Are the toroidal shapes of heavy-ion reactions seen in macroscopic drop collisions?

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ABSTRACT. Experiments involving the collisions of water, and mineral oil, drops are reported. The aim is to search for toroidal configurations predicted by, both, macroscopic fluid dynamic and nuclear models. Instead, we find the formation of thin liquid sheets surrounded by a somewhat thicker rim presenting a fingering instability.

RESUMEN. Se reportan observaciones de colisiones entre pares de gotas de agua y de aceite mineral. Nuestro propósito es buscar la formación de formas toroidales predichas tanto por modelos macroscópicos como por modelos nucleares. En lugar de toroides, observamos la formación de películas delgadas de líquido cuyos bordes, un poco más gruesos, presentan una inestabilidad tipo “fingering”.

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1. INTRODUCTION

We are engaged in establishing a bridge between fields where macroscopic liquid-drop collisions are important and heavy-ion reaction modeling, particularly with those theories in which the quantal effects can, somehow, be switched off, allowing a direct access to the bare liquid-drop aspects. Besides providing an interesting testing-ground for those sophisticated models, this represents the opportunity of applying them to fields like meteorology and spray research, where the theoretical situation is less developed. A subject which recently caught our attention was the predictions [1,2] of nuclear fluid-dynamic simulations concerning the possibility of multifragmentation mechanisms proceeding via the formation of tori, among other exotic shapes. Since similar predictions have also been reported for macroscopic systems [3], we are now experimenting with liquid-drops colliding at the relative velocities where those exotic shapes are expected [3] to appear. The oral presentation included interesting video images.

2. THE EXPERIMENTS

The experiments were carried out with a device which is schematically described in Fig. 1, consisting of two hollow cylindrical shafts to which two hypodermic needles have been soldered radially so as to permit the flow from the shafts’ center out through the capillaries. The shafts are axially rotated by an electric motor, while the liquid is injected at their center, thus forming two centrifuged liquid-drop jets. When rotating near one another
in the same plane, two colliding beams are selected by holes in the cylindrical chambers containing each centrifuge and which, otherwise, act as fluid collectors. The beams from these accelerators are further collimated before they enter a middle cylinder acting as a scattering chamber. All three units, the accelerators and the scattering chamber, are independent modules permitting small relative adjusting displacements.

The high velocity drop-drop collisions are observed with the aid of fast stroboscopic lamps which are triggered by signals generated when a narrow handle, fixed at the bottom of the rotating shafts, points in a given direction. A variable delay unit permits the observation of different stages of the collisions. So far, our observations with this instrument have been limited to visualizations of the time evolution of the shapes assumed by colliding systems. Thus, on this respect, we shall limit ourselves to a qualitative comparison of the observed shapes with what has been predicted by both, nuclear \cite{1,2} and macroscopic \cite{3} hydrodynamic calculations.
3. THE MODEL CALCULATIONS

As mentioned in the introduction, our quest has been to search for "exotic" forms predicted to occur by both macroscopic [3] and nuclear [1,2] fluid-dynamic calculations. For non-quantal systems, Lafaurie et al. [3] have recently simulated the collisions of liquid drops using the finite differences method of solving the Navier-Stokes equations in the bulk and dealing with surface evolution in an ad-hoc way through interface tracking procedures. A sample of the shape evolutions predicted by this model is shown in Fig. 2 which shows some interesting similarities with the predictions of nuclear transport models [1,2] concerning the formation of intermediate tori (see Fig. 3) presenting instabilities of the sort which Rayleigh predicted for long cylinders.

4. RESULTS

In Fig. 4 we illustrate the type of pictures observed. For central collisions, once the two drops touch, incompressibility leads to an ejection ("squeeze-out") of liquid along the contact plane forming pseudo-toroidal shapes which, when observed on an inclined plane, always seem to have a thin liquid membrane filling their central region. Radial flow induces a rapid increase in the radius of this pseudo-torus, reducing its cross-section and transforming the system into a thin disc having a somewhat thicker rim. This bordering rim eventually develops a fingering ("mexican hat") instability which initiates the fragmentation process. When compared with the macroscopic fluid-dynamic predictions (see Fig. 2f), we see that an important difference lies in the central liquid film, which the mod-
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Figure 4. Typical images from fragmentation water drop collision at $W_e \approx 150$. The top two rows show the time evolution of one collision. The bottom row shows different views of the "mexican hat" instability (see text).

Models predict to breakup in the early stages leaving a true torus which eventually fragments through some form of Rayleigh instability. The experiments indicate that those central films live longer than the rapidly expanding tori. This difference with the prediction may be related to the approximate way in which surface tension is treated in the model. That problem may also be present in nuclear fluid-dynamic calculations, which have a similar approach to surface tension.

Recently, Moretto [1] described the fragmentation of both sharp (as in macroscopic systems) and diffuse (as in nuclear systems) surface liquid sheet as due to a geometrical instability which would tend to reduce the high surface-energy by breaking into a number of cylinders which, in turn, break into spherical drops via Rayleigh instabilities. Tori ("donuts") are also described in Moretto's work [1] as unstable shapes which are independent from sheets. Our observation with macroscopic liquids indicates that true tori (i.e., not having a thin internal membrane) should be very rare since, among thousands of collisions we have not identified a single one. Instead, most events show the formation of thin liquid sheets held by a thicker border. Like soap films held by a bubble-making rings, those liquid films are fairly stable, fragmenting only after their bordering frame does. The dynamical breaking of this frame is also somewhat different from the Rayleigh-type instability of a toroidal liquid mass.

5. Conclusion

Preliminary results of a search for exotic shapes during higher energy collisions among water and mineral oil drops are reported. The dynamics of drop collisions differs consider-
ably from what fluid dynamic models predict as, instead of tori, we observe the formation of fairly stable thin sheets surrounded by thicker rims showing a fingering instability.

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REFERENCES