

Practical 1P5: Bubble Raft

What you should learn from this practical

Science

You should be able to recognise a variety of point defects, edge dislocations and grain boundaries in the bubble raft. The existence of a dislocation will be established by measuring a closure failure in a Burgers circuit in the raft. The structures of grain boundaries will be seen to depend on the misorientation between the adjoining rafts.

When the raft is disturbed by tilting or shaking the tray slightly you should see dislocations moving and interacting with each other, with grain boundaries and with point defects. You will see the planes on which slip occurs (i.e. the lines along which the dislocations move) within a grain.

Finally, you will model recovery and recrystallisation by stirring up the raft with a glass rod and then letting it heal over time.

Practical skills

You will photograph your observations. For this it is recommended that you use your own devices (e.g. smartphone); make the demonstrators aware if your group does not have access to a digital camera in some form. Optionally, you may also find it helpful to record videos of the raft to capture the movement defects etc.

Safety Considerations

Be careful that you do not slip on any spilled water or detergent; if you group spills any fluid then wipe it up immediately and warn others to avoid the spillage.

Note that the detergent used in this experiment is very strong – students with sensitive skin should take suitable precautions.

If your group is asked to create glass tubes: Take care when drawing down glass tubes with a flame. Beware of the glass and the flame, and be conscious of the people around you. You must wear a lab coat, gauntlets and safety glasses. Scrap glass must be put in the broken glass disposal box.

Introduction

A bubble raft is a raft of bubbles on the surface of a liquid. When the raft is made carefully, so that the bubbles are small and have the same size, it forms an excellent two dimensional model of a crystalline metal. The regular hexagonal arrangement of the bubbles is analogous to the regular structure of a close packed plane of atoms in a metal like aluminium or copper. That in itself is not very interesting. What makes the bubble raft so useful is that the **defects** in the regular hexagonal array of bubbles are closely analogous to many of the defects in a real crystalline metal. This analogy was recognised in the middle of the last century when W L Bragg and J F Nye published a paper in the Proceedings of the Royal Society (Series A, **190**, 474 (1947)) showing photographs of defects in bubble rafts. Perhaps they got the idea from staring at the bubble raft on the

surface of a pint of beer, or on the surface of a soapy bath. Wherever the idea originated from it has helped generations of materials scientists to get a picture of what defects in metals look like. In fact the bubble raft does more than that because one can use it to see how defects interact with each other, how they move and how they can be destroyed. Thus, the bubble raft provides a picture of the dynamical behaviour of defects as well as their structures when they are stationary.

But, be warned that the 2-dimensional nature of the bubble raft imposes quite severe limitations on it as a representation of a real metal, which is clearly 3-dimensional. For example, an important class of dislocations, called screw dislocations, cannot exist in a two-dimensional bubble raft; in fact all the dislocations one sees in the bubble raft can only be pure edge dislocations.

Overview of practical

You will be shown an excellent film about the Bubble Raft made by Bragg. You will then produce your own bubble rafts; you may need to make your own glass tubes for this purpose, or they may be supplied. You will take photographs of point defects, dislocations and grain boundaries. You will then disturb the raft to study the motion of defects, their interactions and their annihilation. Finally you will study the evolution of the bubble raft after giving it a good stir to observe the recovery and recrystallisation. You will take a series of photographs, and optionally videos, throughout the practical in order to record your observations. Following the practical you will prepare

your report which will involve suitably annotating your photographs, and optionally adding narration to your video(s).

Experimental details

1. If your group has been asked to make fine glass tube nozzles: Make these by heating glass tubes and stretching them rapidly outside the flame. However suitable tubes may be provided.
2. Pour soap solution into a tray, with the black plate on the bottom of the tray to help you see and photograph the bubbles that you will grow. Pour slowly to avoid many unwanted bubbles. Attach the glass tube to the rubber tubing from the nitrogen cylinder. Adjust the flow from the cylinder carefully so that a sensible rate of bubbles is produced in the liquid when the fine nozzle is placed in the tray. Blow the bubbles away from the nozzle as they are produced to prevent them from stacking up in clumps. It will take 15-30 minutes to grow a good bubble raft, covering most of the tray. If your bubbles are larger than 2 mm make another nozzle.
3. You will see that the raft consists of patches in which the hexagonal arrangement of bubbles has a constant orientation, but which changes between different patches. These patches are the analogues of individual crystals or 'grains' in a polycrystal, and the line where different patches meet is a grain

boundary¹. Within each patch you should see a hexagonal arrangement of bubbles, within which you can identify 3 families of lines at 60° to each other along which bubbles touch (these lines are called close-packed directions). The close-packed directions are equivalent to crystal axes and they define the orientation of each grain. Their orientation changes abruptly at a grain boundary. The angle through which the close-packed directions change across a grain boundary is called the misorientation. The maximum possible misorientation is 30° in the bubble raft. **(You should say why this is true in your write-up)**. The misorientation is one of the characteristics of a grain boundary. The other is the line in the bubble raft along which the boundary exists (this is the analogue of the boundary plane in a three-dimensional metal). **Take pictures of 3 different grain boundaries and in your write up show the misorientation and the line along which the boundary exists. Do you see any semblance of structural order in your grain boundaries, or would you describe them as having random structures?**

4. Within each grain you should see a relatively perfect hexagonal array of bubbles, with occasional point defects. **Find and photograph examples of the following point defects:**
 - a) a substitutional impurity (a bubble that has a different size from the rest, occupying a site of the hexagonal lattice).

¹ Remember that because the raft is 2-dimensional, a defect that is planar in a 3-dimensional metal, such as a surface or a grain boundary, becomes a line in the bubble raft, and a linear defect, such as a dislocation, becomes a point in the bubble raft. Exceptionally, a point defect is just a point in both the 3-D metal and the bubble raft.

- b) a vacancy (a missing bubble).
 - c) an interstitial (a bubble occupying a site that is not on the hexagonal lattice, but which is squeezed in between the bubbles of the hexagonal array).
 - d) You may be lucky and be able to observe more exotic combinations of point defects, such as di-vacancies (two vacant sites next to each other), or Frenkel defects (an interstitial and a vacancy near to each other). Photograph any such interesting cases. But make sure you do not mistake a dislocation for a point defect. One quick and easy way to distinguish them is to tilt the tray of the bubble raft gently. If the defect moves it is very likely to be a dislocation. A longer, but more rigorous, way of establishing whether the defect is a dislocation is to construct a Burgers circuit. This is treated next.
5. If you tilt the tray gently or otherwise stress the raft you will see defects moving rapidly along the close-packed directions within each grain. These defects are dislocations. Locate one of these defects near the centre of a grain. If you look along the close packed rows you should see that the dislocation is located at the point where a close-packed row of bubbles terminates.
- Photograph this dislocation for your report.** Look along the other close-packed rows and describe what you see. **Identify the extra 'half-plane' of this edge dislocation.**

(5. Continued) What is the direction of the dislocation 'line' with respect to the bubble raft? The Burgers circuit is a construction that not only tells you whether the defect is a dislocation, but it characterises the dislocation in terms of a vector called a Burgers vector. Choose a bubble a few away from the defect that you believe is a dislocation. Call this bubble **A**. Perform a right-handed (clockwise) circuit, starting and ending at **A**, around the dislocation by counting along the close-packed rows. It is crucial that your circuit encloses the dislocation. For example, you might have to go 6 bubbles to the right, 5 downwards, 5 to the left and 5 upwards to end up at **A** again. If you now repeat this circuit in a perfect region of the raft, by counting out the same numbers of bubbles to the right, down, to the left and up, you will find that the circuit will not end at the same bubble at which you started. This closure failure is the signature of a dislocation: if you have a point defect, such as a vacancy, there will be no closure failure. The closure failure of the circuit (which is called the reference circuit) in the perfect crystal is called the Burgers vector. In fact we haven't defined the positive or negative sense of the vector uniquely yet. To do that we need a convention. It doesn't matter which convention we choose so long as we stick to it for all dislocations. For a Right- Handed circuit around the dislocation line the Burgers vector points from the Finish to the Start: the FS/RH convention. **You should edit suitable photograph(s) to show Burgers circuits associated with a dislocation in your report. In your report, show both the magnitude and the direction of the Burgers vector.**

The two parts of the raft on either side of the close-packed row of bubbles, along which the dislocation moves, undergo a relative displacement equal to the Burgers vector. For this reason the Burgers vector is sometimes called the slip vector: it is the vector by which the two regions of crystal slip past each other when the dislocation moves. **In the write up draw a diagram showing how dislocations move relative to the packing of the bubbles in the bubble raft.** In 3-dimensions the dislocation line moves along a plane and that plane is called the slip plane. The Burgers vector, or slip vector, is the relative displacement of the two parts of the crystal on either side of the slip plane. In the bubble raft the slip 'plane' is just the close-packed row of bubbles along which the dislocation moves.

6. Tilt or shake the tray gently to move dislocations. **What happens when dislocations reach the edge of the raft, or a grain boundary?** If you are fortunate you will see dislocations meeting each other - **what happens? Do dislocations interact with point defects, such as vacancies, interstitials and substitutional point defects in the raft? If so, how?** Try to **photograph** as many of these phenomena as you can. You may also make a video of this activity, and upload it to a suitable location (youtube etc) so that you can provide a link in your report. In any case, make sure to **describe** your observations and **sketch what happens**.

7. Stir the bubble raft gently with a glass rod. This creates a high density of defects in the bubble raft, which is analogous to a piece of metal that has been deformed at low temperatures ('cold-working'). Observe, record and photograph what happens in a period up to 20 minutes after you have stopped stirring. You should see that many of the defects you introduced by stirring are gradually removed², and that the grain size increases. This is the analogue of recovery and recrystallisation. Be warned that many of the changes take place very rapidly in the first 10 seconds or so after you stop stirring, and then the changes occur much more slowly.

Rough Timetable

Day 1: Watch the film by Bragg. Obtain your glass nozzle, and grow your bubble raft. Photograph stationary grain boundaries, point defects and dislocations. Study the dynamical interactions between defects by disturbing the tray gently, using photography and optionally video to record it. Stir the raft to simulate recovery and recrystallisation.

Day 2: If you did not complete the tasks to your satisfaction, you may return on the second day to finish them.

² With the exception of vacancies, which are formed by bubbles popping. Obviously there is no analogue to this phenomenon in a real metal!

What should be in the report

When writing your report, imagine that the reader has not heard of the bubble raft experiment and does not have access to this set of notes that you are reading now – your report should be a self-contained description that would allow the reader to reproduce your experiment and see the same type of phenomena that you did.

- A summary of no more than 100 words of how you made a bubble raft.
- A description of your observations (with illustrative and relevant photographs) of grain boundaries, point defects, dislocations and the Burgers circuit, dynamical interactions between defects and stirring the raft to simulate recovery and recrystallisation.
- Answers to all the questions posed in this write up. They have been highlighted in **bold** to help you find them.

It should be possible to complete your writeup within about 3 hours.

Length of report

No more than **1000 words**.

Points to think about in writing up

Make sure you have done everything you are asked to in points (2)-(7) of the above section on 'Experimental details'. **Make sure you have answered all the questions.** We are looking for evidence that you made the observations you were asked to, and that you understand what you saw. Concentrate on YOUR OBSERVATIONS and explaining them in your report, NOT on other theory.

Marking considerations

You will receive marks for a report that contains answers to the questions posed in this guide, with photographic (or other) examples of all the observations you have been asked to make, accompanied by a concise description of each observation that clearly and correctly identifies the defects and any processes in which the defects are involved during the course of the two dynamical experiments (the dynamical experiments are (5) and (6) of Experimental details).

Not wanted in the report

There should be no background bookwork. None of the material in this guide should be reproduced in your own report.