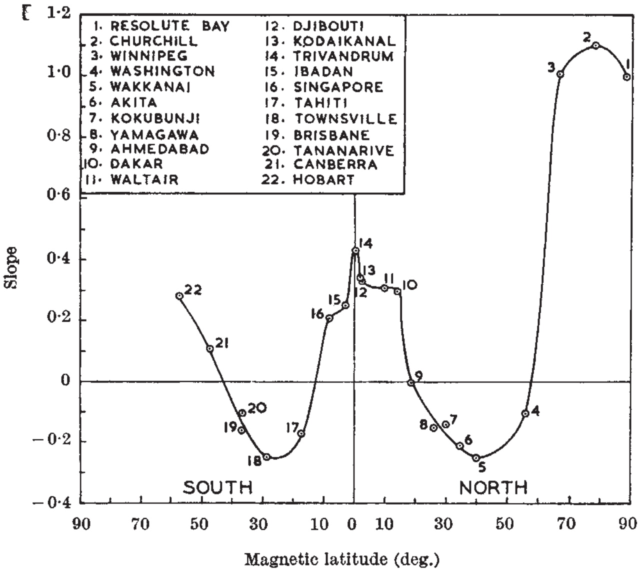

Fig. 1. Plot of spread-F variation with sunspot number versus magnetic latitude

range of 40–120. It is found that the slopes of these linear portions vary widely from latitude to latitude, giving both positive and negative values. Positive slopes are obtained for the stations which show positive correlation of mean percentage occurrence of spread-F with sunspot numbers, and negative slopes are obtained with those which show negative correlation. For most of the stations used in this analysis only data for either ascending or descending sunspot cycles are available and, as such, the slopes obtained from either of these cycles are used assuming that there is no difference between the slopes obtained from the ascending and descending cycles for each station. With the view of determining whether there is any systematic variation of these slopes with latitude, the slopes thus obtained from each of the plots of the individual stations have been plotted against geographic, geomagnetic and magnetic latitudes. Of the three plots, the data for the variation of slope with magnetic latitude fit best into a smooth curve (Fig. 1).

Fig. 1 clearly shows that there is a systematic latitude variation of spread-F occurrence with sunspot number. For example, within the low-latitude range of 12° S. to 18° N., the slopes are positive, indicating that, for the low-latitude belt, the spread-F occurrence increases with the increase of sunspot number, the effect being greater for the stations nearer the magnetic equator. The sunspot effect on spread-F seems to be quite prominent for the stations close to the magnetic equator as can be seen from Fig. 1, in which the slope for Trivandrum (Mag. Lat. 0°) stands out prominently from the rest of the surrounding stations. There is a middle-latitude range of about 20°–60° in the northern hemisphere and 12°–45° in the southern hemisphere where the slopes are negative. This means that for all the middle-latitude stations in the ranges specified, the percentage occurrence of spread-F decreases with increasing sunspot number. Furthermore, the slopes attain a maximum negative value for stations situated about a latitude of 40° in the northern hemisphere and about 30° in the southern hemisphere. It may also be seen from Fig. 1 that the sign of the slope changes from negative values to positive values at high latitudes both in the northern and southern hemispheres, the change being more pronounced in the northern hemisphere. It may also be noted that the curve is not symmetrical with respect to the magnetic equator. The results obtained in this investigation are in general agreement with those reported earlier.

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[1] Wells, H. W., *J. Geophys. Res.*, **59**, 66 (1954).
[2] Singleton, D. G., *Austral. J. Phys.*, **10**, 60 (1957).
[3] Kotadia, K. M., *Proc. Ind. Acad. Sci.*, A, **50**, 259 (1959).
[4] Lyon, A. J., Skinner, N. J., and Wright, R. W. H., *J. Atmos. Terr. Phys.*, **19**, 145 (1960).
[5] Rangaswamy, S., and Kapasi, K. B., *J. Atmos. Terr. Phys.*, **25**, 721 (1963).

PHYSICS

The Bath-Tub Vortex in the Southern Hemisphere

It has long been thought that water draining from a tank would rotate counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere, provided other influences were kept small compared with the influence of the rotation of the Earth. This idea has only recently been tested, by Shapiro in Watertown, Massachusetts, as part of a film on vorticity[2–4], and later by Binnie in Cambridge, England[1]. Shapiro and Binnie both acquired confidence, after surmounting difficulties in their early experiments, that the counter-clockwise rotations observed in their later experiments were due to the rotation of the Earth.

The experiment has now been performed in Sydney, Australia. For this we should like to express appreciation for assistance from the University of Sydney, Tufts University, and the U.S. National Science Foundation.

The apparatus was modelled on Shapiro's. It was a tank, 6 ft. in diameter and 9 in. high, with a central drain pipe 0·375 in. in diameter connected to a draining hose. The tank differed from Shapiro's in ways suggested by early difficulties Shapiro and Binnie experienced. It was made of ply-wood instead of metal, to reduce thermal convection. The drain pipe projected up 1 in. from the bottom, and was tapered to a sharp-edged opening; and the tank was located in a small, cement-walled basement room which had an overhead louvre but no windows, and in which both room temperature and inlet-water temperature remained within a degree of 20° C during the tests. As in Shapiro's experiments, the tank was filled by hose to a depth of about 6 in. above the orifice. The hose was directed so as to leave water swirling counter-clockwise in the tank.

Initially, the apparatus did not work as expected. In the first test, after a 60-h settling period, dust particles on the water surface showed no discernible rotation at any time during an 80-min draining period. This apparently meant that the water was moving to the centre so slowly that the viscous damping effect of the bottom was cancelling the water's angular momentum to the point where no angular momentum was perceptible in the draining fluid. To speed draining, the tank was raised to 30 in. above the floor. From then on, with the increased drop of the draining hose, drainage took about 22 min, and some form of rotation was always observed above the orifice.

Clockwise rotation was observed in all five of the later tests that had settling times of 18 h or more. During the first 10 or 12 min of drainage, no rotation was apparent. Rotation then developed as drainage progressed. In three of these tests a float 0·625 in. in diameter, a slice from a wine cork, was used to indicate rotation. It reached speeds of about one revolution in 8 sec for the runs with settling times of 18 and 20 h, and one revolution in 3 sec in the one run with a settling time of 70 h. One revolution in 3 sec is what one would expect of a ring of particles rotating with the surface of the Earth at the latitude of Sydney, and then brought in from a diameter of 6 ft. to a diameter of 0·375 in., provided the ring conserves its angular momentum.

To provide a comparison with Shapiro's work, a floating cross made of two matchstick segments 1 in. long was alternated in one test with the cork float. Both cross and float rotated at approximately the same speed. Shapiro used a comparable cross. He reported[3] and filmed[4] rotation speeds of one revolution in about 3–4 sec. His drainage time was also comparable, that is, 20–24 min, and he also reports rotation only after about 10–12 min of drainage.

One early test did not fit the pattern of settling-time influence that emerged later from the tests. The tank, after a settling time of only 4 h 40 min, performed as if it had had 20 h of settling time. Near the end of the drainage period, a 0·5-in. patch of dust particles that had accumulated at the centre was rotating one revolution in 8 sec, clockwise. This was the only test in which the tank had not been mostly or wholly covered during the settling period. It was an unusually windy day outside, and just before drainage dust specks on different areas of the water surface were moving in several directions at large speeds of about 1 cm/min. The test may therefore have been significantly influenced by air currents. For subsequent tests, the louvre in the ceiling, which had been blocked off, though not completely, by ply-wood sheets, was additionally covered outside with 'Pliofilm'. The door was kept closed, except briefly to allow entry, and the tank was kept mostly covered by two ply-wood sheets resting on two angle irons placed diametrically across the tank. The angle irons were usually spaced about 3 in. apart, so that surface motions could be observed between them, and the direction of these supporting beams in relation to the room was varied from test to test in an attempt to detect any remaining influence of air currents. Air currents did not appear to be a significant influence in the later tests, but it is our opinion that they are likely to have been the largest of the disturbing influences.

In one early test, after a settling period of only 13 h, the no-rotation period was followed by a period of counter-clockwise rotation, which changed to clockwise near the end of the draining period. (In this particular test it is not known how the tank had been filled.) Shapiro reports one similar test, experienced after a settling time of 4–5 h, attributed to undamped initial angular velocity residing in the upper water, while the water nearer the bottom was rotating in the direction of the Earth's rotation. In another of our tests, with a deliberately short settling time of 3 h, water drained out counter-clockwise during all but an initial 2 min of no rotation. Shapiro reports a similar result. In fact, it would seem that the results of these experiments at Sydney are quite similar to those obtained by Shapiro in the northern hemisphere, with one exception. After suitable settling periods, Shapiro observed counter-clockwise rotation. We, in Australia, observed the opposite.

These tests posed for us an unusual problem in experimental work. Normally, one does experiments in which there is some uncertainty in the expected outcome. In these experiments, however, our confidence in the idea that the Earth rotates, and in the applicability of conservation of angular momentum to masses of fluid, was probably so strong that experimental denial would have been almost inadmissible. We should have gone to unusual lengths to get the apparatus to work as expected. Realizing this, we found ourselves reluctant to accept as conclusive the results we were getting, results which apparently confirmed our ideas. One can never prove, for example, that it was not some small air current which persistently maintained a circulation that gave the results we observed, and that a quantitatively comparable, but oppositely directed, air current caused Shapiro's results. There is, in principle, an infinite number of hypotheses that can explain any set of observations. This difficulty in validation of scientific theories is not a new one and, in this instance, as in all instances, it cannot be proved that any one hypothesis is correct. Nevertheless, we have acquired confidence in the hypothesis that carefully performed experiments on liquid drainage from a tank will show clockwise rotation, if done in the southern hemisphere.

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[1] Binnie, A. M., *J. Mech. Eng. Sci.*, **6**, 256 (1964).
[2] Shapiro, Ascher, H., film, *Vorticity* (Educational Services Inc., Watertown, Mass., 1961).
[3] Shapiro, Ascher H., *Nature*, **196**, 1080 (1962).
[4] Shapiro, Ascher H., four-min film loop No. *FM*–15, *The Bathtub Vortex* (Educational Services Inc., Watertown, Mass., 1963).

ENGINEERING

Variation of Breakdown Voltage of a Positive-point/Plane Gap with Applied Voltage Waveshape

In recent years it has become a well-known experimentally observed fact[1–5] that the breakdown voltages of certain non-uniform field gaps are strongly dependent on the shape of the applied voltage impulses. For positive-point negative-plane gaps it has generally been found that, for standard double exponential applied voltage impulses and with gap spacings of 1–5 m, the breakdown voltage decreases with increasing rise-time, for rise-times of 100–200 μsec, beyond which it increases again. The magnitude of the effect increases with increase of gap-length and for a 5-m gap, for example, the breakdown voltage at the minimum can be as little as 50 per cent of that for a 1-μsec rise-time impulse.

It was suggested[1] that the phenomenon might be due to pre-breakdown corona mechanisms which are dependent on time and could therefore vary with rise-time of any applied impulse voltage. During the discussion on a paper[6] concerning the difficulties of installing a 400-kV grid-system in England and Wales it was suggested that pre-discharge processes occur for slow rise-times and cause the field to become more uniform so that the breakdown voltage increases.

During the course of an investigation of the mechanism of the long spark at CERL the pre-breakdown corona stage was investigated. It was found that the pre-breakdown corona consisted of pulsed discharges and that the pulses carried considerable quantities of charge. Furthermore, the intervals between pulses clearly indicated that space charge fields resulting from earlier corona pulses affected the development of later pulses. This suggested the following mechanism to explain the experimental observations of the dependence of the breakdown voltage with waveshape referred to above.

For the positive-point negative-plane arrangement the corona discharge propagates across the gap by the following mechanism. An electron occurring within a certain distance of the point causes the initiation of an electron avalanche towards the point. Photons produced by the decay of molecules excited during the avalanche produce more electrons further out from the point. These latter electrons start new avalanches. Thus the corona filaments are built up until the electric field is too weak to allow further avalanche propagation.