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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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HYDROMECHANICS

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THE PHENOMENON OF CAPILLARY "BALL PLAY" UNDER WEIGHTLESSNESS

The elastic properties of the phase boundary between different liquids and between a liquid and a gas have long been known ([1–5]), as have the elastic properties of a liquid film bounded on both sides by gas or by another liquid ([6]).

In the experiments described here, an elastic transformation of the surface-tension energy of the phase boundary between two liquids into the kinetic energy of translational and oscillatory motion of a liquid body was observed, in the form of a peculiar "jump" of a mercury drop during transition to a state of weightlessness, as well as the phenomenon of elasticity of a liquid film formed by two phase boundaries between three different media, in the form of a peculiar "reflection" of a mercury drop from the hydrochloric-acid—air interface.

Fig. 1. Upper row —capillary "jump" of a mercury drop and its oscillations relative to its center of gravity, followed by formation into a sphere. The first frame shows the position of the drop 0.15 sec after separation from the container. Lower row —motion of the test body characterizing the acceleration inside the container. The acid level is 10.0 cm relative to the bottom. Filming frequency 12 frames/sec.

To achieve weightlessness conditions, a container weighing about 100 kg was used, dropped from a height of 20 m. During the fall, for approximately 2 sec, the mean acceleration in the container coordinate system was ≈ 6.4 cm/sec^2. This acceleration was determined from the motion of a special test body (Fig. 1, lower row), released from magnetic attraction at the moment weightlessness arose.

Vessels made of organic glass, of size $(3.5 \times 3.5 \times 7)$ cm^3, were placed in the container; into them was poured a 20% solution of hydrochloric acid and placed-

···a large drop of mercury weighing 20 g was formed. In the presence of gravity, such a drop assumed, on the horizontal surface of the bottom of the vessel, the form of a round "pancake" of radius $R = 1.2$ cm and height $h = 0.35$ cm.

Fig. 2. Interaction of the drop with the acid-air interface. Frame 1—the drop near the interface (0.27 sec after the container was detached); frame 2—the beginning of interaction with the interface; frame 3—pushing the drop away from the interface; frames 4-5—interaction of the drop with the boundary film; frame 6—the beginning of the reverse motion of the drop. Height of the HCl column in the vessel, 2.7 cm. Filming frequency, 12 frames/sec.

Fig. 3. Capillary reflection of the drop from the interface. Frame 1—the same as Fig. 2, frame 6; frames 2, 3, 4—motion of the drop after reflection; frame 5—the beginning of interaction with the bottom of the vessel during the reflected motion; frame 6—flattening of the drop upon impact with the bottom of the vessel. Filming frequency, 12 frames/sec.

After the onset of weightlessness, the drop contracted and "jumped" from the bottom of the vessel, acquiring an average velocity $V_0 = 8.7$ cm/sec. In this process, damped oscillations of a complex character were observed (Fig. 1, upper row). The period of these oscillations made it possible, by (2), to estimate the value of the surface-tension coefficient ($\sigma = 340$ dyn/cm).

As the drop moved upward, its oscillations damped out, and it assumed a shape close to spherical. Thereafter an interesting phenomenon was observed

Table 1

No.	Type of energy	Formula for calculation	Value, erg
1	Surface energy of the drop in the overload state	$\sigma 2\pi R(R+h)$	3160
2	Surface energy of a spherical drop	$\sigma 4\pi a_0^2$	2100
3	Energy released in the transition to weightlessness	1—2	1060
4	Kinetic energy of translational motion	$mV_0^2/2$	752

No.	Type of energy	Formula for calculation	Value, erg
5	Kinetic energy of oscillatory motion	$\sigma 2\pi\left[2a_0^2 - b(2a+b)\right]$	270

Fig. 4. Reflection of a drop from the bottom of the vessel and repeated upward motion (“ball game”).
Frame 1 is the same as in Fig. 3, frame 6; frames 2–3: formation of the drop’ s “jump” ; frames 4, 5, 6: repeated upward motion of the drop. Filming rate: 12 frames/sec

pushing through, by the mercury drop, of the acid–air boundary (Fig. 2), deformation of this boundary, braking of the translational upward motion of the drop, and its “throwing” downward (Fig. 3).

This reflection was apparently produced by the elasticity of the HCl film, bounded on one side by air and on the other by mercury. By decreasing the amount of HCl in the vessel, it was possible to prove that this motion is not the result of decelerated motion of the drop under the influence of acceleration, but the result of “reflection.”

With a sufficiently small amount of HCl it was possible to observe the impact of the drop against the bottom, its repeated reflection from the bottom of the vessel, and the start of upward motion (Fig. 4).

The entire motion resembled vertical jumps of a ball between the bottom of the vessel and the elastic HCl–air boundary. The energy balance of the drop motion is shown in Table 1. As can be seen, at the moment of the drop’ s “jump” from the bottom of the vessel, the excess free energy of the surface is completely converted into the kinetic energy of translational and oscillatory motion.

Table 2

Experiment No.	Liquid level height in the vessel, cm	Moment of the start of reflection, sec	Upward motion velocity, cm/sec	Downward motion velocity, cm/sec	γ
1	1.8	0.61	5.8	3.33	0.33
2	2.7	0.81	6.7	3.9	0.34
3	4.5	0.98	5.2	3	0.34
4	5.4	1.08	5.5	3.34	0.367
5	6.5	1.35	5.5	3.34	0.367

By determining the velocity of the drop at the moment of approach to the HCl–

air boundary and the initial velocity of the reflected motion, it was possible to estimate the energy coefficient of capillary reflection of the drop

$$\gamma = W''/W' = (V''/V')^2,$$

where $W' = m(V')^2/2$ is the kinetic energy of the center of gravity of the drop before interaction with the boundary; $W'' = m(V'')^2/2$ is its kinetic energy after reflection from the boundary.

The value of the coefficient γ is given in Table 2.

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Note: Figure translations are in progress. See original paper for figures.