THE GENERATION OF VORTEX RINGS, II

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THE GENERATION OF VORTEX RINGS, II

By Jun-ichi OKABE and Susumu INOUE

A pipette was fixed vertically above water and out of its mouth droplets of colored liquid were allowed to fall freely one by one at long intervals of time. The drop impinged upon the surface of the water below, and as it went down, it was deformed into a vortex ring.

In the present note, three kinds of photographs were reproduced. The first series is made up of the pictures enlarged from the 8 mm-movie films and shows the state of things which take place immediately after the drop strikes against the surface of the water. The second series consists of the photographs corresponding to the various phases of the metamorphoses of a vortex ring, from its birth to its collapse. Finally, the third group is composed of the supplementary pictures which, in a way, seem of some use in understanding the phenomenon.

1. Introduction

In the preceding report,[1] we studied in some detail the successive stages of the generation and the development of the vortex rings emitted vertically upwards from the mouthpiece immersed in the water.

In the followings, the second observations concerning another kind of vortex rings are explained. A pipette equipped with a cock was fixed vertically some 10 mm apart above water, and out of its mouth the droplets of colored water were allowed to fall freely one by one at long intervals of time. The drop impinged upon the water below, and as it went down, it was deformed into a beautiful vortex ring.

Thirty years ago, MAJIMA[2] described an experiment in which he observed the vortex rings were generated and dissolved in the water. Only, he fixed a burette keeping its lower end at 5 mm *below* the surface of the water, and the red ink contained in the burette was let to flow out downwards quietly without interruption owing to the difference in the specific gravities between the ink and the surrounding water. Then he noticed that on the vertical stream-tube moving downwards the swellings like beads grew up here and there which in due course of time evolved into the vortex rings.

As to the final decomposition of vortex rings, on the other hand, OKA published an elegant computation,[3] through which he succeeded to prove that the

1) OKABE, J. and INOUE, S., The Generation of Vortex Rings, *Reports of Research Institute for Applied Mechanics*, vol. 8 (1961), no. 32, pp. 91–101.

2) MAJIMA, S., An Experiment of Vortex Rings (in Japanese), *Kagaku (Sciences)*, vol. 1 (1931), no. 2, p. 54.

3) OKA, S., On the Instability and Breaking up of a Ring of Liquid into Small Drops, *Proceedings of the Physico-Mathematical Society of Japan*, vol. 18 (1936), pp. 524–534.

maximum instability occurs in every case at a certain definite value of the wave-length of the varicosity, indicating that drops of definite size would be formed, and this wave-length varies with the ratio of the radius of the ring to that of the cross-section (*op. cit.* p. 534).

In the present note, three kinds of the photographs are reproduced. The first series is made up of the pictures enlarged from the 8 mm-movie films and shows the initial stages in the generation of a vortex ring evolved from a liquid drop immediately after it strikes against the surface of the water below. The second series shows in magnified scale, with side, and bird's-eye, views, the various phases of the metamorphoses of a vortex ring, from its birth to its collapse. Finally, the third group is composed of the supplementary pictures which, in a way or another, seem of some use in understanding the phenomenon.[1)]

2. Discussions

The formation of a vortex ring when a liquid drop strikes against the surface of the water is too rapid for the naked eyes to follow.[2)] However, by virtue of the movie films reproduced as the first series, it is hoped, the mechanism of the generation of a vortex ring out of a liquid drop falling freely in the water may be interpreted on the analogy of the results of our former experiments of which a full account was given in Part I (*loc. cit.*, especially from 1) to 4) in Section 3, pp. 93–94). Namely, the liquid drop is quite flattened by the impact when it enters into the water, and by the friction with the surrounding water the rotational motion is induced within the small lump of liquid, which in its turn rolls in step by step the lowest part of the wake, or the *stem*, so to speak. After having hauled in all the torn-off wake, the vortex still sucks in water from its center. A ring is thus completed, when liquid is replaced by water and a hole is made at the center.

The second series consisting of 16 photographs shows altogether every step

1) The movies were taken making use of the same illumination (three high tension fluorescent mercury lamps composed of one 700 watt lamp and two 100 watt lamps) as explained in Part I of our note (Fig. 1 and p. 93, *op. cit.*) For the remaining photographs belonging to the second and the third series, however, the stroboflash with 1/3000 second of flashing time was utilized in addition to either one 700 watt mercury lamp or two 100 watt lamps. The mercury lamps were employed in the latter cases to reduce the contrast of brightness.

As to the colored water from which the vortex rings were formed, after a number of trials we found that the following concentrations were most favorable, and almost all the observations were made with this liquid: water 200 cc, fluorescein $C_{20}H_{12}O_5$ 250 mg, and sodium hydroxide NaOH 300 mg.

The Roman numeral attached to each photograph denotes the number of the series: for example, (II, 5) means the *fifth* picture in the *second* series.

2) By our 8 mm-movie camera, 64 frames of pictures were taken per second, and the first half of the Series I is made up of the reproductions of all the frames corresponding to the very initial state of things which take place immediately after the liquid drop impinges upon the water, because the motion changes very rapidly in this period. But the second half of this series is composed of the reprints of the frames, picked up appropriately out of a reel of the film in order to clarify the features characteristic to each successive step of the transition, because in the meanwhile the variation of the phenomenon becomes quite slow.

of the development and the breakdown of the vortex rings.[1] Just as described by OKA (*op. cit.*, especially Fig. 1), slight disturbances grow up into the marked swellings and the contractions along the ring, until it looks like a string of beads. Then each bead sinks downwards individually owing to its larger specific gravity, and a small daughter vortex is thus generated. These processes may be observed in photographs from (II, 5) through (II, 11). The last 5 pictures in this series are the bird's-eye views of the vortex motion, while all others are its side views.

The third group is made up of 8 pictures. The first 5 of them are related with the mode of growth and free fall of a liquid drop and the appearance of the lower portion of our pipette. The remaining 3 correspond to the miscellaneous topics as follows:

(III, 6) shows the secondary vortex generated at the root of the wake of the primary, which has gone out of the scope of this photograph.

In (III, 7) we can observe a very small daughter vortex has been just emitted from the mother by the impulse when the drop of liquid entered into the water.

At the very instant when the drop impinges upon the water, it may be decomposed, by chance, into two similar vortices. The picture (III, 8), although it is very confused, shows one of these cases.

It was found from a number of our observations that the wake of the liquid drop generated when it enters into the water shows, by chance, numerous variations in form. Only a few examples are given by the pictures of the first series, (II, 1), (II, 2), and the upper portion of (II, 12), together with (III, 6) through (III, 8).

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Notes for the photographs:

1) In the first series, the mark $\underline{\nabla}$ indicates the level of the surface of the water.

2) The magnifying ratio of the pictures (III, 1) through (III, 4) is 1 : 2, and the reduction ratio for (III, 5) is 1 : 2/3.

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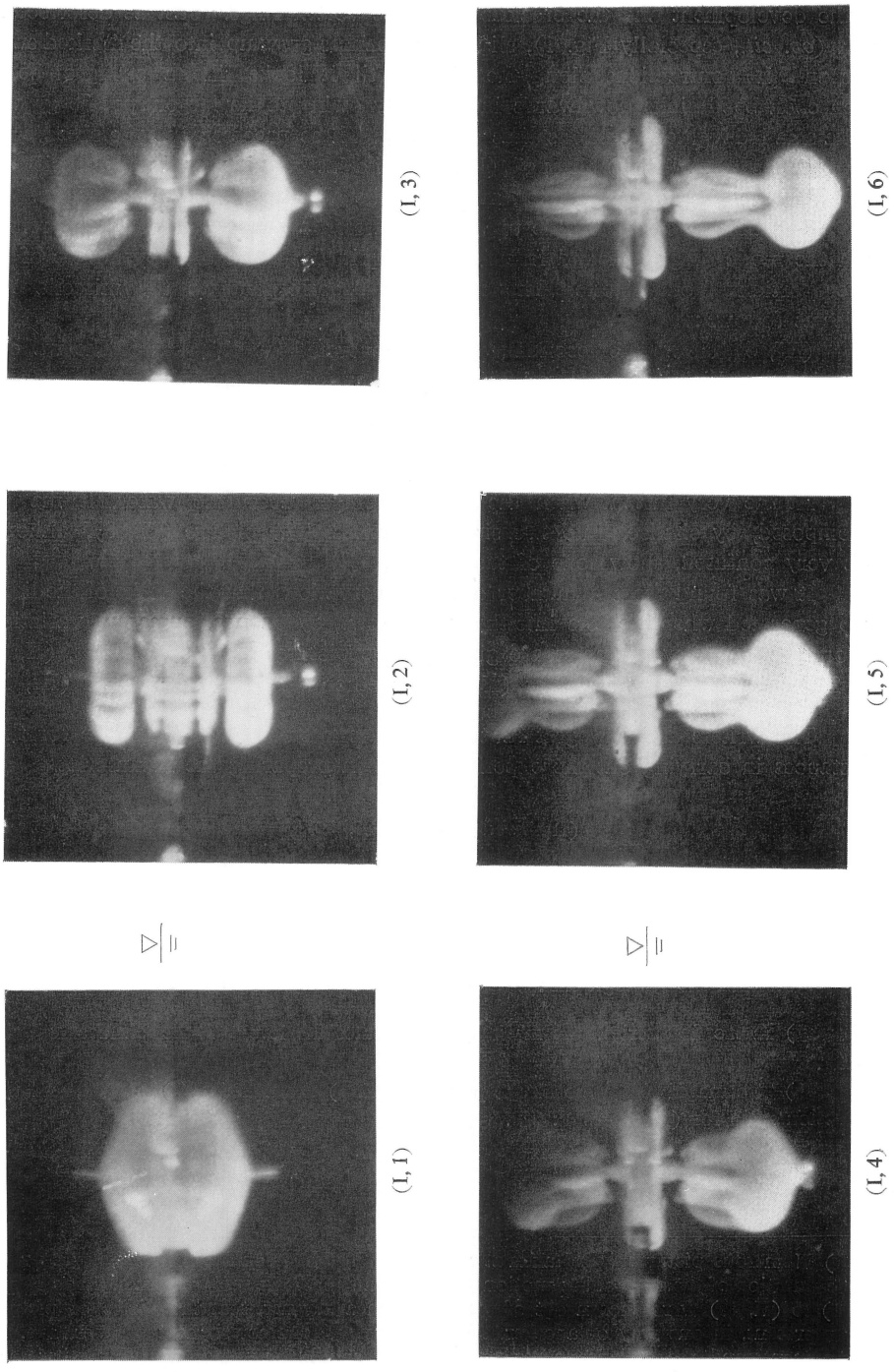
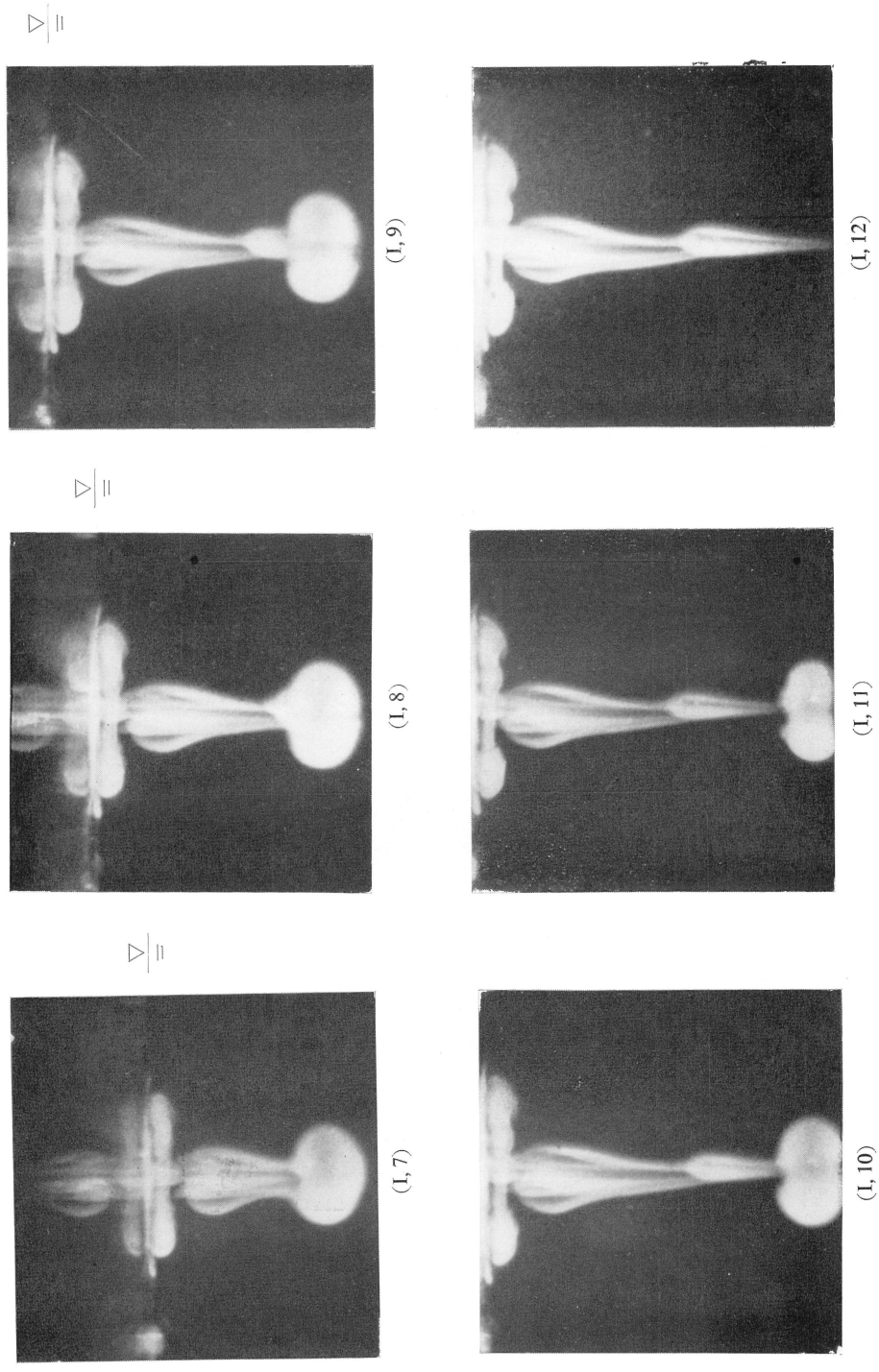
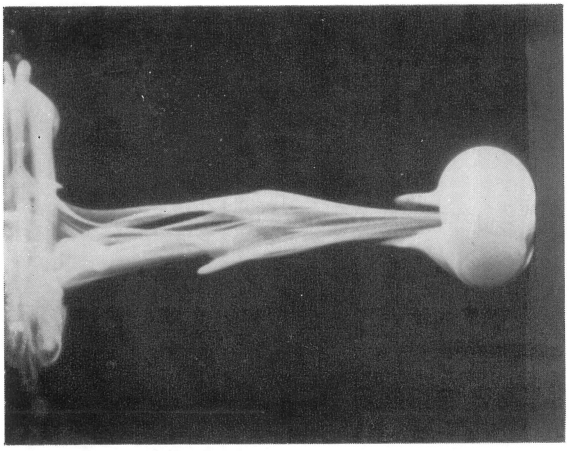
1) Numerous pictures were taken at random with almost uniform probability over the whole duration of the descending motions of the small masses of colored fluid. Photographs (II, 1) to (II, 16) were chosen out of them in such a manner that this series of pictures may represent, in one way or another, the various stages characterizing the generation, the development, and the collapse of vortex rings. It should be noted, therefore, that these pictures do not trace the successive transformations of a particular vortex, but correspond to miscellaneous moments in the course of the metamorphoses of different vortices.


(I, 1)
(I, 2)
(I, 3)
(I, 4)
(I, 5)
(I, 6)


(I, 7)
(I, 8)
(I, 9)
(I, 10)
(I, 11)
(I, 12)



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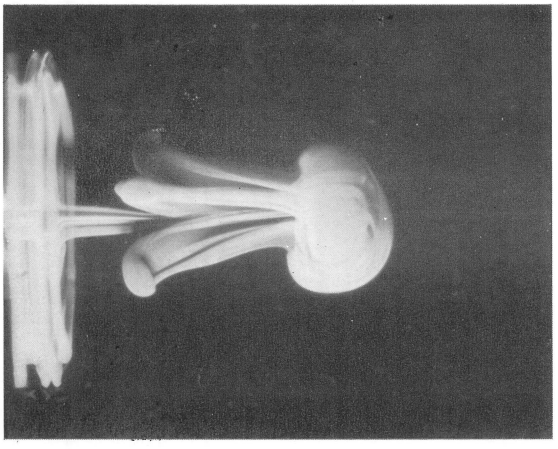

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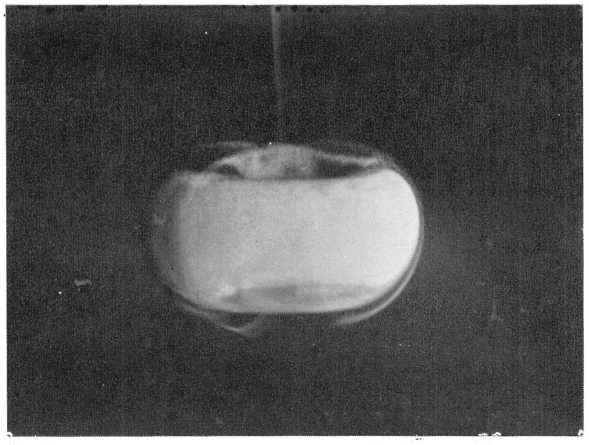

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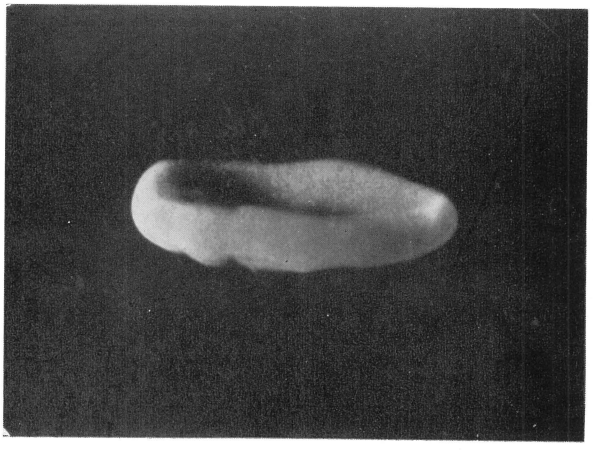

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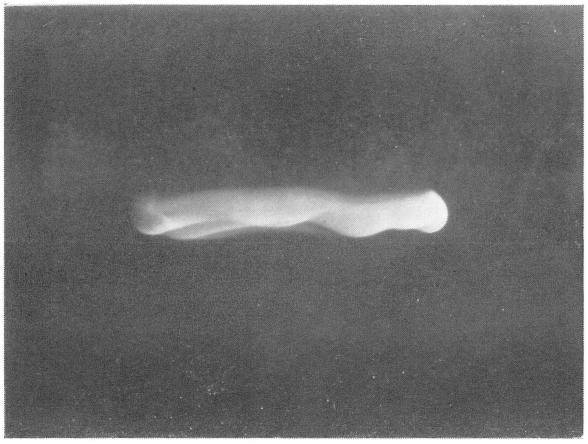

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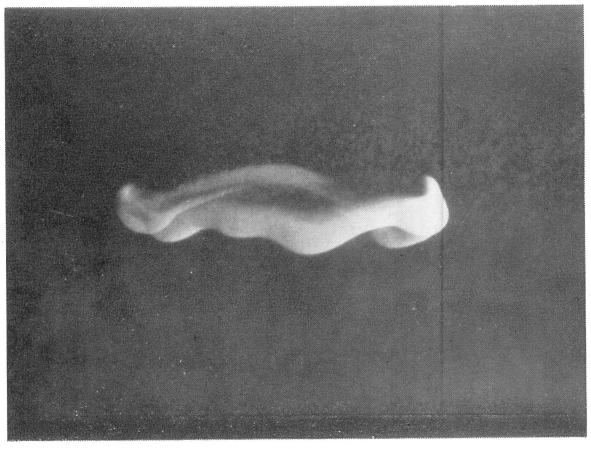

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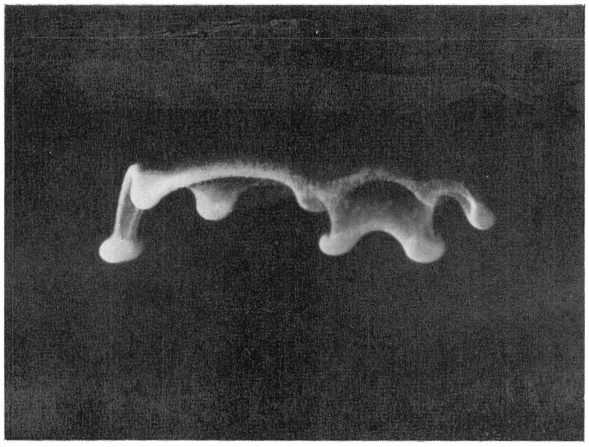

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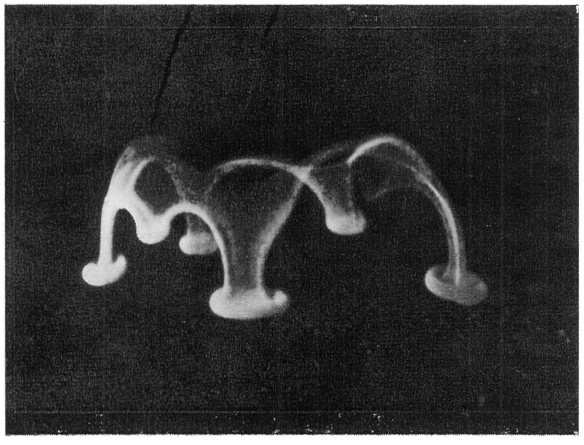

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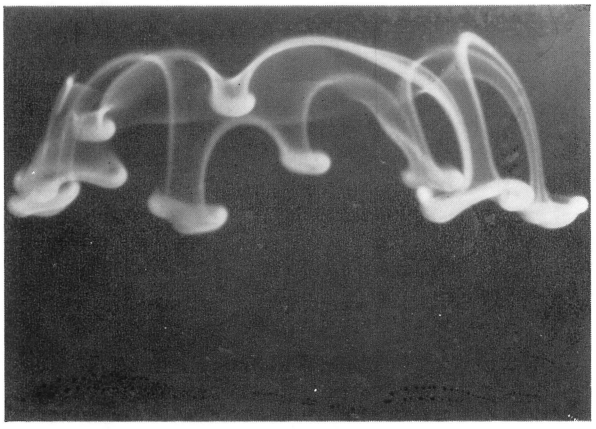

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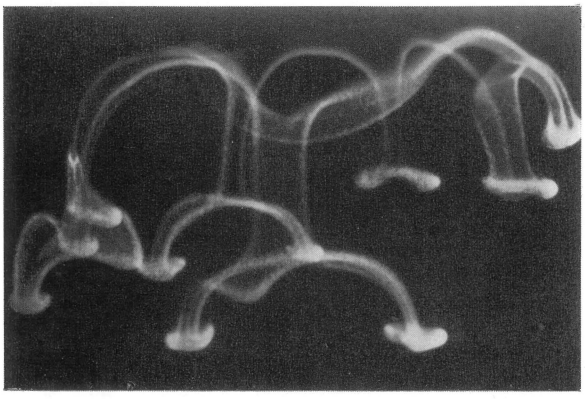

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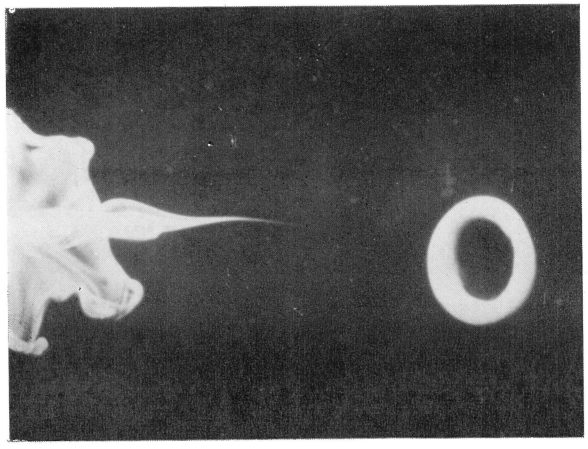

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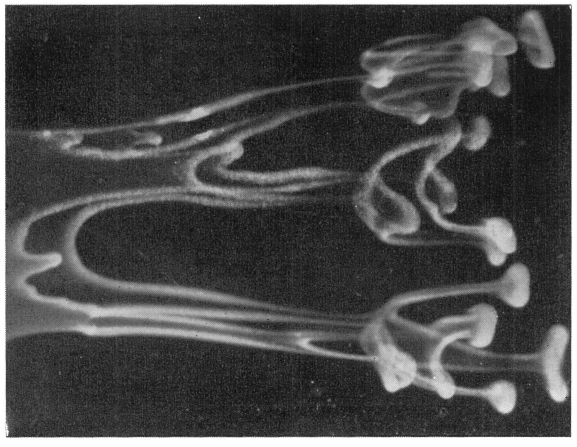

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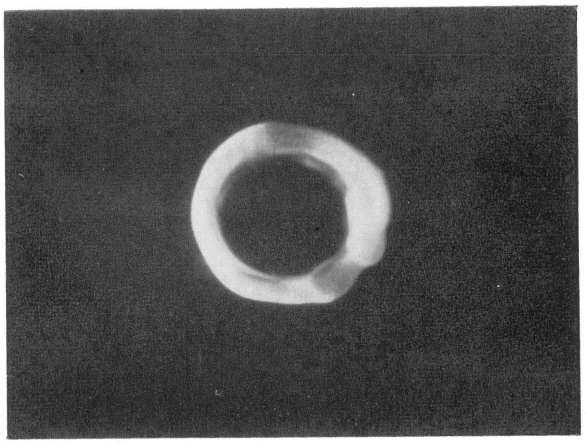

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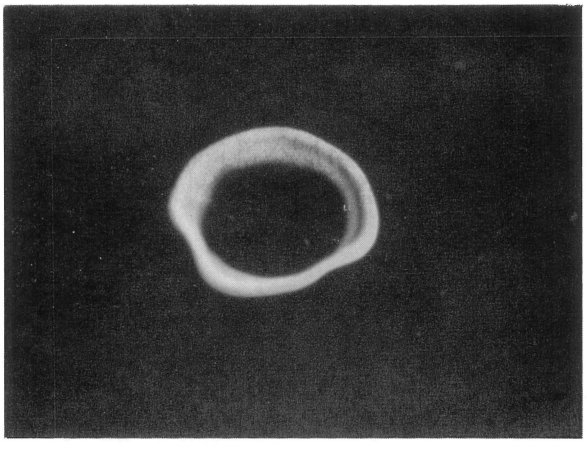

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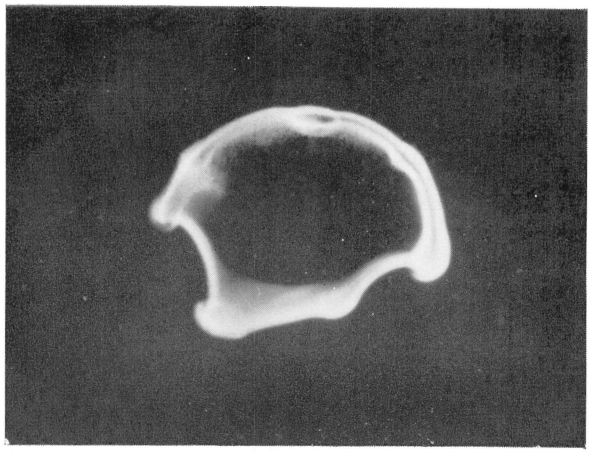

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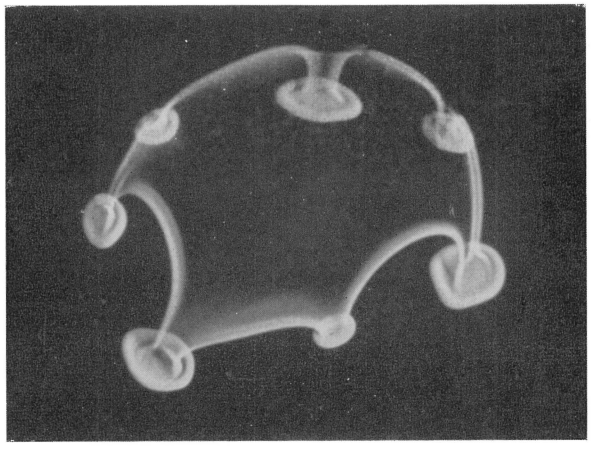
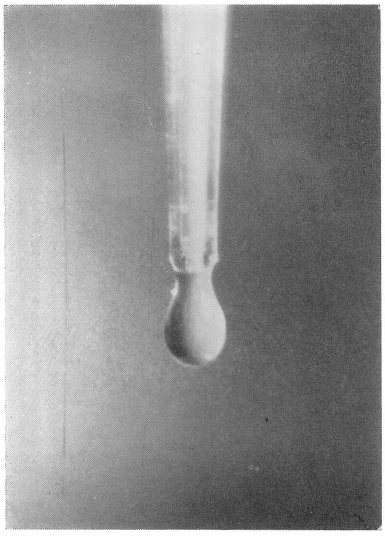


(II, 16)



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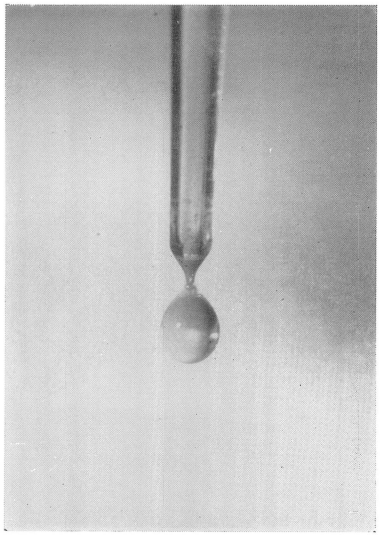

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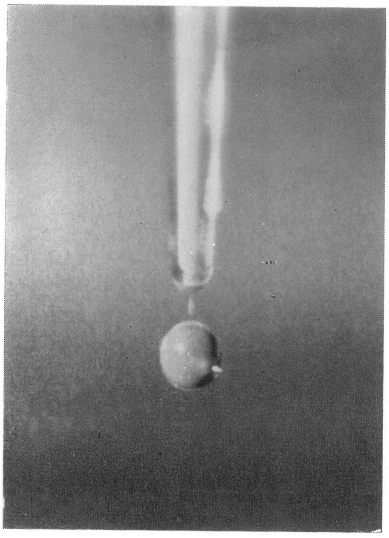

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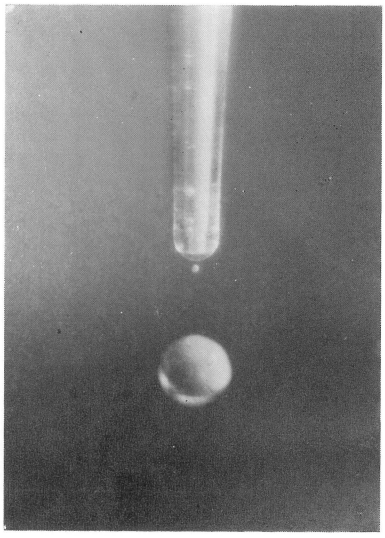

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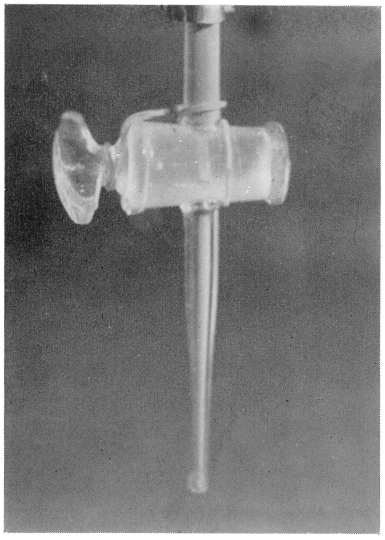

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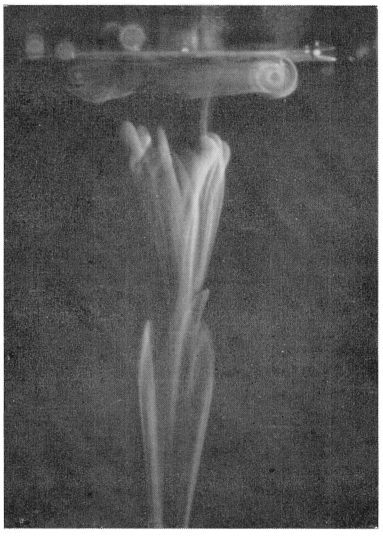

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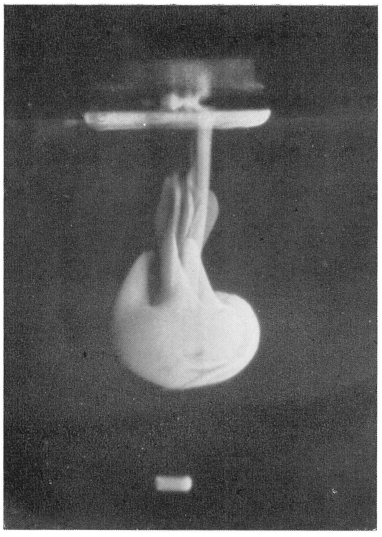

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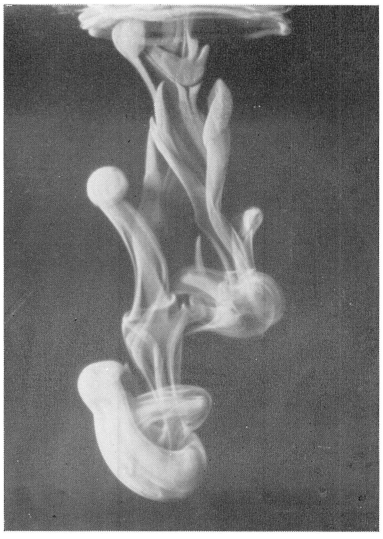

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