From 2124 C.S.T. on, the $H\beta$ intensity at the zenith increased more or less continuously until it reached a maximum at 2142 C.S.T., 7 minutes after it had first been noted that the quiet arc was beginning to form rays and at the time when a well-marked corona was about 10° south of the zenith. The corona then broke up, and the aurora consisted mostly of bright rays, some changing brightness erratically, while the $H\beta$ flux decreased steadily, reaching a level of 0.2 of the maximum only 10 minutes later. Another sky measurement was taken in the south, and by 2200 C.S.T. there was no detectable $H\beta$ radiation from the zenith, though visually the aurora was still extremely bright, being made up in large part by then of rapidly pulsating rays. Faint $H\beta$ radiation could still be measured 60° north of the zenith until 2210, when observations were stopped, but its brightness was only about 0.1 of the maximum flux, and so this measurement is quite uncertain because of the large sky correction and also because some of the flux may have come from the Vegard-Kaplan (2, 15) band of N_2, which is weakly present in auroras (*2*) and is partially transmitted by the filter. The photoelectric measurements therefore show that the primary proton flux occurs not only during the quiet-arc stage, as Fan and Schulte (*3*) have emphasized, but also in this aurora continued and increased into the beginning of the stage of formation of rays, as Bless and Liller (*4*) also found for the aurora of 9–10 April 1957.

The most significant quantitative measurement was the measured $H\beta$ intensity at the zenith, approximately 1.6 $\times 10^{-8}$ erg/cm^2 sec received at the earth from a circle 21.7′ in diameter. (For 2 minutes just at the maximum the recording pen, which was unattended, went off scale, but from the slope of the graph before and after this time it is safe to say that the maximum flux was only about 15 percent above full scale.) This observed intensity corresponds to a total emission in $H\beta$ (assumed isotropic) of 6.4×10^{-8} erg/sec cm^2 column of atmosphere, or of 1.5×10^{9} photon/sec cm^2 column of atmosphere, and since according to the theory worked out by Chamberlain (*5*) each incident fast proton produces about 11 $H\beta$ photons in the course of being slowed down, the maximum flux incident on the earth's upper atmosphere during the aurora was at least 1.4×10^{8} proton/cm^2 sec. This figure is a lower limit to the maximum flux, because protons incident with energies below about 100 kev produce less than 11 $H\beta$ photons (*6*). The measured maximum flux is similar to the maximum flux of 1.0×10^{8} proton/cm^2 sec found by Bless and Liller (*4*) from their measurements of the $H\beta$ intensity during the aurora of 9–10 April 1957 and to the maximum flux of 1.6×10^{8} proton/cm^2 sec measured by Hunten (*7*) as the upper limit for a number of bright auroras, and so a value of this order of magnitude may be characteristic of all very bright auroras (*8*).

DONALD E. OSTERBROCK
Washburn Observatory,
University of Wisconsin, Madison

References and Notes

1. W. Liller, *Astrophys. J.* **122**, 240 (1955); E. R. Capriotti, C. T. Daub, D. E. Osterbrock, unpublished observations made with the 36-in. Pine Bluff reflector.
2. See J. W. Chamberlain and A. B. Meinel, in *The Earth as a Planet*, G. P. Kuiper, Ed. (Univ. of Chicago Press, Chicago, 1954), p. 523.
3. C. Y. Fan and D. H. Schulte, *Astrophys. J.* **120**, 563 (1954).
4. R. C. Bless and W. Liller, *Astronom. J.* **62**, 242 (1957).
5. J. W. Chamberlain, *Astrophys. J.* **120** (1954).
6. ———, *ibid.* **126**, 245 (1957).
7. D. M. Hunten, *J. Atmospheric Terrest. Phys.* **7**, 141 (1955).
8. This paper is part of a program of nebular photometry, supported in part by the Research Corporation.

2 November 1959

Benzimidazole Enhancement of Ion Uptake by Plant Roots

Abstract. Excised barley roots in the presence of benzimidazole accumulate about twice as much potassium in 6 hours as those in a potassium source only. The enhanced rate of uptake is maintained steadily during this time. Sodium and calcium accumulation are similarly augmented but not at identical levels.

In the course of our studies on the physiology of plant roots, the differential effect of certain antibiotic and antimetabolites on growth, water uptake, and ion accumulation have been examined. Several benzazoles, which might be viewed either as purine or indole analogs, were compared in various systems and found to have some activity in repressing root growth and water uptake. Suggestions to the effect that benzimidazole might form complexes with certain metallic ions and thus interfere with their functioning have been postulated by Hillman (*1*) and by McCorquodale and Duncan (*2, 3*). In fact McCorquodale and Duncan (*3*) made the further suggestion that benzimidazole "pumps" ions out of the cell into the external medium, thus causing growth inhibitions due to ion deficiencies. If such is the case, the usual pattern of ion uptake would not prevail. Unexpectedly, however, cation accumulation by barley roots, either excised or attached, was found to be substantially enhanced by certain concentrations of benzimidazole and to a lesser degree by its 5-chloro derivative. Benzotriazole and benzothiazole, which were more active than benzimidazole in repressing growth and water uptake, did not similarly enhance ion accumulation in the ranges tested.

Most of our experiments have been carried out on excised roots from 7-day Atlas-46 barley seedlings grown in mass culture in an aerated medium containing $7.5 \times 10^{-5}M$ $CaSO_4$ and $2.5 \times 10^{-5}M$ $MgSO_4$. The samples of excised roots, 7.5 gm fresh weight in size, were treated with a 200-ml solution containing the cation and antimetabolite at 25°C. The solutions were continuously aerated through sintered glass aerators during the test period, up to 6 hours. Analyses for K^+, Na^+, and Ca^{++} were made by flame photometry in a Beckman model DU spectrophotometer. The amount of cation taken up by the roots was usually determined by difference between the initial and final content of the ambient solution.

In preliminary experiments, excised roots exposed to $1 \times 10^{-3}M$ benzimidazole accumulated about twice as much potassium from unbuffered $1 \times 10^{-3}M$ K_2SO_4 as roots in the same strength of potassium salt alone. The response curve for enhancement of potassium uptake plotted against benzimidazole concentration passes through a peak in the vicinity of $1 \times 10^{-3}M$; at both higher ($3 \times 10^{-3}M$) and lower ($< 1 \times 10^{-4}M$) concentrations the amount accumulated is not significantly different from that accumulated by the untreated roots.

Rate studies showed that the enhanced rate of potassium uptake in the presence of benzimidazole was maintained steadily for at least 6 hours (Fig. 1). In this typical experiment, excised roots in $1 \times 10^{-3}M$ K_2SO_4 accumulated potassium at a steady rate of 30 μg of K per hour, per gram (fresh wt.) after the first hour, whereas with the added presence of $1 \times 10^{-3}M$ benzimidazole, the steady rate was 124μg of K per hour, per gram (fresh wt.)—almost four times higher. At the termination of the experiment; the benzimidazole-treated roots had accumulated 1.0 mg of K per gram (fresh wt.) while the ambient solution, initially containing 78 μg of K per milliliter, was depleted to 40 μg/ml, whereas in the potassium sulfate alone only 0.387 mg of K per gram (fresh wt.) was accumulated with the ambient solution still containing 63 μg/ml. The effect of benzimidazole, therefore, is to augment the accumulation process.

Enhancement of potassium uptake does not necessarily require the simultaneous presence of benzimidazole and

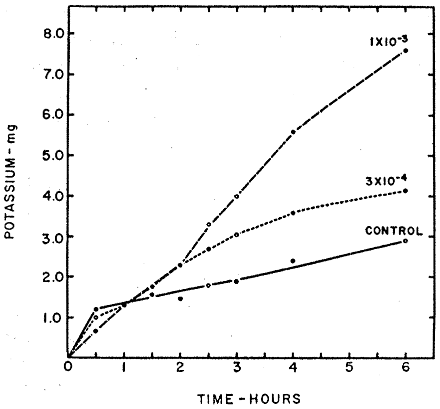

Fig. 1. Rate and extent of potassium uptake by excised barley roots in the presence of various levels of benzimidazole during a 6-hour period (7.5 gm fresh weight of barley roots in 200 ml of $1 \times 10^{-3}M$ K_2SO_4 at 25°C).

potassium salt. Roots pretreated with benzimidazole and then transferred to $1 \times 10^{-3}M$ K_2SO_4 attained a potassium content substantially higher than that of untreated excised roots placed in the potassium source for an equal time (0.68 mg of K per gram [fresh wt.] by the benzimidazole pretreated roots versus 0.32 mg/g [fresh wt.] by the untreated roots; pretreatment and uptake periods were each 3 hours).

The additional increment of potassium entering the roots in the presence of benzimidazole is mobile and becomes distributed through the plant. This was determined in experiments with intact barley seedlings, which, after exposure to $1 \times 10^{-3}M$ benzimidazole and K_2SO_4 for 24 hours, were transferred to potassium-free medium for 1 week to allow transport to the leaves to occur.

The benzimidazole enhancement of uptake is not peculiar to potassium but has been demonstrated also with sodium and calcium, with the use of excised barley roots. The response curves for the different ions do not appear to be identical; in fact, the benzimidazole concentration producing maximum calcium uptake is lower than that for potassium. There also appears to be an enhancement of nitrate uptake, but not of chloride, from their respective potassium salts. Increased potassium uptake has been shown to occur with excised pea roots, but could not be demonstrated with rooted tomato cuttings.

The evidence presently available is compatible with the view that the increased ion uptake induced by benzimidazole is brought about as the result of some enlargement of the specific accumulatory mechanism. The respiratory activity of root tips (Q_{O_2}) is unaffected by benzimidazole at the concentrations enhancing ion uptake. The increased accumulation of potassium is not cyanide-sensitive, and the potassium can be substantially but not completely removed from roots by treatment with excess 0.001N HCl for 3 hours. The normal pathways of ion uptake in barley roots generally favor potassium over sodium. The increase in sodium taken up from Na_2SO_4 when benzimidazole is present is not nearly as large as the increase in potassium from K_2SO_4 under similar conditions; thus the relative ease of entry of these two cations is not changed by bezimidazole.

Benzimidazole therefore may increase the number or capacity of the specific carrier sites, perhaps by incorporation in the carrier, or accelerate the rate-limiting, irreversible step at the inner surface of the membrane whereby the ion is split from the carrier, thus increasing the effective capacity of the carrier complex.

In considering such hypotheses, it would be helpful to know the effect of benzimidazole, if any, in the ion accumulatory systems of mammalian tissue, or of microorganisms (*4*).

M. J. KLINGENSMITH*
A. G. NORMAN

Department of Botany,
University of Michigan, Ann Arbor

References and Notes

1. W. S. Hillman, *Plant Physiol.* **30**, 535 (1955).
2. D. J. McCorquodale and R. E. Duncan, *Records Genet. Soc. Am.* **24**, 584 (1955).
3. → ——— *Am. J. Botany* **44**, 715 (1957).
4. This work was carried out in the Plant Nutrition Laboratory of the University of Michigan as a part of the activities of the Ford Agricultural Plant Nutrition project. Paper No. 25.

* Present address: Department of Botany and Bacteriology, Ohio Wesleyan University, Delaware.

11 September 1959

Magnetic Damping of Rotation of the Vanguard I Satellite

Abstract. Explicit integration of integrals of the type basic to comparison of observed and predicted values of the earth's mean total magnetic field reveals an error in the numerical integration recently employed by Raymond H. Wilson, Jr., in making such a comparison for the special case of Vanguard I. Correction of this error destroys the satisfactory agreement he found between the value implied by rotational damping and the theoretical value.

Raymond H. Wilson, Jr., reports (*1*) satisfactory agreement between the mean total magnetic field of the earth, as deduced from the observed decreasing spin rate of satellite 1958β2, and the value of the earth's mean total magnetic field, as calculated from the theory of L. Bauer. The near agreement found by Wilson rests on his evaluation by numerical integration of the integral

$$h = \int_0^{\pi} \frac{dM}{(1 - 0.19 \cos M)^3} \quad (1)$$

where the constant 0.19 in the integrand is the eccentricity of the orbit followed by satellite 1958β2, and the variable of integration, M, is the mean anomaly of the satellite. This numerical integration is in error, as is shown below. Furthermore, if other elliptic orbits of different eccentricities, e, are considered, each such orbit calls for a separate numerical integration, an obvious disadvantage.

Integrals of the type of Eq. 1 have been explicitly integrated by me in connection with a critical re-examination of the conjecture that the magnetic field of the earth is responsible for such remarkable concentrations of siderites as that within the so-called Farrington circle, a conjecture first subjected to an invalidating numerical test under certain simplifying assumptions some 20 years ago. (*2*).

If we consider the indefinite integral

$$I = \int \frac{dM}{(1 - e \cos M)^3}, \quad 0 \leqq e < 1 \quad (2)$$

suggested by an obvious generalization of the definite integral (Eq. 1), it is not difficult to verify that, except for the integration constant $I = J/2(1 - e^2)^2$, where J is given by

$$J = \frac{(4e - 3e^2 \cos M - e^3)}{(1 - e \cos M)^2} \sin M - \frac{2 + e^2}{(1 - e^2)^{\frac{1}{2}}} \arcsin \frac{\cos M - e}{1 - e \cos M} \quad (3)$$

Since for the special case considered by Wilson, the term in Eq. 3 involving $\sin M$ as a factor vanishes at the limits of integration, while e has the value 0.19, it is found that

$$h = \frac{-2.0361}{2(0.9639)^{5/2}} \times \arcsin \frac{\cos M - 0.19}{1 - 0.19 \cos M} \Bigg|_0^{\pi} = 1.11606\pi \quad (4)$$

a value more than 11 percent in excess of the value $h = 1.0051\pi$ implied by Eq. 15 in Wilson's paper. The correct value of the time mean field according to Bauer's theory is therefore $\overline{H}_B = 0.15767$ gauss and not 0.142 gauss. The discrepancy between this value of $\overline{H}_B$ and the observed value $\overline{H}_O = 0.138$ gauss is almost five times that obtained by adopting the erroneous value $\overline{H}_B = 0.142$ gauss.

In view of the importance of the problem attacked by Wilson, the un-