

too small to account for the volumes involved in the transpiration stream, and root pressure cannot usually be demonstrated in transpiring plants. Although this argument is frequently raised, it is an obvious *non sequitur*. Transpiration, when it does occur, provides a mechanism capable of moving large quantities of water, but this can quite well occur independently of other mechanisms; they are in no way mutually exclusive; and the common methods so far devised for demonstrating root pressure require the abolition of the transpiration mechanism during the test. Scholander has recently introduced a method which does permit simultaneous demonstration of the two and has measured them simultaneously in certain vines (7, 8).

3) It has been stated, for example by Kramer (9), that "A . . . reason for doubting that . . . root pressure phenomena play an essential role in the intake of water, is the fact that it [root pressure] apparently never occurs in Gymnosperms. It would be very surprising if such a process were essential in one group of plants, yet not even occur in another [similar] group." And again, "Root pressure has never been observed in the Gymnosperms, and it is probable that active absorption never occurs in that group" (9, p. 790).

This last argument, if based on incontrovertible evidence, would indeed seem to make untenable any idea of root pressure being of general importance in the movement of water to the tops of tall trees.

On a suggestion from Scholander, made during the discussions at the Symposium on the Physiology of Forest Trees at the Cabot Foundation, Harvard Forest, Petersham, Mass. (Apr. 1957), we set out to examine the validity of this argument (10). Simple manometers were attached to the roots of three species of Gymnosperms: *Pinus strobus*, *Picea glauca*, and *Picea rubens* and, for comparison, on three Angiosperms: *Betula lutea*, *Populus alba*, and *Fraxinus americana*.

The procedure was as follows. Trees of as uniform age and size as possible were chosen, 15 to 20 feet in height, 25 to 40 years old. Roots were traced away from the trunk until branches 0.5 to 1.0 cm in diameter were exposed. These were severed perpendicular to the axis. Since such tissues, in actively transpiring trees, sometimes show negative pressures in the vessels, the roots were left for about 15 minutes to allow any air which might be sucked into the vessels by this negative pressure to come into equilibrium. A second cut was then made about 15 cm acropetal to the first so as to expose a new series of water-filled vessels, now in equilibrium. A rubber hose of suitable diameter was turned back upon itself for a distance of about

2 cm and was then placed on the root by rolling the everted portion on, so that the root tissues were not torn or bruised. A simple manometer of about 0.5 mm internal diameter was then attached to the hose and suitably supported in a vertical position. Readings of the height of fluid in the tubes were recorded at intervals from 11 July to 19 August 1957. It is to be noted that this is the driest part of the year, a season when transpiration is at a maximum and when positive sap flow is least likely to be evident, even in Angiosperms.

Of 51 manometers placed on roots of 17 coniferous trees, 24 (47 percent) showed positive sap flow. In 14 (27 percent) the columns developed were more than 40 cm in height. This was commonly the length of our manometer tubes, and greater heights could be read only by splicing on further tubes. In 13 cases such additional tubes were attached and flows up to 80 cm were recorded. In one case a mercury column was added, using a horizontal "S" connection and a mercury rise of 4 cm, equivalent to about 55 cm of additional water, to a total of about 70 cm, was recorded. In eight cases flow over the top of the manometer occurred and the fluid was lost. In one case a flask was attached and 30 ml of fluid were collected. This was on a red spruce root (*Picea rubens*).

Under comparable conditions, the maximum flows observed from Angiosperm roots were 100 cm (*Betula alba* and *Fraxinus americana*). It is significant that no flow was observed in either Gymnosperms or Angiosperms growing on dry soil, whereas flow was observed in trees growing in moist locations.

From these experiments it is clear that, contrary to previous statements (8) active water secretion and "root pressure" do exist in Gymnosperms and can be demonstrated in several species under the conditions in which they are demonstrable in Angiosperms. Angiosperms do not, as has sometimes been suggested, occupy a unique position in this respect. The supposed absence of root pressure in Gymnosperms is not a valid argument against the general significance of root pressure in the water economy of plants.

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10. The work presented here was carried out as part of the Jackson Laboratory's program of training in research for secondary-school students, during the summer of 1957.

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Effect of Transverse Atmospheric Drag on Satellite Orbits

In considering the various factors which influence the orbits of earth satellites, it is obvious that the motion of the earth's atmosphere, rotating with the earth, will tend to deflect the motion of the satellite. An approximate formula may be devised very simply to indicate the maximum perturbation caused by this effect.

When a satellite enters the atmosphere, the relative velocity giving rise to the air resistance, or drag force, is the resultant of the orbital velocity and the rotational velocity of the atmosphere. For any orbit not in the plane of the equator, the drag has a component transverse to the orbital motion, tending to deflect the motion and thus to change the plane of the orbit.

To derive an *approximate* formula for the *maximum change* to be expected, we make two simplifying assumptions: (i) that the plane of the elliptical orbit is parallel to the polar axis of the earth (a polar orbit); (ii) that closest approach (perigee) always occurs at the equator (actually, the position of perigee would change progressively for a polar orbit; for exact calculations suitable averaging factors must be included); (iii) that the satellite is spherical (actually, if it were finned so as to head into the relative wind, or if it tumbled at random, the averaged results would be the same as far as the total orbit change is concerned).

No assumptions need be made with regard to the magnitude of the drag or its dependence on velocity. The ratio of the component of drag, D_t , transverse to the orbit and the component, D_o , parallel to the orbit, will be the same as the ratio of transverse and orbital components of the relative wind velocity, v_e and V_o . That is:

$$D_t/D_o = v_e/V_o, \quad (1)$$

where v_e is the cross-wind due to the earth's rotation.

On each revolution, the satellite suffers a small change in velocity, ΔV , due to drag (primarily near perigee) and a corresponding change in momentum, ΔMV . ΔV and ΔMV may be separated into components ΔV_o and ΔMV_o parallel

to the unperturbed orbit and ΔV_t and ΔMV_t transverse to them. Let $\Delta\theta$ be the angle by which the velocity is deflected. This will be

$$\Delta\theta = \Delta MV_t / MV_o \quad (2)$$

since ΔV is small. But the change in momentum is proportional to the product of the force acting and the time during which it acts, so that

$$\Delta MV_t = D_t \Delta t \quad (3)$$

and

$$\Delta MV_o = D_o \Delta t, \quad (4)$$

where Δt is the time during which the forces act.

From Eqs. 1 and 3

$$\Delta MV_t = \frac{v_e}{V_o} D_o \Delta t, \quad (5)$$

or, by Eq. 4,

$$\Delta MV_t = \frac{v_e}{V_o} \Delta MV_o, \quad (6)$$

so that, substituting Eq. 6 in Eq. 2,

$$\Delta\theta = \frac{v_e}{V_o} \frac{\Delta MV_o}{MV_o} = \left(\frac{v_e}{V_o}\right) \left(\frac{\Delta V_o}{V_o}\right) \quad (7)$$

Since this deflection is assumed to occur near the equator, the orbit plane will be tilted by the same angle with respect to the equatorial plane, so that the orbit for the next revolution would not pass exactly over the poles. On each revolution, a similar effect occurs; but since the effect is small, we may assume that the polar orbit is approximately maintained and regard the equation as giving the total change in orbit inclination corresponding to any given change in orbital velocity, regardless of how many revolutions are involved.

Two further assumptions are to be made now, one with regard to the average orbital velocity, the other with regard to the fractional change of the velocity. We assume 18,000 mi/hr as a fair average and assume a change of 20 percent as a maximum value over the portion of the satellite's life during which elliptical orbit shrinks to a circular orbit. The transverse component of the relative wind velocity is just the earth's rotational velocity, taken as 1000 mi/hr at the equator. Then, over this phase of the satellite's lifetime:

$$\Delta\theta_{\max} = \frac{1000}{18000} = \frac{20}{100} = 0.01 \text{ radian or } 0.6^\circ \quad (8)$$

Somewhat more refined calculations, which take into account the inclination of the orbit and the progression of perigee, predict changes in orbit inclination of 0.1° to 0.2° from the original inclinations (of 65° and 35°) for U.S.S.R. and U.S. satellites launched so far (over their lifetimes, but not includ-

ing the last revolution). Unfortunately, up to the time of writing, the observational data published on orbit inclinations have not been of sufficient accuracy to check these predictions on the first two U.S.S.R. satellites. Because of the smallness of this effect it is unlikely that it can be used to obtain any definite information on winds and tides in the upper atmosphere.

Although the transverse atmospheric drag effect is seen to be small throughout most of the satellite's lifetime, it becomes of major importance in the last few thousand miles of the final revolution, when the velocity decreases from around 17,000 mi/hr to some lower value at impact. For all satellites so far put in orbit, the mass-area ratios are such that the satellites may be expected to lose substantially all forward relative velocity in the lower atmosphere, and to fall nearly vertically before impact, if they withstand the frictional heating without burn-up.

As a simple case, consider impact at the equator. The "orbital" motion, just before impact, will be in the plane of the equator. Therefore, the change in orbit inclination will be equal to the initial inclination, whatever its original value.

Only large meteorites or satellites having mass-area ratios many times larger than present satellites would be expected to have any appreciable residue of forward velocity at sea-level impact. Even for these, $\Delta\theta$ would be a major fraction of θ , as may be calculated roughly by applying Eq. 7 in several steps over the velocity range.

Perhaps it should be pointed out explicitly that $\Delta\theta$ is measured with respect to the initial orbit plane, fixed in space. From the moon, for instance, the curvature of the orbit path would be observable. To an observer stationed at the equator on the projected track of the orbiting satellite, no such curvature would be apparent. Neglecting the small change of the atmospheric cross wind with latitude near the equator, the apparent course of the satellite in polar orbit relative to the observer on the equator will be slightly westward, as the result of the orbital velocity and the rotational velocity of the earth's surface. The satellite will stay on this course, relative to the (rotating) observer, regardless of the time-velocity history along the course, since both the transverse and orbital components of velocity change proportionately with the decrease of the resultant. The observer will note only the slowing, and the change of motion from horizontal to nearly vertical. The satellite would arrive at the point of impact several minutes later than it would have passed over had it not been slowed or stopped by the atmosphere. During this delay the earth's revolution

would move the impact point many miles, but this motion is, of course, not apparent to the earth observer.

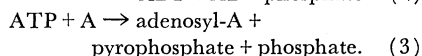
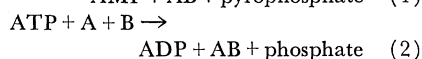
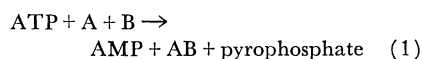
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Role of Magnesium in Enzyme-Catalyzed Syntheses Involving Adenosine Triphosphate

Adenosine triphosphate or one of the polyphosphates with which it is in equilibrium (guanosine, cytosine, and uridine triphosphates) is a reactant in each of a large number of enzymatic syntheses (1, 2), and these ATP- (3) or polyphosphate-dependent syntheses account for the preponderant proportion of all known biosynthetic reactions. These reactions fall into one of the following three categories (4):



Regardless of the category, all known ATP-catalyzed reactions show an absolute requirement for magnesium ions (2). Other divalent metals such as Mn^{++} or Ca^{++} may replace Mg^{++} in some cases, but the maximal activity which these ions induce may equal but never exceed the maximal activity which obtains in presence of Mg^{++} .

Since a very wide spectrum of synthetic reactions is encompassed by ATP-dependent enzymatic processes, the universal requirement for magnesium ions undoubtedly reflects some important underlying chemical principles. This report deals with several considerations which may throw light on these principles.

Magnesium ions chelate rapidly with ATP (5), polyphosphates (6), phosphoric esters, inorganic phosphate, hydroxy acids (7), amines (8), and amino acids (9) under physiological conditions. Thus all the reaction partners in known ATP-dependent reactions are capable of chelation with magnesium ions. The effect of magnesium chelation in such reactions is to lower the free energy of activation of the rate-determining step. This is accomplished in two ways—first by lowering the heat of activation of the reaction, and second by virtue of a stepwise mechanism that eliminates the unfavorable entropy of activation in the rate-determining step.

The manner in which chelation of the reactants with magnesium ions reduces the heat of activation has been well discussed by others (10). Essentially, mag-