In this section of Resonance, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. “Classroom” is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

The Inveterate Tinkerer
6. Bubble Raft

In this series of articles, the authors discuss various phenomena in fluid dynamics, which may be investigated via tabletop experiments using low-cost or home-made instruments. The sixth article in this series explores crystalline defects and motion of dislocations using bubble rafts.

Materials

Petri dish, triethanolamine, glycerol, oleic acid, distilled water, micropipette tip, aquarium pump, isopropanol, dishwashing liquid, glass tray, black paper, syringe needle, halogen lamp, cotton earbuds.

Method

A bubble raft [1–3] is a monolayer of bubbles floating on the surface of a liquid, which may be used as a two-dimensional model for the face-centered cubic or the hexagonal closed-packed structure of metals. The bubbles are attracted together by surface tension forces to form a raft. One may identify the analogs of several crystalline defects as well as visualize the motion of dislocations in the lattice upon deformation of the raft. Such defects are responsible for the electrical conductivity, mechanical strength, and

Keywords

Crystals, lattice, dislocation, point defects, grain boundary, Frenkel pair.
We used the formulation given in [1] for preparing the bubble raft solution: 13.6 g of oleic acid is mixed with 50 ml of distilled water and 73 ml of 11.3% aqueous triethanolamine solution. To this solution, 142 g of glycerol is added. The solution is then left to stand for a day, and the clear liquid is drawn out from below. The clear liquid is poured into a petri dish (diameter = 13.5 cm) with a base which is spray-painted black. A raft of bubbles is formed by blowing air through a micropipette tip placed beneath the surface of the solution, using an aquarium pump and valve. By controlling the flow-rate of air from the pump, the size of the bubbles can be varied. The typical diameter of the bubbles produced by this method is ~3 mm. Unwanted bubbles can be removed by touching with a cotton earbud soaked in isopropanol. By compressing the raft using a glass slide, one may create multilayer rafts. However, structural details are difficult to resolve in such a three-dimensional raft. The individual bubble size depends on the (non-uniform) flow rate of air from the aquarium pump as well as compression forces in the close-packed lattice. As an illustration, we show a portion of the raft which is near ‘perfect’ with no crystalline defects (see Figure 1). Some demonstrations with the bubble raft may be seen in the video: [youtube.com/watch?v=qroQ3GEcfMw](https://youtube.com/watch?v=qroQ3GEcfMw)

**Figure 1.** A bubble raft with nearly crystalline order.
We now discuss some analogs of crystalline defects that were observed in bubble rafts:

1. **Point Defects** *(see Figure 2)*

(a) **Vacancy**: A crystalline defect in which an atom or ion is missing from one of the lattice sites. Individual bubbles can be popped to form vacancies in the bubble raft by touching with a cotton earbud soaked in isopropanol. However, at times, there is spontaneous popping of bubbles, which has no analog in a real crystal. Upon deformation of the raft, vacancies are not observed to move from their respective locations.

(b) **Substitutional Impurity**: An atom/ion which is not normally found in the crystal structure, but is lodged in, and replaces an atom/ion which is ordinarily located in the crystalline lattice.

(c) **Interstitial Impurity**: Small impurity atoms in a crystalline...
Figure 3. Edge dislocations.

lattice that are on off-lattice sites between the lattice atoms.

(d) Frenkel Pair: When an atom or ion leaves its place in the crystalline lattice and becomes an interstitial by lodging in a neighbouring location.

2. Line Defects

Edge Dislocation (see Figure 3): This defect is equivalent to the introduction of an extra row of atoms in the crystalline lattice. To observe the motion of dislocations, we prepared 700 ml of bubble raft solution by mixing 1 part by volume glycerine, 2 parts by volume Joy dishwashing liquid (Procter and Gamble), and 50 parts by volume deionised water. The solution was poured into a glass tray placed on a black sheet of paper. A syringe needle was used in place of the micropipette tip to direct air under the surface of the solution, producing bubbles of diameter $\sim 1$ mm. Air was blown gently on the edge of the raft, producing rapidly moving dislocations which zip across the raft and are absorbed (and emitted) at grain boundaries (see below). A halogen lamp (500 W) was used as a light source. We also noted an instance wherein, a moving dislocation met a vacancy, consumed it, and climbed up one row of bubbles. In another instance, two equal and oppositely moving dislocations were observed to cancel one another.
3. Planar Defects

*Grain Boundary* (see Figure 4): Most crystals are polycrystalline in nature, made up of small, randomly oriented crystals separated by an interface. These interfaces may be seen by etching the crystal with an acid. Each crystal or ‘grain’ has a different orientation with respect to the normal vector of the planar lattice. The bubble raft analog of grain boundaries may be seen using the aqueous...
glycerol-dishwashing liquid formulation mentioned above. In a tilt grain boundary (see Figure 5), two adjacent grain boundaries meet at an angle while lattice positions are mirrored across a twin grain boundary (see Figure 6).

**Suggestions for Further Work**

*Recrystallization:* We used the aqueous glycerol-dishwashing liquid formulation referred to above to visualize recrystallization. If the raft is broken up by stirring using an earbud, one observes merging of separate rafts and reduction in the extent of grain boundaries over a period ~ 30 minutes as shown in the time-lapse photographs (see Figure 7). The rate of recrystallisation may be increased by heating the liquid in the glass tray using a hot plate [3].

**Figure 7.** Recrystallisation in the bubble raft after stirring at (a) $t = 0$ (b) $t = 30$ minutes later.
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Suggested Reading


[3] A video illustrating the effects of high temperatures on grain boundaries and dislocations in a bubble raft may be seen here: youtube.com/watch?v=g6Hp0untVPi
