pears likely that the tension cracks and noises located behind the true failure surface indicate the development of potential, though ultimately more stable, shear surfaces. The head and toe zones were notably free of comparable noise activity. On several occasions two or three noises occurring within a few seconds of each other were located within 2.5 cm of each other (Fig. 2); this phenomenon has been described as a chain-reaction microfailure.

These studies in the laboratory and in the field have important practical connotations. Fieldwork demonstrated the ability of a survey of rock noises to identify the active portions of a large landslide and to locate the depth of the seat of sliding from relative noise rates in a borehole through the slide. Laboratory study of noises from small-scale landslides demonstrated that noises occurring shortly before failure originate from the central part of the surface of sliding that later develops; this result suggests that arrays of conventional seismic geophones on the ground surface may be able to define the geometry of an impending landslide even before it occurs.

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Splashing of Drops on Shallow Liquids

Abstract. *The events that follow the splashing of a drop on a liquid depend on the depth of the liquid. When the depth is less than about 5 millimeters the crown that is ejected is more unstable than that from a splash on a deep liquid. As the depth is decreased from 25 to 7 millimeters, there is an increase in the maximum height to which the Rayleigh jet rises, and in the number of drops that break away from the jet. With depths less than 7 millimeters these two quantities fall off sharply, and no jet drops are produced for depths less than about 3 millimeters.*

The sequence of events following the collision of a liquid drop with the surface of a deep liquid have been photographed and described (*1*, *2*). Comparatively little work has been done, however, on the splashing of drops on shallow liquids, although this phenomenon plays an important role in soil erosion and the dispersal of seeds and microorganisms by raindrops (*3*, *4*). Gregory *et al.* (*4*) investigated the splashing of water on thin films of spore suspensions and found that the number of splash droplets increased markedly as the thickness of the film decreased from 1 to 0.1 mm; they did not investigate changes in the nature of the splash with decrease in depth of liquid. We now describe modifications that occur in the Rayleigh jet and in the crown as the depth of liquid into which a drop splashes is progressively decreased.

The incident drops were produced by forcing liquid at a constant pressure through a 26-gauge stainless steel hypodermic needle; their diameters varied from 2.4 to 3.8 mm, with the distance of fall always 75 cm. The liquid into which the drops splashed was contained in a 45-cm square tank, 25-cm high. In addition to the permanent base, the tank had a false base that could be positioned at any level within it, so that quick and accurate changes could be made in the effective depth of liquid without addition or removal of liquid. Photographs were taken with a high-speed 16-mm camera that was generally operated at 1000 frames per second.

Because a mixture of milk and water gives good contrast against a dark background, it has been commonly used for photography of the splashing of drops on liquids. In the first series of experiments the incident drop and the liquid in the tank consisted of a

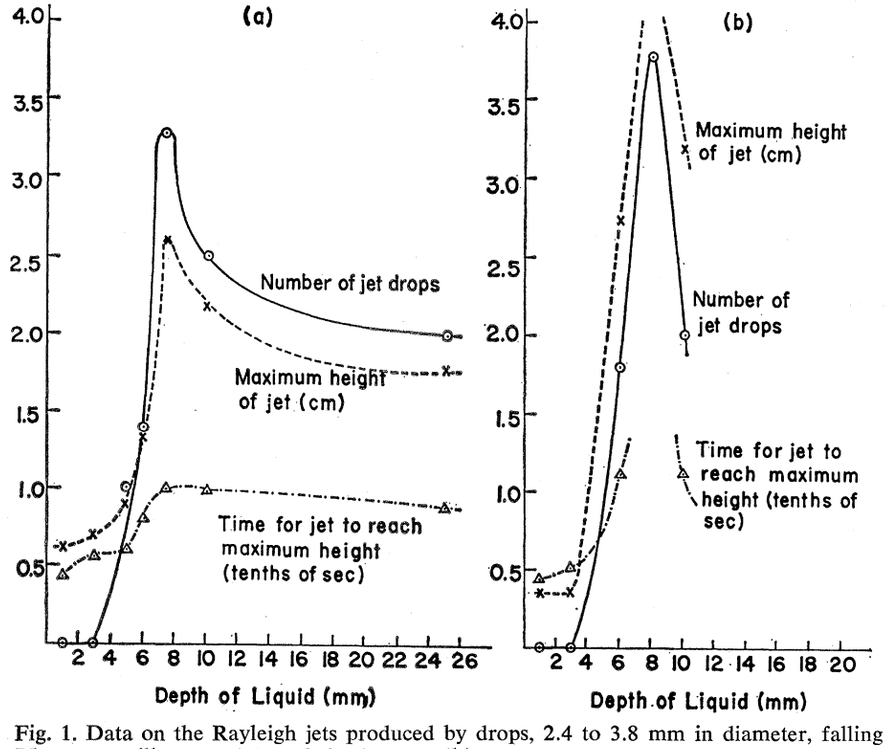

Fig. 1. Data on the Rayleigh jets produced by drops, 2.4 to 3.8 mm in diameter, falling 75 cm on milk-water (a) and dyed water (b).

mixture of homogenized milk and tap water at 1 : 14.

With depths of 25 mm or greater, the sequence of events following the impact of a drop on a liquid surface is the same as for splashing on a deep liquid: A crown of liquid is thrown up around the point of impact, droplets are ejected from the crown, a jet of liquid (the Rayleigh jet) emerges from the center of the crown, and two drops break away from the jet (*2*, plates).

As the depth of liquid is decreased below 25 mm, some changes occur in the mode of splashing, particularly in the behavior of the Rayleigh jet. For various depths of milk-water, Fig. 1a shows the maximum height to which the jet rises, the time taken for the jet to reach maximum height, and the average number of drops that break away from the jet. With depths between 25 and 7.5 mm, these three quantities increase with decrease in depth, but with depths less than 7.5 mm they all fall off sharply. With splashing on milk-water less than about 3 mm in depth a small Rayleigh jet is produced but does not disintegrate.

Some of the more unusual events occurring when drops splash into shallow liquids are illustrated in Figs. 2–4. The number superimposed on each photograph (bottom right) is the time lag in milliseconds between the drop's collision with the surface and the event shown. With a depth of 10 mm the first drop that breaks away from the jet does so in the same manner as with splashing into a deep liquid (Fig. 2a). However, the behavior of the remainder of the jet is unusual: first it becomes detached from the bulk liquid (Fig. 2b) and then it may break into two drops (Fig. 2c). With a depth of 7.5 mm the first two jet drops form in the usual way before the remainder of the jet separates from the horizontal surface and usually assumes a spherical shape before colliding with the bulk liquid. In some instances, however, the jet breaks into four drops. Figure 3 shows an especially interesting incident that occurred with a depth of 7.5 mm: the jet broke into four drops (Fig. 3a), but the second drop to enter the liquid (Fig. 3b) reappeared (Fig. 3c) before finally subsiding.

The depth of liquid also affects the stability of the crown. In the case of deep water, when the crown approaches its maximum height small jets of liquid shoot out from points on the circumference of the crown, and small

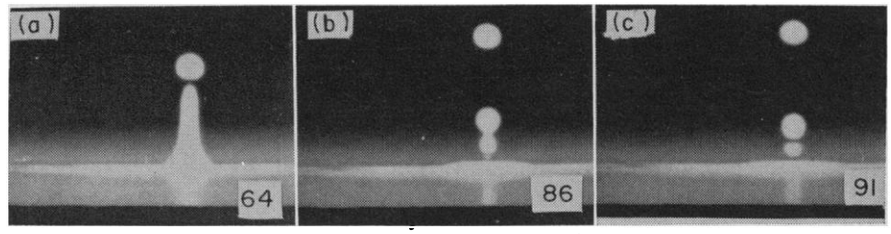

Fig. 2. Behavior of the Rayleigh jet produced by a milk-water drop, 3.3 mm in diameter, falling into a layer of milk-water 10 mm in depth (× 1.3).

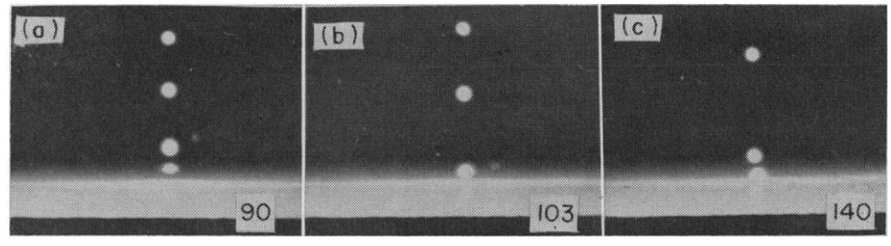

Fig. 3. Behavior of the jet drops produced by a milk-water drop, 3.0 mm in diameter, falling into a layer of milk-water 7.5 mm in depth (true size).

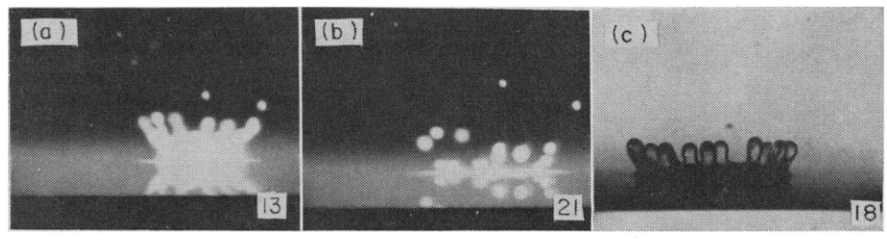

Fig. 4. Break-up of the crown (a and b) for milk-water 1 mm in depth (× 1.5), and instability of the crown (c) for dyed water 1 mm in depth (× 2.1).

droplets may break away from these jets. However, when milk-water is shallower than about 5 mm, the crown tends to disintegrate completely into fairly large droplets (Fig. 4, a and b).

The surface tension of the mixture of milk and water used by us was 65.07 dyne/cm at 20°C, significantly less than the surface tension of water—72.75 dyne/cm at 20°C. To determine whether the phenomena described are affected by surface tension, a second series of experiments was carried out with dyed water; it consisted of 28 g of blue dye in 60 liters of tap water; the surface tension was 72.73 dyne/cm at 20°C.

Measurements of the Rayleigh jets produced, when drops of dyed water were dropped on dyed water of various depths, are shown in Fig. 1b; they resemble those obtained with the mixture of milk and water, although the peaks are even more pronounced in the dyed water. With a depth of 8 mm the Rayleigh jet rose above 6 cm and beyond the field of view of the camera. One should note that with a depth of 250 mm of dyed water the average number of jet drops was 3.5. The crown that forms in dyed water when the depth is less than about 5 mm also shows signs of instability (Fig. 4c), but it does not disintegrate into the large droplets observed with milk-water.

Theoretical explanation of our results is a difficult problem in fluid dynamics. It is known, however, that with splashing on a deep liquid the Rayleigh jet is produced by the subsidence, followed by the upward motion, of the liquid from the crown. Also, the impact of a drop on a liquid produces a vortex ring that travels down into the bulk liquid. It seems likely, therefore, that the peaks in the curves in Fig. 1 occur at the depth (7 to 8 mm) at which the liquid from the subsiding crater starts its upward motion to form the Rayleigh jet at the same time as the energy from the vortex ring arrives back at the surface of the liquid after being reflected from the base of the tank. These two notions then combine to produce an ab-

normally high Rayleigh jet. It is possible that the unusual breakup of the crown (Fig. 4) with depths less than about 5 mm occurs when the reflected energy of the vortex ring reaches the surface during the period while the liquid from the crown is flowing downward. This interpretation would also account for the sharp reduction in the height of the jet with depths less than about 5 mm.

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Radioisotope Uptake as a Measure of Synthesis of Messenger RNA

Abstract. *Exogenously supplied radioactive uracil (or guanine) enters the intracellular pools of RNA precursors in* Escherichia coli *only as nucleotides are removed from these pools by net synthesis of RNA. Consequently uptake of uracil over a short period does not measure the sum of the synthesis of all forms of RNA, unstable and stable, as is often supposed. Uptake of uracil during changing conditions of growth may be influenced by changes in types of RNA's being made; under such conditions that no stable RNA is being made, the synthesis of unstable forms may be greatly underestimated.*

Radioactive uracil, as well as the other nucleic acid bases, is very widely used for measurement of the rate of biosynthesis of RNA. Interpretation of such experiments, however, is complicated by the existence of an unstable fraction of the RNA, the messenger (mRNA), which, at least in bacteria, is undergoing rapid turnover (*1, 2*) (Fig. 1). Over long periods (relative to the half-life of the messenger) the mRNA becomes completely labeled, and uptake data primarily indicate the synthesis of the stable forms of RNA, since the mRNA amounts to only a few percent of the total RNA accumulating in the cell. On the other hand, it is often stated that the amount of radioactive uracil incorporated into RNA, in a pulse of labeling, is proportional to the sum of the rates of synthesis of mRNA and stable RNA. I now examine this point in particular, and the view that messenger synthesis in general can be measured by isotope uptake.

An assumption made in use of the pulse-labeling technique is that the radioactive precursor freely and rapidly enters the cells' internal precursor pools (*3*). In some of the earliest studies of the turnover of mRNA in bacteria, Gros *et al.* showed that, after addition of radioactive guanine to a culture of *Escherichia coli*, the specific activity of the intracellular guanine nucleotides rose only slowly (*2*); they explained this result in terms of a continuing dilution of this pool by the breakdown of mRNA. An additional assumption, implicit in their interpretation, is that the entry of guanine from the medium into the cell is limited in some fashion. This assumption was borne out in an extensive series of studies of the transport of nucleic acid precursors into cells and their incorporation into RNA, in which workers at Carnegie Institution found that the rate of entry of uracil or guanine into cells did not exceed the rate of their utilization in synthesis of RNA (*4*); that is, that uptakes of uracil and guanine were somehow linked to their metabolism.

The experiments now described extend these last observations and point out their implications in terms of the interpretation of isotope-uptake experiments. They show that the rate of incorporation of uracil and guanine by *E. coli*, even over relatively short periods, is clearly limited at some step in the conversion of the base in the medium to a nucleotide in the cell. This limitation is such that the amount of radioactive base entering the cell does not exceed the amount being removed in the net synthesis of RNA; the consequence is that, even over short periods of labeling, isotope incorporation largely reflects the rate of synthesis of the stable forms of RNA. And by extension, under such growth conditions that there is no formation of stable RNA, synthesis of mRNA may go undetected or be greatly underestimated.

In a labeling experiment several factors may contribute to the rate at which the pools of nucleotides become radioactive: First, the synthesis of stable forms of RNA leads to a continuing flow of nucleotides through the pools; if the exogenously supplied base is used preferentially and *de novo* synthesis of the related nucleotides is inhibited, the pools will rapidly become radioactive (*5*). Second, one can envision that the enzymes responsible for the uptake reactions (1 and 2 in Fig. 1), and the interconversions of the various nucleotide derivatives within the pool, might catalyze an exchange reaction; if this were so, the nonradioactive nucleotides in the pools, and those formed by the degradation of mRNA, would be dispersed into the larger amount of radioactive precursors in the medium. Finally, if the addition of a radioactive base to the medium causes very great expansion of the pools of nucleotides in the cell, the nonradioactive molecules will be simply diluted out.

Table 1. Guanosine triphosphate pool of *Escherichia coli* after addition of guanine. *E. coli* B/1 was grown to an O.D.$_{540}$ of 0.4 in a tris-buffered medium containing $6 \times 10^{-4}M$ phosphate, and supplemented with 0.4 percent glucose, thiamine-HCl at 0.05 mg/liter, adenine at 10 mg/liter, and $H_3{}^{32}PO_4$ at 10 mc/liter. Portions of this medium were analyzed for inorganic phosphate and radioactivity for direct determination of the phosphate specific activity. To a series of culture flasks, guanine was added as indicated, and 2 minutes later, 1-ml samples were removed into 0.5 ml of $0.75M$ perchloric acid; to each sample was added 1.5 μmole of each of guanosine monophosphate, diphosphate, and triphosphate, and 0.05 μc of ^{3}H-guanosine triphosphate. The cells were removed by centrifugation, and the supernatants were desalted by absorption to and elution from charcoal (*12*). The guanosine triphosphate was then isolated by electrophoresis in *p*H 3.5 ammonium formate ($0.07M$) and $10^{-3}M$ EDTA, and after elution a second electrophoresis in *p*H 7.5 phosphate buffer ($0.02M$) and $3 \times 10^{-3}M$ EDTA. The guanosine triphosphate (GTP) spots were counted directly in a mixture of toluene, 2,5-diphenyloxazole, and *p*-bis-[2-(5-phenyloxazole)]-benzene in a liquid-scintillation counter. The recovery of GTP was calculated on the basis of recovery of the ^{3}H-GTP added. An O.D.$_{540}$ of 1.0 corresponds to a dry weight of 0.34 mg/ml. The doubling time was 49 minutes.

Guanine conc. (M)	GTP (mμmole/mg, dry wt)
0	3.7 ± 0.1*
0.33×10^{-5}	4.7
1.0×10^{-5}	4.3
0.33×10^{-4}	4.7
1.0×10^{-4}	5.6
0.33×10^{-3}	4.6

* Four determinations.