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Abstract

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GROUND-BASED EXPERIMENTS WITH WEIGHTLESS LIQUIDS

In theoretical papers ([1,2]) we investigated the behavior of a liquid losing its weight: a) under ideal wetting of the underlying solid surface, b) in the absence of wetting. In both the first and the second cases, the main attention was directed to the form of the surface of the liquid in a state of static equilibrium when its weight is reduced by a certain number of times. The dynamic aspect of the problem was investigated only schematically: with abstraction from the forces of internal and surface friction and without taking into account the energy on the contact surface between the liquid and the solid body. Under such a schematization it turned out that the molecular forces curving the interface between liquid and air can carry the system through the position of static equilibrium and draw it to some extreme state; after this the system must go back, pass the position of static equilibrium, and return to the initial position, from which the oscillatory process will begin again.

In papers ([1,2]) it was noted that the forces of surface and internal friction must considerably complicate the motion created by surface tension and accompanied by inertial forces. On the other hand, the dynamics of the system under investigation must reflect the significance of the surface energy where the liquid is in contact with the solid underlying surface, and therefore it is in principle possible to use observations of the phenomena described for an experimental determination of this energy (as is known, up to the present time it has been possible to determine experimentally only the energy at the water-paraffin interface).

The study of all kinds of disturbances, the struggle against them, and the development of a new method can most reliably be carried out when weightlessness arises instantaneously, after which the liquid under investigation must be photographed by a motion-picture camera with a sufficiently large number of frames per second; and this is easily feasible in ground-based experiments with a freely falling projectile, inside which the necessary experimental apparatus must be placed—the weightlessness arises instantaneously, at the moment the projectile begins to fall.

Figure 1 schematically shows a longitudinal section of such a projectile, constructed according to our design. Its length is 1200 mm, and the diameter of its largest cross section is 400 mm. The stabilizer fins are not shown in the diagram. With the streamlined surface shape and the falling speeds realized, the air resistance is negligible in comparison with the weight of the entire projectile (250 kg), and therefore the acceleration differs negligibly little from g, and the fall may, with sufficient approximation, be considered free.

Inside the projectile, on a round object table 1, there is placed a paraffin cuvette, the bottom of which is bounded above by the surface of a circular cone with an angle of 174° at the vertex; in other words, the generators of the cone are inclined to the horizontal plane at an angle of 3°. This makes it possible, before the projectile falls, to ensure a stable position of the "disk-shaped" layer of non-wetting liquid in the cuvette, despite the unavoidable small deviations of the projectile axis from the vertical. The cuvette with the liquid is reflected in mirror 2 with external silvering, onto which the lens of motion-picture camera 3 is focused from above, allowing up to 64 frames per second to be obtained. In each frame above the liqui-

the reading of a chronoscope is recorded, whose hand, mounted on the axis of a Warren motor, makes 1 revolution per second; the small divisions of the dial are marked at intervals corresponding to one hundredth of a second. The image of the chronoscope on the frames also makes it possible to determine the linear scale: the diameter of the outer circumference of the dial corresponds to 30 mm. In Fig. 1 the chronoscope is not shown, so as not to overload the diagram. For the same reason, the powerful projection lamp used to illuminate the objects is not shown there either.

The tower for dropping the projectile—welded from structural steel—was installed on the annular balcony of the control tower of the storm basin at the Marine Hydrophysical Institute of the Academy of Sciences of the Ukrainian SSR in Katsiveli. The projectile is released by means of a throw-off shackle of the type widely used in glider work in the air and in towing equipment at sea. This ensures the absence of jolts and an undistorted beginning of free fall.

Having reached a certain calculated level, the projectile is caught by reliable rubber shock absorbers and gives up its kinetic energy to them. With the local architectural dimensions, for the first experiments described we provided free fall over a distance of about 4 m, i.e., a free-fall duration of about 0.9 sec. On the basis of formula (6) from (?) one may expect that in such a time one complete cycle of oscillations will have time to occur in 20 g of water or in 130 g of mercury that have lost weight. In Fig. 1, above the cuvette, the expected profiles are shown schematically: "flat" in the initial state and rounded in the state of weightlessness. On the scale of the diagram these profiles correspond to 30 g of water.

It was very important to record on motion-picture film the moment of loss of weight. Reliable recording was achieved by a very simple method. All units of the apparatus in the falling projectile were energized with alternating current, which was supplied through a soft two-conductor cord running downward, from the ground (it did not interfere at all with free fall). The motion-picture camera was started by means of an electromagnet powered from an internal step-down

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

transformer, through a recti–

Fig. 1

a power supply with "smoothing" capacitors. The illuminating lamp and Warren motor were powered from a 127 V circuit. All these objects were switched on simultaneously by an internal automatic device, precisely when weightlessness arose.

For this purpose we constructed a "weightlessness relay." At one end of its light balance beam a load of mass 300 g is suspended; at the other there is a silver contact and a spring that would press this contact against a fixed one if the moment of the force of its tension were not somewhat smaller than the moment of the weight of the load about the axis of the balance beam. When the release mechanism on the tower operates and the projectile begins its free fall, the load instantly becomes weightless, the spring presses the movable contact against the fixed one, and all the electrical equipment inside the projectile comes into operation.

Fig. 2

From the known moment of the force of the spring tension, the moment of inertia of the load about the axis of the balance beam, and its angular displacement when the contacts close, the interval of time required for the relay to operate was calculated. It turned out to be about 0.01 sec. The delay in starting the motion-picture camera and the tripping of its obturator is estimated at about 0.03. Consequently, the first frame is taken 0.04 sec after the onset of weightlessness.

There might have arisen a danger of vibration of the contact on the balance beam after its impact against the fixed contact. Therefore the same balance beam simultaneously closes a circuit parallel to the circuit of the camera-starting electromagnet: rectified current passes through the winding of a second electromagnet, which deliberately attracts the balance beam to itself. To stop all the instruments in the projectile it is necessary to switch off the current in the external circuit–in the soft cord supplied from the ground. We perform this operation 2 sec after the start of the projectile' s fall.

Thus, on the film the first frame corresponds to the beginning of the state of weightlessness (with the correction); the end of the working process–the entry into action of the shock absorbers–is clearly visible from the slightly shaken image in the next frame. Checking the time against the readings of the chrono-

Fig. 3

Figure 3: Fig. 3

scope confirms that the projectile is indeed falling freely, with acceleration equal to g.

The first experiments were carried out with a supersaturated solution of nigrosine in distilled water, in order to judge the role of surface and internal friction in the investigated changes of the water surface. Against the white background of positives printed from the motion-picture frames, the profile of the surface of the black liquid is clearly visible.

In Fig. 2 one of these positives is reproduced, corresponding to the greatest—

which is why the top of the curve rises to 13 mm above the bottom of the cuvette. As we see, the water does not have time to assume the shape of a sphere, but rises only in the form of a "hill" with gentle slopes. Meanwhile, the nitrosine solution does not wet the paraffin surface; only friction prevents the sphere from forming within the time corresponding to formula (6) from $^{(2)}$.

A quite different picture is observed in experiments with mercury, taken in an amount of 130 g. Here the enormous surface tension and the enormous density of the liquid greatly diminish the role of internal and surface friction in dynamic processes. However, even in this case deviations may arise from the simple scheme to which Fig. 2 and formula (6) in article $^{(2)}$ correspond.

In Fig. 3a one sees the profile of a "flat" mercury disk in the cuvette 0.07 sec after the onset of weightlessness. It has already managed to deform slightly, and moreover nonuniformly: more strongly at the right edge. Instead of the simple oscillations corresponding to index $n = 2$ of Legendre functions according to Rayleigh $^{(2,3)}$, partial oscillations have appeared here, which soon led to an almost complete separation of the mass of mercury into two bodies close to spherical in shape. This is seen in Fig. 3b, corresponding to 0.19 sec after the onset of weightlessness.

An even more complex form of the surface is shown in Fig. 3c; here, 0.27 sec after the onset of weightlessness, smaller partial waves appeared on the main surface of the liquid. They quickly die out, and already in Fig. 3e, corresponding to a time of 0.39 sec after the start of the experiment, one sees a well-formed simple mercury surface—this is a truncated sphere 33 mm in diameter, whose surface makes an angle of about 95° with the inclined surface of the cuvette bottom.

Fig. 3

It is important to note that this form of the mercury surface remains until the end of free fall. It arose without passing through a state of static equilibrium, but approached this state in a kind of aperiodic process. Apparently, the damping of the oscillations described in (2) is caused here by contamination of the mercury surface with some impurities that were present in the paraffin, although the paraffin was called "purified for laboratory purposes." It is possible that the mercury itself also contained impurities, although it too was considered "pure."

The experiments described show that the proposed method of ground-based experiments is promising and, at the same time, that in the future it will be necessary to pay extremely serious attention to the ideal purification of the substance, both the liquid and the solid substrate.

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

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