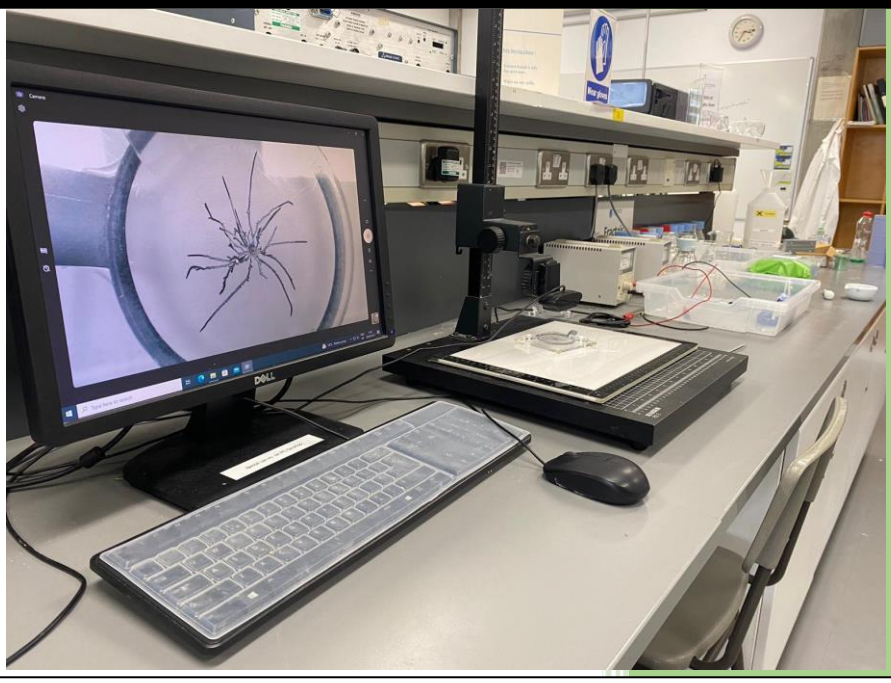
Junior Sophister Laboratory

Fractals



Fractals

This experiment introduces students to the theory behind fractals, which will be investigated as outlined below.

A student completing this experiment should achieve the following experimental learning outcomes:

1. To gain a greater understanding of the underlying physics of how fractals are produced in the manner demonstrated in this experiment.
2. To gain an improved understanding of the different structures that these fractals can form into. What makes them different from each other, and what causes any certain structure to form instead of the others in a certain situation.
3. Gain more experience in using special software (ImageJ in this case) to process an image.

Students must read the background materials in advanced of attending the laboratory.

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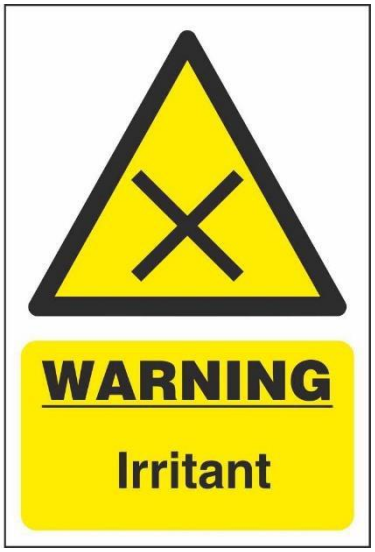
Safety Warning:



The chemical used in this experiment, Zinc Sulfate Monohydrate, is an irritant to the eyes and skin and can cause harm if ingested or inhaled. For protection, all students doing this experiment are to wear gloves, goggles and the lab coats available at the front of the room. A detailed risk assessment is available in Appendix 2 at the end of this document.

N.B Read appendix 2, - Chemical Risks Assessment-, before commencing experiment.

Introduction

In this experiment you will use the methods of fractal geometry to analyse the morphology of zinc electrodeposits. A CCD camera is used to capture images of the zinc deposits that are then analysed using a PC and appropriate methods.

Ideal, or mathematical, fractals have the property of scale-independence or self-similarity, that is, they look the same over all scales. Some fractals, such as the Koch curve, are exactly self-similar - they look exactly the same regardless of the scale on which they are examined. Other fractals are statistically self-similar, i.e. different regions and scales will look similar but not identical to other regions and scales. The Mandelbrot set, perhaps the most famous of all fractals, is of this type.

Real fractals, such as those you will grow in this experiment, clearly cannot be fractal over all scales - the size of the deposit will provide an upper limit for example - but there is a surprisingly large range over which scale-independence can be seen. It is possible to grow deposits of greatly varying structure. These structures fall into four broad categories: dense radial, diffusion-limited aggregation (DLA), dendritic, and stringy. These morphologies are common to many examples of growth phenomena at unstable interfaces, such as those which occur during crystallisation.
DLA is intuitive and easy to model. Imagine a sea of particles in random motion. Fix one particle at the centre. This particle becomes 'sticky' and another particle that bumps into it stops moving and becomes another 'sticky' site. In this way the fractal grows radially outward.
In this experiment you will grow a deposit of zinc from a solution of zinc sulphate in an electrolytic cell and examine how the shape and fractal dimension of the resulting deposit depend on the cell voltage and electrolyte concentration.
There are several definitions of fractal dimension but they all give an indication of how completely the fractal appears to fill space.

After a suitable deposit is grown an image of the fractal is captured using a CCD camera in conjunction with capture software. The image is then opened in another program which determines the fractal dimension.

Experimental Details

Using the sample bottles and the deionized water provided, make up aqueous solutions of zinc sulphate of varying concentration between 0.01 and 1M. First make up 200 ml of 1 molar solution and progressively dilute a fraction of this to obtain lower concentration solutions. Note, use the

chemical equation for the Zinc Sulphate as shown in Appendix 2, and remember what a ‘mol’ of a substance refers to, and how it is defined. (Tip: When making the solution, to avoid clumps forming, put deionized water in the beaker first, then add the powder slowly.) Using the ring anode and graphite cathode (0.5 mm pencil lead), grow the deposits between the perspex plates provided, as described in refs 1 and 2; it is important to remove any air bubbles between the plates. To determine how the morphology and fractal dimension depend on cell voltage and electrolyte concentration grow deposits for each of at least three concentrations (for example 0.01, 0.1 and 1M) at each of at least three different voltages. When a deposit has reached a suitable size (3-6 cm across), carefully remove the electrode and position the perspex below the video camera. Details of capturing and processing the image and of finding the fractal dimension are given below.
As well as including the images (together with their fractal dimensions) in your report plot a phase diagram **(as in the paper by Grier et al.)** showing the fractal shape and dimension for each of your sets of voltage, concentration values.

1. Capturing and processing the image

In this section, a CCD camera is used to view the fractal and the image is captured as a digital picture with the Windows Camera App. The image is edited using the ImageJ software. A still of the image is then saved in the form of a bitmap (.bmp) file.

First create and name a folder to keep captured photos in (make sure each lab partner keeps copies of the images.) Next turn on the Windows Camera app and apply the following camera settings.

Windows Camera settings:

Settings > Photo Quality 4:3 (640 x 480)
Settings > Pro mode on
Pro mode > framing grid > cross hairs

Physically adjust the camera so that it is focussed on the fractal growth and use the cross hairs to ensure the centre of the image is the centre of the fractal. Next turn on the light box and by tapping

on the power button, alternate between its different light settings to get the sharpest contrast of the dark fractals against the white background.
(The programs you will be using are sensitive to the continuous distribution of dark pixels in the image so you should ensure that the ring anode is not visible in the frame.) Take a picture of your image, relabel and rename it appropriately and transfer it to your previously created folder.

Next open ImageJ and open your saved image. Click Image-> Adjust->Brightness and Contrast. Adjust the Brightness and Contrast for maximum image contrast so that the dark Fractal stands out clearly against a plain white background. Take care not to increase the contrast to a point where the image starts to loose detail. Then save and print the image in your folder. Check that the print **Properties** are set to **Grayscale** under the **Color** tab.
The *BENOIT* analysis software takes the images white points as data points. Therefore, it is necessary to invert the dark fractal image. To achieve this reopen ImageJ and invert the adjusted image by clicking Edit-> Invert. Once again adjust the brightness and contrast settings so that you have sharp white fractals on a dark background. Note where the centre of the fractal is by placing your mouse over the centre and noting the x, y coordinates in the top window in ImageJ. (The centre of the fractal is not necessarily the same as the centre hole position where the graphite cathode was placed). Save the image as a BMP for import into Benoit.

2. Determination of fractal dimension using BENOIT software

Before starting the analysis you can save time by initiating the growth of the next deposit using the second set of apparatus.
Double click on Benoit shortcut on the desktop. On your desktop open the text file Benoit Ser no, use the information on this file to log in to the Benoit software leaving the email and phone number section blank.
Select analysis method – note that you must use both:

- mass dimension
- box counting

For a detailed explanation of these options see the appendix below. After selecting an analysis method, by clicking OK, you will then be asked to open your saved BMP file.

Analysis will then auto run with Default settings and give a result.

Once you have run the mass dimension method in its default setting, change the centre of the image to the coordinates of the centre of the fractal obtained from ImageJ. This is done by entering the x and y coordinates you obtained from the ImageJ software into the horizontal and vertical boxes respectively under coordinates of circle centre. Click Start at the top of the screen and you will now be running the mass dimension with the centre of the image aligning with the centre of the fractal.
Evaluate the change in the fit and the exponential formula when the central point for the analysis is displaced by 5 pixels. Is it different to the fit values obtained from the initial estimation of the position of the centre of the fractal? Why do you think this is and how might this be useful?

Print out the resulting curve by clicking on the print icon above it and then compare the results from the two analysis methods – Box counting and Mass dimension. You must comment on the accuracy of these analysis methods and the appropriateness of the fit to the dat. How can this be improved? Improve these fits as necessary.
To switch between analysis methods, the file has first to be re-selected by clicking the back arrow (green) on the top-left of the screen.

[Printing – Before selecting PRINT the scale of the x-axis can be changed with:
> SCALE UNITS >Width > X axis = max width of image =640 pixels.]

Make sure in your report that you discuss your findings and link them back to the relevant theory. (ie the physics behind said results). Consider the physical models behind such crystal growth.

References:

1 D Grier et al, *Morphology and Microstructure in Electrochemical Deposition of Zinc*, Phys. Rev. Lett,. **56,** 1264-1267, (1986).

2 Yasuji Sawada et al, *Dendritic and Fractal Patterns in Electrolytic Metal Deposits*, Phys. Rev. Lett., **56**, 1260-1263, (1986).

3 M Matsushita et al, *Fractal Structures of Zinc Metal Leaves Grown by Electrodeposition*, Phys. Rev. Lett., **53**, 286-289, (1984).

4 Leonard M Sander, *Fractal Growth Processes,* Nature, **322**, 789-793, (1986)

5 Amnon Aharony, *Fractals in Physics,* Europhysics News, **17**, 41-43, (1986).

6 D G Grier et al, *Stability of the Dense Radial Morphology in Diffusive Pattern Formation*, Phys. Rev. Lett.**59**, 2315-2318, (1987).

7 R Julien, Aggregation phenomena and fractal aggregrates, Contemp. Phys., **28**, 477-493, (1987).

8. Jurgen Peitgen, *Chaos and Fractals,* Shelf Mark 514.7 N21.

Appendix 1: Dimension algorithms

Mass Dimension

This method of fractal dimension is described in ref 1 (Grier et al). The fractal dimension is determined by counting all the points, N(r) within a given radius r. The fractal dimension is then given by plotting log N(r) vs log r and measuring the slope in the linear region.

Box Counting:

This very common method of determining the fractal dimension is described in ref 8 (Peitgen). A mesh, with mesh size, s, is drawn over the image and the number of squares that contain a portion of the growth is counted to give N(s). This process is repeated with a different sized mesh. As with the other two methods, a log - log plot is required to obtain the fractal dimension, in this case plotting log N (s) against log (1/s) and measuring the slope. The mesh size reduces in size as the analysis progresses.

Appendix 2:

Summary -For more details see Material Safety Data Sheet (MSDS) located on bookshelf.

Chemical Risk Assessment Form -*Summary*

Chemical Name	ZINC SULFATE MONOHYDRATE (7446-19-7)	**Assessor** P. Flanagan (Physics), Prof. R Barklie	
	$ZnSO_4 H_2O$		
Location/Room No.	Physics SNIAM 1.18	**Date** 06/10/03	

Area	Hazard	Risks	Risk Rating	Protection and Prevention Measures
Storage			LOW	KEEP TIGHTLY CLOSED. STORE IN A COOL DRY PLACE. INCOMPATIBILE WITH STRONG OXIDIZING AGENTS
Use	IRRITANT	IRRITATING TO EYES AND SKIN. MAY BE HARMFUL IF INHALED OR SWALLOWED.	MEDIUM	DO NOT BREATHE DUST. AVOID CONTACT WITH EYES, SKIN AND CLOTHING. WEAR COMPATIBLE CHEMICAL-RESISTANT GLOVES AND CHEMICAL SAFETY GOGGLES. AVOID PROLONGED OR REPEATED EXPOSURE.

Emergency Procedures
In case of fire:

EXTINGUISHING MEDIA
WATER SPRAY.
CARBON DIOXIDE, DRY CHEMICAL POWDER OR APPROPRIATE FOAM.
SPECIAL FIREFIGHTING PROCEDURES
WEAR SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING TO PREVENT CONTACT WITH SKIN AND EYES.
UNUSUAL FIRE AND EXPLOSIONS HAZARDS
EMITS TOXIC FUMES UNDER FIRE CONDITIONS.

Personal Protection Equipment

SAFETY SHOWER AND EYE BATH. MECHANICAL EXHAUST REQUIRED.COMPATIBLE CHEMICAL-RESISTANT GLOVES. CHEMICAL SAFETY GOGGLES.

First Aid

IF SWALLOWED, WASH OUT MOUTH WITH WATER PROVIDED PERSON IS CONSCIOUS. CALL A PHYSICIAN.
IF INHALED, REMOVE TO FRESH AIR. IF NOT BREATHING GIVE ARTIFICIAL RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.
IN CASE OF CONTACT, IMMEDIATELY WASH SKIN WITH SOAP AND COPIOUS AMOUNTS OF WATER.
IN CASE OF CONTACT, IMMEDIATELY FLUSH EYES WITH COPIOUS AMOUNTS OF WATER FOR AT LEAST 15 MINUTES.