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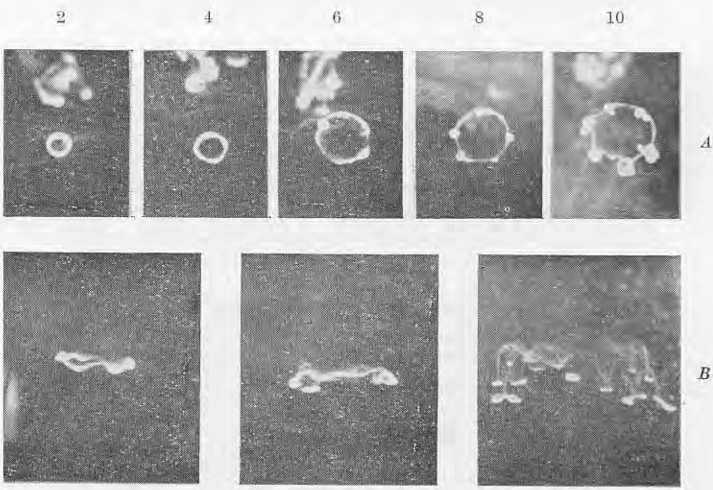
Instability Effects in Vortex Rings produced with Liquids

ONE of the commonest examples of a vortex phenomenon may be observed in the formation of smoke rings. Detailed studies of the structure of smoke rings were made many years ago by R. W. Wood[1]. Smoke is, however, rather unsatisfactory for observation because of rapid diffusion and the fact that the rings are easily disturbed by air currents.

It was discovered that the changes in the physical evolution of a vortex with time could be more easily observed and photographed in a liquid. Once the vortex process is started no additional energy is required to keep the ring in motion. The changes in the shape of the vortex are governed by its rotational energy and the frictional or viscous forces in the liquid medium. As these liquid vortex rings aged, definite progressive instability effects were observed. The changing structure of the vortex as instability occurred made them interesting subjects for study.

A clay–water mixture was used to produce visible rings. Both kaolinite and bentonite-type clays were



Figs. 1*A* and *B*. Numbers denote time in seconds after the drop enters the tank

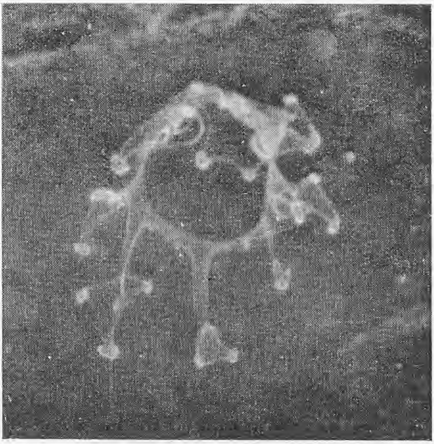


Fig. 2

found to be satisfactory; however, kaolinite produced rings which maintained their continuity for a longer period of time and was selected for study. A 5 per cent mixture was used, and most of the clay particles stayed in suspension for several hours. The suspension was placed in a micropipette which was placed vertically over a cylindrical glass tank 6 in. in diameter and 14 in. deep, filled with water. The tip of the pipette was located about 2 cm. above the water and was adjusted to deliver about 0·1 c.c. per drop. Under these conditions a vortex ring formed less than one second after a drop of the clay–water mixture was ejected and entered the tank.

The various stages of evolution of a number of rings, as viewed from above the tank, are shown in Fig. 1*A*. The numbers represent the approximate time elapsed in seconds after the drops entered the tank. The rings are seen to increase rapidly in diameter. From the theorems of Helmholtz[2] it is stated that, as the vortex stretches, the angular velocity of rotation increases in proportion to the decrease in cross-sectional area. This relationship is given by Prandtl[3] as:

$$\Gamma = 2\,\omega\,a$$

where Γ is the circulation of the vortex filament, ω its angular velocity, and a the cross-section. With the increase in angular velocity of the vortex, instability occurs, and thick and thin regions begin to form

Fig. 3

around the ring as may be seen in the 4-sec. photograph. After about six seconds the beginning of secondary rings may be seen, and these are well formed after eight seconds. These secondary rings also expand and become unstable, as may be seen in the last photograph of this series.

Since secondary rings have a greater angular velocity than the primary vortex, they travel downward into the tank at a faster rate. This effect may be seen in Fig. 1*B*, showing photographs taken normal to the direction of travel of the rings or viewed from the side of the glass tank. The thick regions which form secondary rings are on a lower plane than the primary ring. At twelve seconds, portions of the second set of rings are distorted and descend more rapidly.

The formation of the third set of rings may be seen in detail in Fig. 2, taken after about seventeen seconds and again viewed from above the tank. The third ring groups are formed at the tips of triangular streamers which a few seconds before were the second set of rings. Five complete sets of rings have been observed; however, these are difficult to photograph because of the lack of contrast and diffusion of the suspension.

Occasionally the forces on the clay–water drop were not uniform as it entered the tank and irregularly shaped secondary rings were formed as shown in

Fig. 3. Here most of the primary ring has flowed into one large secondary ring formation.

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[2] von Helmholtz, *Crelles J.*, **55**, 25 (1858).
[3] Prandtl, L., "Essentials of Fluid Dynamics", pp. 56–74 (Hafner Pub. Co., New York, 1952).

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