressed at 18° than at 25°C, but again this does not seriously alter the significance of the results.

Table 1 lists the strains of flies and the number of crossveinless individuals produced. It will be seen that 11 of the 21 strains contain at least one crossveinless fly in the F_2 generation. We may conclude, then, that at least half the wild pairs contain at least one of each gene necessary to produce the rare combination leading to the *cve* phenotype. These results confirm a preliminary experiment carried out in 1958 in which four out of seven wild pairs produced at least one crossveinless fly out of 1000 flies in the F_2 generation.

It is not certain that all crossveinless flies carry the same *cve* genes; indeed, this is improbable in the light of a comparison of certain results obtained by myself and others on various strains selected to breed true for the crossveinless trait (*4*). In addition, no set of *cve* genes has been so completely characterized as to permit a unique formulation of the distribution of these genes in a population.

It can easily be shown, however, that the estimate of "at least half the

Table 1. Crossveinless flies in F_2 progeny of wild pairs; 1000 flies were counted in each case. Letters represent the grocery stores from which the original females were collected. Total percentage of crossveinless flies, 0.6.

Strain	Crossveinless flies (*N*)
AP-1	1
AP-2	2
AP-3	7
AP-4	0
AP-5	1
MD-1	0
MD-2	0
MD-3	36
R-1	0
R-2	9
R-3	1
R-4	0
R-5	5
R-6	0
S-T	0
S-2	0
S-3	0
S-4	45
S-5	0
W-1	7
W-2	5