Applied Mineralogy and Petrology

A Lab Manual for EART2231 at the University of Western Australia

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In this chapter

Welcome 4
- License 4

Acknowledgements 5

Downloads 6

Preface 7
- About this book 7
- Introduction 8
  - Quick Access 8
  - Mineralogy 8
  - Petrology 8

I Quick Access 9

Microscope Setup and Use Reminders 10
- Correct Use of Microscopes 10
  - At the start of a session 10
  - During a session 11
  - At the end of a session 12
- General Care 12

Useful Tables, Charts, and Diagrams 13
- Reading Ternary Diagrams 13

Process flow charts 14

II Mineralogy 15
- Crystallography 16
- Physical Properties of Minerals 16
- Optical Properties of Minerals 16

1 Crystallography 17
  - 1.0.1 The Unit Cell 17

1.0.2 Symmetry Elements 17
1.0.3 Crystal Lattice 17
1.0.4 The 7 crystal systems 17

2 Physical properties of minerals **18**

3 Optical properties of minerals **19**
3.1 Plane Polarised Light 19
3.1.1 Opacity/Transparency 19
3.1.2 Colour 19
3.1.3 Relief 19
3.1.4 Cleavage and Fracture 19
3.1.5 Growth Features 19
3.2 Cross Polarised Light 19
3.2.1 Birefringence 20
3.2.2 Extinction Angles 21
3.2.3 Twinning 21
3.3 Further concepts 21
3.3.1 Colour perception 21
3.3.2 Sources of Light 21

III Petrology **25**

4 Description of Igneous rocks and textures **26**

5 Classification of Igneous Rocks **27**

6 Phase Diagrams **28**

7 Igneous Processes **29**

Appendices **30**

A Resources **30**

B References **31**

Welcome

This lab manual covers the introductory topics for the Mineralogy and Petrology component of EART2231 - Earth Materials, for Semester 1 2023 at the University of Western Australia. This is not intended to be a comprehensive guide on these subjects, but a curated 'launch pad' from which we can direct you to further available resources.

License

This manual was written in Quarto Markdown, and contains executable code blocks. All text and supporting code is available on github at orthospar/AppMinPet.

Acknowledgements

The material contained here has been built upon the following coursework notes and handbooks compiled by C.I. Mathison for use with previous Earth Science courses at UWA:

- "Polarising Microscopy of Minerals and Rocks" (Yellow Book) compiled by Dr Charter Mathison
- "Mineralogy and Igneous Petrology" (Blue Book) compiled by Dr Charter Mathison
- "Practical Mineralogy and Petrology" (Orange Book) compiled by Dr Charter Mathison

Copies of these (and some other reference texts) are available in the Second Year Lab or via request.

Downloads

This document is a work in progress, and will be continuously updated. Nevertheless, downloads are available via the link at the top left of the page. If you do download a copy of this text, please check the homepage periodically for newer versions. Any comments and suggestions (spotted some typos?) can be added via the built-in tools in the online version, edited and pushed via github, or alternatively you can send me an email.

Preface

About this book

This is a lab manual created using Quarto markdown and executable code. It contains many interactive elements and is designed to be read within a browser with an internet connection, however a static version is also available in pdf or epub format.

The online version leverages a few extra features that are not typically found in textbooks. The first of these is a range of embedded interactive elements such as quizzes, interactive plots, and other visualisation tools, made possible through the use of Quarto. These will not work in the downloadable formats.

> **i** Figures in pdf and epub
>
> As of 25 January 2023, figures rendered via ObservableJS (the interactive figures) are not built into the pdf or epub formats *at all*. This feature is slated for a future Quarto update (ETA: Mid 2023), where static versions of the figures will be automatically generated and inserted during document rendering. Until then, please refer to the online version for these figures.

The second feature is :Nutshell. Nutshell links are identifiable by their little : (colon) in front of the hyperlink. These links open the target site within the textbook itself, allowing seamless reading without jumping across multiple tabs. They also provide summary snippets and definitions, such as :Mineralogy or :Petrology. These will be used to provide further information, internal references to definitions, or links to other media (such as youtube videos). In the downloadable formats, Nutshell links will render as normal hyperlinks.

The third tool is Hypothes.is, which allows you to create public comment and discussion threads about the content on each page. You can also create your own private annotations. This does require an account to use, so it is up to you if you wish to join in or not. The hypothesis toolbar is located at the top-right of the page.

> **i** Note
>
> It is possible to add public annotations and comments to pdf and epub files via the hypothesis website, however these will not be integrated with comments on the main

website. We encourage students to use the online version for use with Hypothesis.

Introduction

This lab manual has been specifically tailored to the content taught during the first half of EARTH2231 - Earth Materials, at the University of Western Australia. We have arranged the material into the following parts:

Quick Access

In this part we provide quick navigable access to some of the tables, graphs and process flow charts that you will use on a daily basis when doing any thin section microscopy (including sedimentary and metamorphic petrology, which we do not cover here).

Mineralogy

In this part we cover some introductory and basic principles of Mineralogy. We largely focus on crystallography and optical mineralogy, and the core concepts that you will be required to know for further Earth Science courses. Each chapter contains the requisite material for that week, i.e., Week 1 is Chapter 1. The only exception is Chapter 0, which is revisionary material (assumed knowledge from EART1104 - Discovering Earth), which we will cover as a 'refresher' during the lab in Week 1.

Petrology

In this part we apply our new-found mineralogical skills towards the observation, description, and analysis of igenous rocks. Again, each chapter covers the material for the corresponding week.

Part I

Quick Access

Microscope Setup and Use Reminders

! First time set-up

Do not touch the microscopes until you have been intially instructed on their use.

We will demonstrate the correct way to handle and set-up the microscopes during the first laboratory session in which we will use them. Remember that these are a shared resource with your colleagues and each microscope will have multiple regular users throughout the semester. It is in your interest, as a community, to make sure the microscopes are properly looked after.

Correct Use of Microscopes

At the start of a session

- Carefully place the microscope on the bench, directly in front of you, and not placed too far back on the bench.

Do: Always use two hands!

Always use two hands when picking up and moving the microscope – one hand on the neck at the back of the microscope, and one hand underneath the base.

! Don't: Grab the microcope by the head!

The head, stage and turrent of the microscope are not always secure, and are not designed to bear the full weight of the microscope.

- Plug in the power supply box. Make sure the dial is set to low voltage, and then turn it on. Slowly turn up the voltage to sufficient illumination.

Halogen bulbs

The light source is a halogen bulb, which is a kind of incandescent light source. As such, bulbs can 'blow' with sudden changes in voltage and temperature. Slowly turning up the voltage improves their life span... and makes it much less likely to blow during an exam!

Before you place a slide on the stage, using the lowest power magnification, check the following:

- Under PPL check that the light is uniform with no shadows or obstructions.
- Under XPL, check that the view is black. Not just a bit grey, and definitely not pink/purple!

During a session

- Always start at the lowest magnification
- Change to higher magnifications by holding the **rim of the turret**, not via the objective lenses.
- Change through the higher magnification lenses in order, and focus each lens before moving to the next
- Pay close attention to the working distance at each magnification, make sure you do not focus the objective lens **into** the slide.

! Focusing at high magnification

Only use the fine focus control, particularly with 40x objective lenses or higher. The coarse focus will move the stage too much, and you risk pushing the objective lens *through* the stage, breaking the slide and damaging the lens.

- Always switch back to the lowest power objective before removing or changing slides.
- Only work on one slide at a time, and return the slide to the correct tray or drawer immediately when finished.

! Never leave the slide on the stage

Even if you are only walking away for a few minutes, put the slide away (and turn off the power and put the cover on the microscope). Leaving slides on the microsope stage makes them unavailable to other students, and risks lose and/or damage to the slides if the microscope is packed up accidentally with the side still on the stage.

At the end of a session

- Set the objective lens to the lowest magnification
- Remove the slide, and store it where it belongs.
- Turn down the voltage on the power supply unit, then turn it off.
- Place the dust cover back on top of the microscope.
- Carefully, using two hands, return the microscope to the cupboard.

General Care

- Operate moving parts gently (such as the stage, turret, analyser, diaphram, etc) and take care not to bump the microscope.
- Do not touch the lens surfaces, and never attempt to clean them (they can be scratched easily). If you suspect your microscope needs care and maintainence, let your instructor know and we can arrange to have it cleaned.
- Wash your hands before using the microscope! Not only is this important for the management of repiratory illnesses such as COVID-19, but this helps to keep the microscopes clean and grime free.
- Do not eat or drink at your desk with the microscope out! Water is the only exception. If you want to have a coffee, or an energy drink, walk away from your desk and take 5-10 mins. This is also good for your eyes and posture.
- If you are not actively using your microscope, turn it OFF and put the cover on! Dust is a menace and gets in there even if you are only gone for 10 mins.

Useful Tables, Charts, and Diagrams

How to use

Full descriptions of how to *use* this material (and what it means) will be provided in later sections, please follow the relevant links if you need to refresh your memory.

Reading Ternary Diagrams

```
import {ternarySlider} from '@yurivish/ternary-slider'

pc = d3.format('.0%')

viewof Composition = ternarySlider({
    value: [0.3, 0.2, 0.5],
    labels: ['MgO+FeO', 'Fe2O3', 'SiO2']
})
```

The pointer indicates a composition of:

- ${pc(Composition[0])} MgO + FeO,
- ${pc(Composition[1])} Fe_2O_3,
- ${pc(Composition[2])} SiO_2

Process flow charts

Part II

Mineralogy

This section of the textbook deals largely with crystallography and optical mineralogy. We also revise and expand upon your existing knowledge of the physical properties of minerals.

Crystallography

Learning Outcomes

- Understand the definition of a mineral, unit cell and crystal lattice
- Recognise symmetry elements
- Classify minerals into one of the 7 crystal systems based on symmetry

Physical Properties of Minerals

Learning Outcomes

- Revise physical properties of minerals
- Predict physical properties based on crystal structure

Optical Properties of Minerals

Learning Outcomes

- Correct use of a petrographic microscope
- Describe optical properties of minerals in thin section
    - in Plane Polarised Light
    - in Cross Polarised Light
- Classify (and identify) minerals observed in thin section

1 Crystallography

1.0.1 The Unit Cell

2D vs 3D examples

1.0.2 Symmetry Elements

Mirror Planes Rotation Axes Center of Inversion

(Extension: Other elements)

1.0.3 Crystal Lattice

Application of symmetry elements to the unit cell - build a repeating structure in 2D and 3D

1.0.4 The 7 crystal systems

Recognition based on symmetry

(Extension: Bravais Lattices)

2 Physical properties of minerals

3 Optical properties of minerals

We recommend the open access textbook "Guide to Thin Section Microscopy" by Raith, Raase, and Reinhardt (2012) for ongoing use as a detailed reference companion. This textbook is worth getting printed and bound by a high quality professional printing service.

3.1 Plane Polarised Light

3.1.1 Opacity/Transparency

3.1.2 Colour

3.1.2.1 Pleochroism

3.1.3 Relief

3.1.4 Cleavage and Fracture

3.1.5 Growth Features

3.1.5.1 Habit

3.1.5.2 Zonation

3.2 Cross Polarised Light

The upper polarisation plate (the anlyser) is oriented perpendicular to the orienation direction of the lower polarisation plate. Since the lower polariser is, by convention, orientated in an E-W direction (or left-right), the upper polariser is hence oriented in a N-S direction (or up-down). If no thin section is inserted, then the view through the oculars should be **dark/black**.

3.2.1 Birefringence

Upon insertion of the upper polarisation plate (the analyser) the most striking observation is the sudden bright colourful display of :Interference Colours, particularly in minerals such as olivine. Interference colours are only visible in *anisotropic minerals* arise as a function of thin section thickness and the :Birefringence of the mineral.

```
//| panel: input
viewof biref = Inputs.range(
  [0.0005, 0.14],
  {value: 0.01, step: 0.0005, label: "Birefringence:"}
)
```

```
data_intspec = FileAttachment("int_spectra.csv").csv({ typed: true })
```

```
//| label: fig-int_spectra
//| fig-cap: "Spectral contribution to the observed interference colour as a function of b

Plot.plot({
  x: {label: "Wavelength (nm)"},
  y: {
    domain: [0,1],
    label: "Relative Intensity",
    labelOffset: 0},
  margin: 40,
  marginBottom: 80,
  style: {
    background: "#CCCCCC",
    fontSize: 20,
    color: "Black"
  },
  marks: [
    Plot.areaY(interference_filtered, {
      x: "wl",
      y: "value",
      fill: "hexvis"})

      ],
  width: 800
})
```

```
interference_filtered = data_intspec.filter(function(intspectra) {
  return biref == intspectra.biref;
})
```

3.2.2 Extinction Angles

3.2.3 Twinning

3.3 Further concepts

There are further techniques not covered here, such as obtaining an :optic figure and measuring the corresponding optic angle (or 2V). It is sufficient at this stage to know that they *exist* – we will cover this technique in a later course. There are also a few other concepts that the beginning microscopist should be aware of. These are covered in this section.

3.3.1 Colour perception

We all see the world differently, and this should not be a disadvantage when it comes to microscopy. Due to the different physical interaction properties of light between dyes and inks, LED/LCD computer screens, camera detectors, and how interference colours arise, it is not suprising that dramatic differences in perception of colours often arise between depictions of what is seen down the microscope versus what is actually observed, even in individuals with full colour perception.

Figure Figure 3.1 is an :Ishihara colour perception plate. This is not a faithful reconstruction (due to colour rendering in various digital display technologies) but it is sufficient to illustrate the point here. You should be able to distinguish the number 74. If you see the number 71, or no number at all, then please alert your demonstrator so that we can help provide you with some extra materials and assistance. For instance, instead of using digitally rendered or print copied of the Michel Levy chart, we will provide you with a quartz wedge plate which can be viewed under cross polarised light to use as the true point of reference for the interference colours.

3.3.2 Sources of Light

An important effect to take note of is how the generation of interference colours under cross polarised light is also a function of the spectral distribution of light interacting with the crystalline material. For the interference colours to behave as we expect them to as a function of birefringence, it is important to use an even a distribution of light as possible.

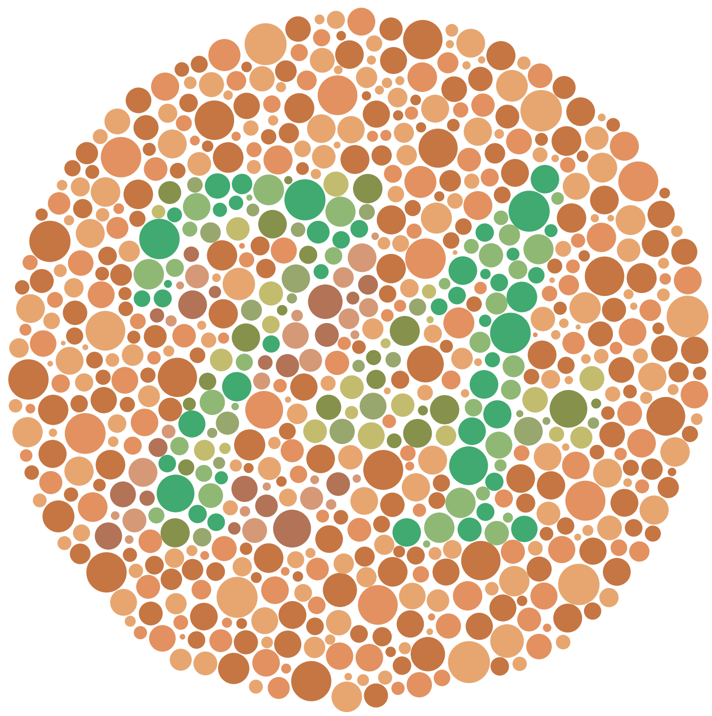

Figure 3.1: Ishihara Plate 9. The number 74 should be visible - please alert your demonstrator if you see the number 71 or no number at all.

Modern :LEDs do not produce a uniform or continuous spectral distribution. Even the Nobel Prize winning blue LED and its subsequent combination with Ce-doped :YAG as a yellow phosphor still does not produce a sufficiently uniform spectrum suitable for XPL microscopy.

As such, our microscopes are equipped with :halogen bulbs, a modification to the standard tungsten-filament incandescent bulbs of the 20th Century. Yes, it's old-tech, but it's what we have. Notice in Figure **?@fig-bb_spectra** that the light emitted from these bulbs is still skewed towards the yellow-red side of the spectrum. The microscopes compensate for this by filtering some of the yellow-red light to even out the distribution a little and make the general spectrum more 'white'.

The key message is that the bulbs in your microscopes will produce a significant amount of infrared radiation (i.e., ***heat***). Don't leave them on for long periods unattended. When turning them on and off, it is best to start at low voltage and ramp it up slowly (over a couple of seconds) rather than just turn it on at full voltage. This increases wear on the bulbs, and makes them more likely to blow (which is not good if it happens during an exam).

```
//| panel: input
viewof TempK = Inputs.range(
  [1500, 10000],
  {value: 1700, step: 100, label: "Temperature (K):"}
)
```

```
data_bbspec = FileAttachment("bb_spectra.csv").csv({ typed: true })
```

```
//| label: fig-bb_spectra
//| fig-cap: "Relative spectral distribution of emissions for Black Body Radiation at a gi

Plot.plot({
  x: {label: "Wavelength (nm)"},
  y: {
    label: "Relative Intensity",
    labelOffset: 0},
  margin: 40,
  marginBottom: 80,
  style: {
    background: "#CCCCCC",
    fontSize: 20,
    color: "Black"
  },
  marks: [
    Plot.image([{ url: "https://upload.wikimedia.org/wikipedia/commons/d/d9/Linear_visible
```

```
    {
      x: 565,
      y: -0.2,
      width: 383,
      height: width*0.1,
      src: "url"
    }),
    //Plot.ruleX([380]),
    //Plot.ruleX([750]),
    Plot.areaY(filtered, {
      x: "wl",
      y: "value",
      fill: "hexvis"})

      ],
  width: 800
})
```

```
filtered = data_bbspec.filter(function(bbspectra) {
  return TempK == bbspectra.temperature;
})
```

Part III

Petrology

4 Description of Igneous rocks and textures

5 Classification of Igneous Rocks

6 Phase Diagrams

7 Igneous Processes

A Resources

Resources, such as other texts, etc.

B References