to the same environmental influences as these substances are when they are produced in such well-known, conspicuous, and highly evolved genera as *Cladonia, Parmelia* and *Usnea*. Perhaps the lichenologist can at last solve some of his puzzles by studying this little French weed that finds the greenhouse so congenial (*6*).

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References and Notes

1. The generic identification of the algal component was made by Dr. Vernon Ahmadjian of Clark University.
2. The microchemical and chromatographic determinations of these substances were made by Dr. Chicita F. Culberson, Lichen Chemistry Laboratory, Duke University.
3. Most of the specimens of orchids in this collection were gathered in the former French colonies and sent to Paris for culture rather than being propagated in France.
4. Book-length summary: Y. Asahina and S. Shibata, *Chemistry of Lichen Substances* (Japan Society for the Promotion of Science, Tokyo, 1954).
5. General review: W. L. Culberson, *Rev. Bryol. Lichénol.* **29**, 321 (1960).
6. The observations reported here were made while I held a grant from the National Science Foundation.

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Spiral Flow in Rivers, Shallow Seas, Dust Devils, and Models

Abstract. *Spiral flow has been observed in meandering rivers, braided rivers, very shallow sea water, model experiments, and dust devils. Experimental work also produced standing spiral waves and spouts of water. Many observed spirals reversed direction from time to time. Geometry of the system, roughness, and turbulence are perhaps dominant in the control of spiral flow.*

Spiral flow, a common phenomenon in fluid motion, has been somewhat neglected, perhaps because it is not easily observed. The purpose of this note is to call attention to a wide range of situations where spiral flow has been reported.

Leliavsky (*1*) has summarized the findings of several workers who have related spiral flow to stream meandering. Einstein and Harder (*2*) described a circulatory motion in stream bends, in which the surface water tends to move toward the outside (concave) bank and the bottom water tends to move toward the inside (convex) bank. I have performed a series of model experiments (*3*) which appear to establish a sequence as follows: roughness, turbulence, spiraling, meandering. I have, moreover, observed the same general circulation patterns in small- to medium-sized natural rivers. This sequence is thought to apply also to oceanic currents such as the Gulf Stream, and to atmospheric currents such as the jet stream, except that in atmospheric currents roughness is not necessary to produce turbulence.

Hugh Casey (see *4*) produced several simultaneous adjacent spiral cells in a relatively wide, shallow experimental flume. One of these spiral cells was primary, inducing the formation of two immediately next to it, which in turn induced two others. Van Straaten (*5*) described ripple-mark-like features which may have been formed in the same way as the long, parallel ridges left by the scouring action of Casey's multiple spirals. Stokes (*6*) reported similar ridges ("rib and furrow") from lithified sediments. I have observed the same phenomenon on modern tidal flats and in various shallow-water currents (*7*). Jordan's large symmetrical sand waves may have had a similar origin (*8*). Bagnold (*9*) described a similar mechanism in connection with the growth and dissipation of sand dunes or ridges.

Some of the experiments (*3*) already referred to resulted in distinctive stream sedimentation. This finding led to the conclusion that multiple spiral cells, if large enough, create a complex of more-or-less diamond-shaped bars which, taken together, make the braided pattern. Bars of this type formed where several conditions were maintained: ample bed material of sand size; great mobility of bed material (that is, in rivers, very little clay to act as a binding agent), and therefore high width-depth ratios; and proper size of the system (widths of about 1 m to 1 or more km). Smaller systems carrying silt were also braided. Where materials were mobile and coherent (rather than mobile and loose) and abundant, and the system was large, meandering resulted. Where materials were abundant, mobile, and coherent and the system was small, "rib and furrow" or "spiral flow" ridges resulted. Where mobile bed materials were not abundant but roughness was much the same throughout and walls were rigidly fixed, a system of standing waves arose. The use of tracers made verification of spiral flow possible.

Kennedy and Fulton (*10*) have described a series of experiments in which helical overturn seems to be related to water depth.

If a large tub, filled with water, is allowed to stand and then is drained from the bottom, a helix develops in the drain, as is well known. Theoretically this helix should rotate according to the Coriolis principle (Ferrel's law), hence in a single direction. If the tub is large enough, this result can be obtained. With smaller tubs (that is, 1 m across), a helix appears in the drain but its directional properties do not relate clearly to the earth's rotation. In several hundred trials recorded, all in the United States, the rotation was counterclockwise in 58 percent of the trials, clockwise in 42 percent. These figures are not, however, stable; at one time late in the series of experiments the ratio of the percentages was almost 1 : 1. More interesting was the fact that, with a single tub, about 10 percent of the trials produced no spiral; about 25 percent produced one spiral, about 25 percent two and about 25 percent three successive spirals, and about 5 percent four, about 5 percent five, and about 5 percent six successive spirals. These successive helices could be distinguished from each other by the fact that, except in about 2 percent of the instances, the direction was reversed from one spiral to the next. The tentative conclusion drawn was that bottom roughness, turbulence, and width-depth ratios controlled the spirals. Sibulkin (*11*) has also described reversals in the bathtub vortex.

A series of seven dust devils (whirlwinds), which I sighted quite by accident during field work one dry summer, passed close enough for me to determine rotation directions with certainty. Of these, two showed counterclockwise rotation and four showed clockwise rotation. The seventh passed directly overhead, picking up paper trash in large quantities so that detailed air-current directions could be noted. As it approached, it changed direction from counterclockwise to clockwise; it reversed direction once again before passing out of sight. For the seven dust devils, clockwise rotation was observed in five instances, counterclockwise rotation in four.

The reversing dust devil altered only one obvious feature: ground roughness, in the form of trees and houses. It is concluded, tentatively, that roughness was responsible for the reversals. These events were reported formally at the national meeting of the American Meteorological Society, in Tallahassee, in the fall of 1961. At that time several meteorologists commented that a pronounced Coriolis effect should not be expected for spirals of such small size when there is significant roughness.

The Kármán vortex trail (*12*) is of importance in turbulence theory. Vortices of this kind commonly form as a result of an adverse pressure gradient associated with sudden changes in channel depth or width, or with changes in velocity, or behind obstructions to fluid flow, especially in streams of water. Such vortices are easily seen when suitable tracer materials (aluminum chaff, dye, heavy floats) are put in the water. If flow past an obstacle is essentially symmetrical, two lines of vortices occur, one on each side of the wake. The two sets are staggered, so that no one vortex is directly opposite a vortex of the other set. The rotation in one set is opposite to that in the other, and there is a tendency for an upstream current to form between the two sets.

Outside of each vortex set, between it and the main stream of water, a spiral standing wave may develop. Within this wave there is an "up" motion on the side next to the vortex trail (the inside) and a "down" motion on the outside, as well as general longitudinal flow. Two such waves occur in strongly developed symmetrical flow behind an obstacle, one on each side, each presenting essentially a mirror image of the other. When viewed from above, the two waves combine to produce a clearly defined ogive pattern, with the point at, or immediately upstream from, the obstacle.

Along the side of a channel, behind a roughness element, a single vortex trail, with a single spiral wave outside it, may appear. If two spiral waves, developed from opposite channel walls, cross in midstream, a "rooster tail" (spout of water) is formed (*13*). Spiral waves on several scales have been observed, from small ones (measurable in centimeters) to large ones (measurable in tens of meters). They are responsible, in some instances, for the local transportation of sediment. They form at Froude numbers above $F = 1.0$, and at Reynolds numbers in the range $R = 120$ to $R = 4000$, when roughness is present. (No observations above $F = 3$ and $R = 4000$ were made.)

Spiral flow has been noted in two other connections. In one case, the flow appears to be a duplicate of Reiner's teapot effect (*14*); whether or not this is purely a surface-tension effect is not clear. In the other case the flow is a surface-tension feature which can be observed in tiny model streams flowing across waxed glass or heavily waxed paper. The surface-tension spiral produces an unstable meander-like pattern which changes position and appearance rapidly and erratically.

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References

1. S. Leliavsky, *Introduction to Fluvial Hydraulics* (Constable, London, 1959), pp. 95–147, 185–186.
2. A. Einstein and A. N. Harder, *Trans. Am. Geophys. Union* **35**, 114 (1954).
3. W. F. Tanner, *J. Geol. Educ.*, in press.
4. V. Kolar, *Rozpravy Cesk. Akad. Ved.* **66**, 105 (1956).
5. L. M. U. J. van Straaten, *J. Sediment. Petrol.* **21**, 47 (1951).
6. W. L. Stokes, *Bull. Geol. Soc. Am.* **68**, 1872 (1957).
7. W. F. Tanner, *Trans. Gulf Coast Assoc. Geol. Soc.* **12**, 295 (1962).
8. G. F. Jordan, *Science* **136**, 839 (1962).
9. R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Methuen, London, 1941), p. 176.
10. R. J. Kennedy and J. F. Fulton, ASME-EIC Hydraulics Conference paper No. 61-EIC-1 (1961).
11. M. Sibulkin, *J. Fluid Mech.* **14**, 21 (1962).
12. R. H. F. Pao, *Fluid Mechanics* (Wiley, New York, 1961), pp. 399-403.
13. J. F. Kennedy, *Calif. Inst. Technol., Rept. No. KH-R-2* (1961), p. 74.
14. M. Reiner, *Deformation, Strain and Flow* (Interscience, New York, 1960), p. 27.

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Mariner II: High-Energy-Radiation Experiment

The radiation experiment on Mariner II was undertaken to investigate (i) the dependence of the intensity of ionizing radiation in space upon distance from the sun; (ii) temporal variations of the radiation and their correlation with measurements of the magnetic field and plasma flux at the location of the spacecraft, and with solar-terrestrial disturbances; and (iii) the intensity and extent of magnetically trapped radiation, if any, around Venus.

A systematic dependence of radiation intensity upon distance from the sun is inferred from the observation that cosmic ray intensity at the earth is inversely correlated with solar activity throughout the 11-year solar cycle. Assuming that the cosmic radiation in space far from the sun is constant, and that some of it is excluded from the region of the earth's orbit when the sun is active, one concludes that there is a region in which the radiation decreases as the sun is approached. It is of interest to know whether this decrease occurs in a restricted region beyond the earth's orbit or whether it occurs gradually so that there is a gradient near the earth.

The intensity and the time history of the increased charged-particle radiation which is observed at the earth immediately after some solar flares apparently depends upon (i) the character of the radiation ejected into space from the flare region; (ii) the location of the flare on the sun with respect to the earth; (iii) the distribution of the interplanetary magnetic field prior to ejection of the radiation from the sun; and (iv) the alterations in the interplanetary magnetic field caused by plasma ejected from the sun during and after the ejection of energetic charged particles.

Observation of solar-flare radiation and simultaneous observation of variations in plasma flux and the magnetic field at the spacecraft, outside of the geomagnetic field, will contribute to an understanding of these phenomena. In addition, measurements of the time required for radiation to propagate from the position of the spacecraft to the earth will be of interest.

If Venus has a magnetic field similar to the earth's, then it is to be expected that energetic charged particles are trapped in some regions around the planet. Measurement of both the magnetic field and the radiation near the planet can provide a better description of the planetary field than measurement of the magnetic field alone could provide.

Mariner II is well suited to the investigation of these phenomena. In approximately 100 days it travels from the earth, at 1.0 astronomical unit from the sun, to Venus, at 0.72 astronomical unit from the sun, remaining close to the plane of the ecliptic. Its attitude is completely stabilized so that the roll axis lies parallel to a radius vector from the sun at all times. Orientation about the roll axis is fixed so that the parabolic antenna, hinging on an axis perpendicular to the roll axis, can always point at the earth.

After being launched, the spacecraft falls behind the earth in its orbit; it later passes it, and when it meets Venus it is ahead of the earth. While passing,