the polarities shown, the direction of the e.m.f. induced in B is "in," as indicated by the cross, the filaments f and f′ acting concurrently. This agrees with the general law that when the primary current decreases, the secondary induced e.m.f. is in the same direction as the primary current.

The tube A may be considered as consisting of pairs of filaments, such as f and f′. Since an elementary e.m.f. is induced in B by each pair of filaments, and the action is cumulative, a finite e.m.f. should be induced in B when di/dt in the whole tube has a finite value.

Thus, according to Reasoning I, there should be no e.m.f. induced in B, while according to Reasoning II, there should be an induced e.m.f. of finite value. Before unraveling this seeming paradox, the following propositions should be considered:

(1) Is it legitimate to speak of an e.m.f. induced between the open ends of a long straight conductor? To measure this e.m.f. it would be necessary to introduce leads to a voltmeter, thus forming a closed circuit. If an electrometer be used instead, the circuit would still be closed through electrostatic lines of force within the instrument. Should the leads and the measuring instrument be placed within the tubular conductor A, there should be no indication when the current i is varied. Should the instrument and the leads be placed outside A, a loop would be formed, linking with some of the external flux H, and the induced e.m.f. would depend upon the total flux enclosed by the loop.

(2) Careful writers do not speak of an e.m.f. induced in an open straight secondary conductor, but of the direction of the secondary current. This implies a closed secondary circuit and avoids the vexed question as to the seat and location of this e.m.f. See, for example, J. C. Maxwell, *Electricity and Magnetism*, Vol. II, p. 178; Foster and Porter, *Electricity and Magnetism*, p. 394.

(3) In Fig. 3, let K be a straight infinite conductor carrying a current i. Let N be a parallel secondary conductor of finite length, with open ends, at a distance r from K. Let the current i return through a cylindrical shell P of very large radius R.

The lines of force due to i are concentric circles, and the flux Φ, comprised between N and P, per unit of axial length, is proportional to $i \log(R/r)$. Should i vary at the rate di/dt, the e.m.f. induced in N, per unit length, would be proportional to $(di/dt) \log(R/r)$. But R is arbitrary and tends to infinity, so that the e.m.f. induced in N seems to be indefinitely large. Here again, to measure this e.m.f., the circuit of N would have to be completed, for example by means of a parallel wire N′, at a distance r′. The flux enclosed in this secondary loop has a finite value, proportional to $i \log(r'/r)$, and the e.m.f. induced in the loop (not in one of the conductors) has a definite value (finite) confirmed by experiment.

(4) If an e.m.f. could be induced in a long straight secondary conductor, as shown in Figures 1 and 3, then by grounding one end and providing the other end with a sharp point, an intense local electrostatic field should be produced. The existence of this field could perhaps be demonstrated by some delicate ionization experiment, Stark effect, etc. On the other hand, grounding one end would give a closed circuit, through displacement currents along lines of force between the sharp point and the ground, so that the experiment may not be conclusive.

Thus, on the whole, it seems as though the foregoing paradox is based on the impossibility of either computing or measuring an e.m.f. induced in an open conductor, without considering a return circuit of some kind, either conducting or through a dielectric. In view of the very fundamental nature of the phenomena and laws involved, it is hoped that other points of view will be contributed to this discussion.

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RATE OF VIRUS SPREAD IN TOMATO PLANTS

WHEN a plant is inoculated at one point with a virus disease, at what rate does the infective principle diffuse itself to other stems, leaves or shoots? Assuming that the incubation period is constant—that symptoms will appear in a given time after the infective agent has reached any point—the appearance of symptoms in a succession in other portions of the plant distant from the point of inoculation ought to provide a measure of the rate of virus spread from the original inoculation point. This observational method, however, relies on uniformity of growth in all parts of the plant and such uniformity may not exist; it further depends on the detection of symptoms at the same stage in their development, which is by no means a certain procedure.

The more direct method of measuring the progress of virus in a plant system here outlined appears to avoid the disadvantages mentioned and to provide a means, accurate within certain limits, of measuring the rate at which the virus moves from part to part of the plant. The results of the short series of preliminary tests are here recorded largely for the purpose of calling attention to and illustrating the method, since the conclusions that might be drawn from the few cases under observation must necessarily be accepted as only a rough approximation to the truth.

Eight tomato plants in pots were grown in such a manner as to develop several horizontal branches, each

of which was bent and led under the earth in a secondary pot to encourage rooting and thus form a readily detachable second plant. The rooting process was hastened by a partial cut between the original and secondary pots. There was thus produced a "colony" with all its units organically connected but capable of being separated at any time and in any fashion desired. The colonies were grown in a greenhouse under a close cheese-cloth cage. The greatest care was taken throughout to avoid accidental infection through insects, handling, touching of leaves, watering, etc. There is no evidence that any such accidental infection occurred anywhere in the series.

When all secondary plants were well rooted but still attached to the parent plant a single shoot of the parent was inoculated with freshly expressed juice from tomato leaves showing marked mosaic. A glass tube drawn to a capillary point was used for the purpose, pressure being supplied by means of a dropper bulb on the end. Inoculations were made near the growing point.

TABLE OF RESULTS INDICATING THE RATE OF SPREAD OF TOMATO VIRUS IN TOMATO PLANTS

Series of Colonies	Condition of all shoots twenty-four days after inoculation date; 0 – healthy; X – mosaic					
	Inoculated shoot	Daughter plants separated from colony at specified intervals after inoculation date				
		3 days	10 days	15 days	19 days	24 days
A	X	0	X	X	X	
B	0	0	0	0	0	
C	X	0	0	X	X	
D	X	0	0	0	X	X
E	X	0	X	X	X	X
F	X	0	X	X	X	XX
G	0	0	0	0	0	0
H	X	0	0	X	X	

After inoculation a single secondary plant was removed from each colony at intervals of three, ten, fifteen, nineteen and twenty-four days where the number of daughter plants was sufficient for such a series. These isolated plants were kept under observation to see if mosaic developed.

Twenty-four days after inoculation a record of the various series indicated that in two colonies (B and G) the inoculation had failed. There was no sign of mosaic in the shoot originally inoculated or any of the daughter plants in either colony. In the remaining six all plants removed after nineteen days had marked mosaic symptoms on the young growth; in five of the six the disease had appeared in plants removed after fifteen days; and in three plants taken away after ten days the disease was also evident. None of the plants removed after three days had developed mosaic twenty-four days after inoculation.

It is evident from the above results that the infective principle was unable to pass from the point of inoculation beyond the place of separation in any case in three days; that in half the cases not more than ten days was required to traverse this distance; that in five out of six cases the virus had passed into the daughter plants in less than fifteen days; and that in only one case was a period of fifteen days insufficient. In this case the two plants removed after nineteen days were both affected by mosaic on the twenty-fourth day, so that if one allows for a suitable incubation period it is evident that the point of separation must have been passed near the fifteen-day period.

The distances to be traversed by the virus in these colonies varied from eight to eighteen inches. We may see from the above records that these distances were traveled by the virus in periods which might be something less than ten days or slightly more than fifteen days. We have no right to assume that a uniform advance was made during this period, but for purposes of expressing the rate of progress of the virus in concrete fashion it may be permissible to adopt the average rate in common usage for such purposes. On this basis the transfer of mosaic virus appears to take place through the shoots of the tomato plant at a rate somewhere in the neighborhood of one to two inches per day or one to two millimeters per hour.

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FEEDING PLANTS MANGANESE THROUGH THE STOMATA[1]

DOES manganese benefit plants mainly by increasing the oxidative power of the soil, as has been claimed by Skinner and Reid[2] or is its chief value as a promoter of enzyme activity within the plant, as stated by Bertrand?[3] McHargue[4] has demonstrated

[1] Contribution 354 of the R. I. Agricultural Experiment Station, Kingston, R. I.

[2] Skinner, J. J., and Reid, F. R., "The Action of Manganese under Acid and Neutral Soil Conditions." *U. S. D. A. Bull.* 441. 1916.

[3] Bertrand, Gabriel, "Sur l'intervention du Manganese dans les Oxidations provoqués par la laccase." *Compt. Rend. Acad. Sci.* (Paris) I: 124: 1032–1035.

[4] McHargue, J. S., "The Rôle of Manganese in Plants." *Jour. Am. Chem. Soc.* 44: 1592–1594. 1922.