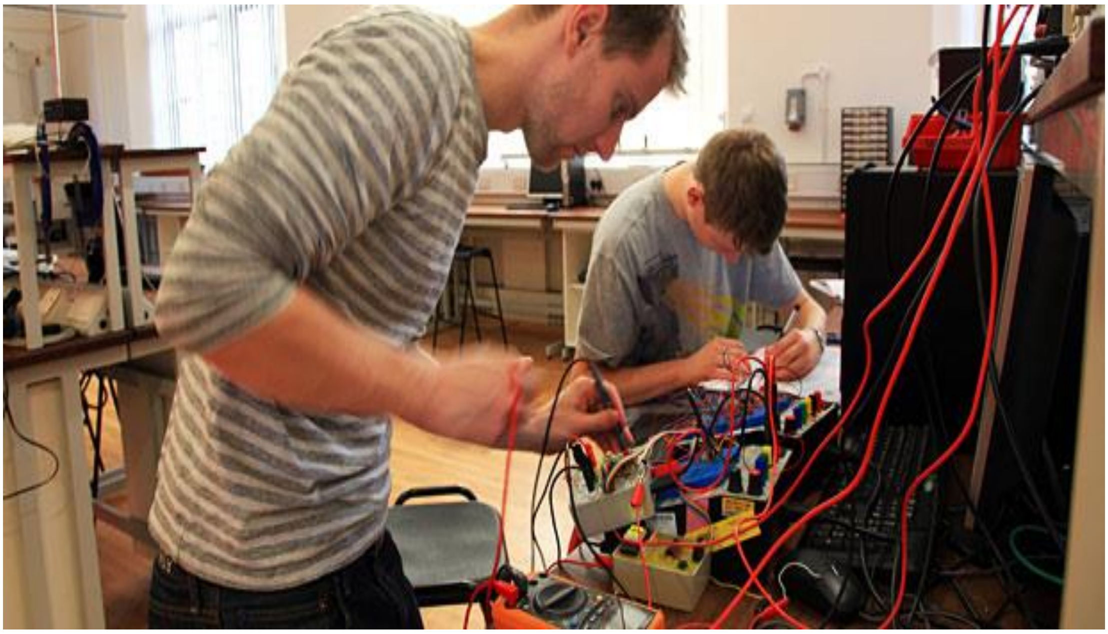
University of BRISTOL School of Physics

LEVEL 6 MSci LABORATORY

HANDBOOK

2022/2023



Introduction

The MSci Laboratory provides a range of experiments to develop your experimental research and report writing skills. The experiments are more demanding than those in Year 2 and in many cases allow students to use advanced instrumentation and research methods. Experiments are generally associated with particular research groups or topic, with an academic supervisor from the research group responsible for each experiment.
All information about the course is given on the Blackboard under:
[Welcome page – Practical Physics 301 2022 (bris.ac.uk)]

Timetable

You will be required to carry out ***one experiment***. There are 6 in-lab sessions in total for each experiment (experiment weeks 1-6). Each experiment contains also online material on the Blackboard for study: pre-lab online introduction* (week 0, before the experiment starts) and additional online material for study during weeks 1-6. There are 3 lab groups: **Group A (Thursdays)** or **Group B (Fridays)**, timetable weeks 2-7 in TB1 and **Group C (Thursdays)** weeks 13-18 in TB2.
Laboratory hours are 10:00-13:00 and 14:00-17:00.

> * - The online pre-lab session contains material which you must engage with before the start of the lab. This session is not timetabled but might contain a synchronous online session with your supervisor. In this case he/she will inform you about the time and invite you to it.

Attendance

If you are physically present in the lab for any of the sessions you must sign in at the beginning of each morning and afternoon session, that is at 10:00 and 14:00. If your lab session is online, your supervisor will keep record of your attendances. Satisfactory attendance is required to pass the Unit. In addition, **your electronic notebook must reflect the work done in each week** and not filled retrospectively at/after the end of the lab.

Selection of Experiment

This needs to be completed by **Monday, 26 September week 1.**

- Listen to the introductory presentation online on Blackboard: Welcome Page
- Find in which Lab group you are (A,B,C). You have been already allocated a lab day by the central team (e.g. Friday, Group B). Some of you have given us your preference for a lab partner. If not, you might want to contact someone in your group and see if they are happy to be in a pair with you. If no lab partner found - don't worry, just follow other steps below.
- Read the description of all experiments in this Handbook. Discuss with your lab partner, if you have one.
- Submit your preferences online. You should sign up, giving your preferred laboratory partner, for either group A, B or C. Only one person per pair shall submit this form. If you have no partner, just input NONE and we will pair you up. On the online form you should indicate your preferred experiments in the rank order. As there are only a fixed number of apparatus sets, we may not be able to allocate your first preferred choice. Allocation of experiments will be finalised after the sign-up process is completed. In the event of an experiment being over-subscribed, the allocation will be performed randomly. Normally, students on the Physics with Astrophysics programme will be given preference for the Astrophysics experiments, although all students can put them in their list of preferences. Note, Theory experiments are only for Theoretical Physics MSci programme.
- Your preferences must be indicated **by 17:00 on Monday, 26 September in week 1.**

Notebook

Each individual student is responsible for keeping **their own** laboratory notebook. Each of you must submit ***an electronic labbook*** for this unit.

A good notebook should be an experiment diary, documenting what you did on every day, *in and outside the lab, written down as you went along***.** It is important for your notebook to be comprehensible to someone other than yourself, but some "untidiness" is expected. If you are working as a pair, your notebook should be maintained separately from your partner as much as it practically possible. It is your personal record of the experiment and will be used for assessment of your work in the lab.

The notebook must contain clear record of what you have been doing on a daily basis, with notes on aims, theory, etc. Even for a computational project there is still scope for making written notes. The degree to which the code is commented on, and sensibly organised, will also be considered. For further guidance, please see the assessment notes in the appendix of this handbook.

Your supervisor's assessment of your work in the lab will be based on your organisation and logical approach to the experiment; your lab notebook is a primary indicator of this.

Electronic lab books

The format of MSci lab electronic labbook is based on the OneNote Microsoft Office365 package. This is very versatile tool allowing integration of notes, sketches, graphs, links, images and videos, as well as research data in one package. The guidelines for a good electronic lab-book keeping are similar to those for paper notebooks. It is advisable, that a **good and clear structure followed inside the lab book file**, e.g. separate page notes for each lab day, experimental methods, analysis, theory, extra material, etc. Please, get yourself familiar with the Office 365 package before the lab start. There are different versions of OneNote (see Blackboard), make sure you use the appropriate one. All experiments will be required to produce an electronic lab book at the end of the lab for assessment.

> N.B. Even if you used paper based notes throughout the lab, you must scan or take good quality photos of these notes and insert them into the OneNote document as images without reduction in size. If you have a paper lab book in addition to the electronic version: **Do not work on loose sheets of paper or in a rough book (you will be penalised if you do)**. Your additional notebook should be a bound book so that sheets of paper cannot be added or removed. You should not have recorded data on scraps of paper – or in the back of your notebook, even if it is written up later.

You shall submit this document on Blackboard unit as **a single pdf file.** You shall also share the original via Microsoft tools (e.g. OneDrive) with you supervisor in the week 1 (please allow editing so supervisor can insert comments). **Each student should submit their own electronic lab book.** Though it is possible to share some notes on the experiments and data, all analysis and conclusions should be individual work. Please make sure you **reference any work/material which is not your own**, such as texts, images, data, graphs or external resources you use in the electronic lab book appropriately.

Assessment

You will be assessed on your **notebook** containing your laboratory notes written during the experiment and a **report** written after the experiment. The assessment will be based on the following criteria.

Scientific content: Assesses the level of understanding of the relevant physics, including background / theory and measurement / analysis techniques.

Quality of work: Assesses how carefully/accurately/successfully the work was planned and executed.

Communication skills: Assesses how well the report is written and organised, and the quality of the notes taken.

You will be given a written feedback, which addresses the criteria above and a single overall mark on the 21 point scale.

The report should be in the style of a scientific paper in the American Physical Society's *Physical Review*. The report should explain what you did and be comprehensible to a *physicist* in another field. Hence you should introduce the experiment appropriately. Some notes on the style and content of the report are given below, however the best way to learn the style in which professional scientific papers are written is to read several actual published papers.

It is strongly recommended that you use the *Latex* document preparation system to produce your report. You should use the RevTex 4 package to get the report in the correct format. The required style is a two-column format, using a 10pt font, and should not be longer than **4 pages of A4**. More details of the required format and a template can be found on Blackboard. **The 4-page maximum includes all graphs, figures, references and appendices** (not recommended for 4 page article)**.** Exceeding this page limit will be considered poor style and your mark will be reduced accordingly.

The report should be submitted electronically via Blackboard for assessment. There is no need to submit a separate paper copy. However, please ensure that the report prints out correctly and does not require special system resources, fonts, etc. As the notebook forms also a part of the assessment, it should also be submitted electronically before the deadline.

The report must be written and prepared individually. Report is not a collaborative project with your partner. This includes all diagrams and figures. You are advised that we use anti-plagiarism software to scan all submitted work. This compares your work to others that have been submitted in your group or previously by other students and also to the resources on internet. You are reminded that plagiarism is taken very seriously by the University of Bristol and usually results in a minimum penalty of a mark of zero been awarded for the unit.

For late submissions standard University penalties will be applied (-10 marks/100 per working day). For work submitted seven calendar days after the submission deadline the student will receive a mark of zero. Late work will still need to be completed and handed in, in order to satisfy the requirements for passing the unit.
If you believe your mark is unfair, then you have the right to ask for it to be reviewed by the Laboratory co-ordinator (or his delegate). Please note, that as a consequence of this review you mark could be revised up or down.

Deadlines:
All deadlines are at 12.30pm on the day indicated
Groups A/B – **Monday 28th November** (week 10)
Group C – **Monday 20st March** (week 21)

Laboratory Staff

Position	Name	Room	E-mail address
Laboratory Coordinator	Dr Andrei Sarua	3.39	a.sarua@bristol.ac.uk
Technical Support	Tom Kennedy	2.18	Tom.Kennedy@bristol.ac.uk

The Experiments

Code	Title of Experiment	Supervisor	Pairs
AFM	(AFM) Atomic Force Microscopy	Dr Massimo Antognozzi	1
CR	(CR) Properties of Cosmic Ray Muons	Dr Konstantinos Petridis	1
FIS	(FIS) Fourier Image Spectroscopy of Microstructures	Dr Ian Lindsay	2
JN	(JN) Johnson Noise	Dr Adrian Barnes	2
MAP	(MAP) Characterization of Monolithic Active Pixel Sensors	Dr Jaap Velthuis	1
NMR	(NMR) Pulsed Nuclear Magnetic Resonance	Prof Stephen Hayden	2
OVS	(OVS) Optical Vibrational Spectroscopy	Dr Andrei Sarua	1
[redacted]	[redacted]	[redacted]	[redacted]
RT	(RT) Observing Water Masers with the Coldrick Radio Telescope	Prof Mark Birkinshaw	2
SEM	(SEM) Secondary Electron Microscopy	Dr Matt Smith	1
STM	(STM) Scanning Tunneling Microscopy	Prof Neil Fox	2
TE	(TE) TESS exoplanet time series data analysis	Dr Hannah Wakeford	2
 IM WT LB	Theory Labs (Theoretical Physics only) (IM) Ising Model (WT) The Wetting Transition (LB) Lattice Boltzmann Method	 Prof James Annett Dr. Stephen Clark Dr Alan Raynolds	 2 2 2

Group A: Thursday, weeks 2-7
Group B: Friday, weeks 2-7
Group C: Thursday, weeks 13-18 (Physics/Philosophy, ERASMUS, Phys Innov.)

(AFM) Atomic Force Microscopy	*Dr Massimo Antognozzi*

This experiment will make use of an Atomic Force Microscope (AFM). The goal is to familiarize the student with the basic principles and operation of this instrument. Different specimens will be investigated, from mineral surfaces to biological molecules (DNA and proteins). The understanding of the mechanical behaviour of micro-scale force sensors is crucial to correctly interpret the AFM results, for this reason part of the project will be dedicated to the development of techniques to investigate the mechanical response of AFM cantilevers. You will also learn some programming in the Labview environment.

(SEM) Secondary Electron Microscopy	*Dr Matt Smith*

Scanning Electron Microscopy (SEM) uses a beam of high energy electrons to provide an image of the surface of a material at a higher resolution than optical microscopy. In addition, the interaction of the electron beam with the surface releases X-rays which are characteristic of the elemental identity of the surface, and back scattered electrons which can give information about the orientation of the crystal structure.

The teaching lab has recently installed a new Tescan SEM and this experiment will use the new instrument to analyse a range of different materials. Students will learn how to use the secondary and backscatter electrons and X-rays to investigate the microstructure of materials such as chemical vapour deposited diamond, stainless steel and oxide particles. They will explore the effect of the beam voltage and current on the resolution of their images, and how the beam voltage can affect the interaction volume of the electrons with the sample and hence its sensitivity to elemental composition with different depths. Finally, the students will explore a complex specimen with a ceramic protective layer on a nickel superalloy jet engine turbine blade, and use all the different detectors on the SEM to compare the structure of a freshly made coating with one that has been in use on an aircraft.

(FIS) Fourier Image Spectroscopy of Microstructures	*Dr Ian Lindsay*

Imaging "small" structures is of great interest for many fields of science. Optical microscopy allows one to study structures far smaller than observable with the naked eye; however, the resolution limit of optical microscopes is typically limited to the wavelength of the light being used. To image smaller structures it is often necessary to use expensive and complex techniques such as electron microscopy.

However, information about some sub-wavelength structures may be gained if they are periodic. For example, a diffraction grating may have groove spacing smaller than the wavelength of light, but the angle at which a beam of light is diffracted will give information about the groove spacing. In this experiment you will use a technique called "Fourier image microscopy" to study the angular dependence of the reflectivity of a variety of structures, revealing that the optical properties of many surfaces are governed by periodic (or almost periodic) sub-wavelength structures.

You will first set up the Fourier imaging experiment by using a grating of a known pitch to calibrate your system. This will give you a practical insight into how lenses perform Fourier transforms, as well as giving you practice as aligning optical systems. You will then study the reflectivity of a variety of structures. These may include artificial structures such as CDs and DVDs which are effectively gratings, and natural samples. These may include opals, which consist of sub-micron sized tightly packed spheres which show a wavelength-dependent angular reflectivity, and biological iridescent structures such as butterfly and beetle wings, whose colour comes not from dyes or chemical colour but from sub-wavelength periodic structures on their wings.

This experiment is based on a very similar one used in the Photonics group to study reflectivity of man-made photonic crystals and biological iridescent structures. You will use very similar techniques, studying structures that are still not yet well-understood by the research community. The project will give you an insight into how biology uses structure to control light, as well as the man-made structures we design for photonic circuits and light control for lasers and solar cells.

(TE) TESS exoplanet time series data analysis	***Dr Hannah Wakeford***

Exoplanets, planets that orbit other stars, have been discovered in their thousands in just the past two decades. Currently the *Transiting Exoplanet Survey Satellite* (TESS) is in orbit around the Earth surveying the whole sky for exoplanets that periodically transit their bright host stars. TESS has imaged many thousands of stars producing high cadence time series data in ~month long sectors of the sky. In this experiment you will examine a series of TESS time series light curves to search for signatures of astrophysical phenomena such as eclipsing binary stars, stellar activity (flares, rotation, variability), and transiting exoplanets. You will approximate and measure the periodicity of signals in the data to determine their astrophysical origin to measure the target star and system characteristics. Using this information along with fundamental laws of planetary motion and physics we can determine the period, orbital distance, and size of discovered transiting exoplanets (or stars) in the data.
Key learning objectives include: getting hands of experience with space-based time series data; understand and identify by eye any astrophysical phenomena apparent in a range of datasets; be able to examine in detail periodic repeating phenomena extracting precise periods and amplitude changes in stellar flux detailing their origins.
This experiment will require moderate/good python coding skills for the whole project making use of the *Python lightkurve* software package.

(JN) Johnson Noise	***Dr Adrian Barnes***

Quantum mechanics dictates that electrons inside conductors are continually scattering between states with different energy and momentum. The size of the spread in energy accessible to different electrons is controlled by the Pauli Exclusion Principle and the temperature. These quantum thermal fluctuations actually manifest themselves in a remarkably simple fashion, namely they produce fluctuations in the current and thus the voltage measured across the conductor. These voltage fluctuations are called Johnson noise. The amplitude of the fluctuations is uniquely determined by Boltzmann's constant the resistance of the conductor and the temperature. Hence, this effect can be used to produce an *absolute* thermometer (i.e. one that relies only on the values of fundamental constants and does not require calibration against a standard). Such absolute thermometry effects are actually quite rare and so Johnson noise occupies a key position in Metrology - the science of measurement.

In this experiment you will study these voltage fluctuations, using spectral analysis techniques (Fourier transforms), and determine a value for Boltzmann's constant. You can then use the effect to produce an absolute temperature measurement. This will then be tested by changing the temperature of the resistor, either by heating or cooling with liquid nitrogen. A further aim of the experiment is to give a practical introduction to interfacing data acquisition electronics to a computer, which may be of great use to you in the future (for example, in your final year project). You will gain experience in the practical use of Fourier transforms as a tool to analyse complex spectra. This project requires computer programming in the language Python.

(MAP) Characterization of Monolithic Active Pixel Sensors	***Dr Jaap Velthuis***

Monolithic Active Pixel Sensors (MAPS) are a novel and exciting development in imaging sensors. They are used for example in the camera of your mobile phone. They are low power, can be made very thin (<20μm) with still very good performance and it is possible to incorporate signal processing on the chip. Dedicated sensors are developed for **Particle Physics** mainly with the Linear Collider in mind. For this application it is of paramount importance that the sensor will

detect all traversing particles and that their hit position can be reconstructed with excellent precision.
In this lab experiment you will be given a set up with a MAPS device. You will learn about various characterization techniques using light and radio-active sources.
You will study important variable like the noise, the signal, the thickness of the sensitive layer and the size of the charge cloud in the device. You will need to develop your own data analysis software in Python, C or C++ and ROOT. After learning the characterization techniques, you will focus on one aspect and study this in detail.

(NMR) Pulsed Nuclear Magnetic Resonance	***Prof Stephen Hayden***

Nuclear magnetic resonance is a powerful probe used in physics, chemistry and biological research. The applications are widespread, ranging from the identification and structure determination of complex molecules, imaging of the human body, and the study of magnetic fluctuations in metals. This experiment will provide an introduction to the NMR technique using a commercial teaching spectrometer. Various different techniques will be used to measure the NMR relaxation rates of protons in water. The experiment will then go on to apply these techniques to investigating how the resonance changes with the environment of the proton nucleus.

(OVS) Optical Vibrational Spectroscopy	***Dr Andrei Sarua***

This experiment studies interaction between photons of light and quantised vibrations of atoms in matter, i.e. phonons. When a laser beam is incident on a material the light can scatter either elastically (the scattered light is at the same frequency as incident beam) or inelastically (with a change in frequency). The latter is known as the Raman effect and the frequency shift of scattered light depends on interactions of the incident photons with the electrons and vibrational excitations in the material. This is enabling access to the information about chemical bonds, structure, composition, stress, temperature, etc., in the materials. Hence, Raman spectroscopy is an extremely versatile, non-destructive and widely used analytical tool in the material science and chemistry as well as in industry: e.g., in forensics, environmental monitoring and process control. Since 2020 there is even a Raman spectrometer on Mars (SHERLOC instrument on Perseverance rover).
In this experiment, you will examine phonons and phonon dynamics in different solid crystalline materials by recording their Raman spectra. Spectra will be acquired using a commercial Raman spectrometer, similar to the equipment you can find in many research and analytical labs. Here the laser beam is focused on the sample surface using optical microscope into a micrometre sized spot, which allows studying of matter on a small scale. This is a multiphysics project: covering quantum and macroscopic theory of solids, light-matter interactions and practical aspects of laser spectroscopy, optics and instrumentation.

(STM) Scanning Tunneling Microscopy	***Prof Neil Fox***

In 1982 a paper was published announcing the successful measurement of the tunnel current between a tungsten and a platinum electrode in adjustable vacuum conditions. This result was the first step towards scanning tunnelling microscopy (STM), which was officially born a few months later with the publication of a first image of a metallic surface. The next paper showed, for the first time, atoms imaged in real space using STM. In 1986 Binnig and Rohrer were awarded the Nobel prize in Physics for developing this technique. STM is a very good example of how a fundamental understanding of quantum mechanics can be used to produce significant technological innovation.

In this experiment you will use a STM to image the surface of crystals with atomic resolution. This will teach you the principles of the STM technique as well as how it is used in a practical situation. In the second part of the project, you will use STM to probe the electronic properties of technologically-important materials.

(RT) Observing Water Masers with the Coldrick Radio Telescope	***Prof Mark. Birkinshaw***

Water masers are regions characterised by bright, coherently amplified emission lines at microwave frequencies. They are often associated with star forming regions. In this experiment you will plan and perform observations of masers with the Coldrick radio telescope and use your data to map the maser emission and estimate their distances. If the telescope is being serviced the experiment will use archival, rather than new, data.

(CR) Properties of Cosmic Ray Muons	***Dr Konstantinos Petridis***

Whilst our lab is too small to accommodate an accelerator-based particle physics experiment, we can make use of another handy source of high-energy particles: cosmic rays. A stream of charged particles, mostly muons, continually passes through us at ground level. By stopping some of these muons in a heavy absorber and employing scintillation detectors, we can observe their decay and measure their lifetime. This project is a particle physics experiment "in miniature", and uses the type of apparatus that was winning Nobel Prizes only fifty years ago. It provides a good introduction to the detector techniques used in modern particle, nuclear and astrophysics, and to the type of statistical analysis used in these areas. The experiment will develop experimental skills in electronics hardware, computing (Python) and in data analysis.

Theoretical Physics:

(IM) Ising Model	***Prof James Annett***

The Ising model represents a simplified magnet in which each atom has a spin, which can only take one of two values, 'up' and 'down'. Historically, it played a fundamental role in the theory of phase transitions in statistical physics, since it goes from a non-magnetic state at high temperature to a magnetic state at low temperatures, below the Curie temperature Tc. But there are many surprises, and the model and its close relatives are still central to modern physics. For example, the 2016 Nobel prize was awarded to Kosterlitz and Thouless for the theory of phase transitions in the related XY model (where the spin is still fixed in size, but can have any direction in the x-y plane). The Ising model is discrete and so is particularly suited for investigation by computers. In this laboratory we shall investigate the thermodynamics of the Ising model using the Metropolis Monte-Carlo method. Using this approach we shall investigate the Ising model in zero, one and two dimensions, seeing how the statistical state changes as temperature and magnetic field are varied. In particular we will use the Metropolis method to investigate the 'critical exponents' in the two-dimensional model, which represent how the magnetization, energy, entropy, heat capacity, etc., change near to the Curie temperature Tc. Optionally, the role of the lattice geometry, dimensionality, and similar models, such as Potts and XY could also be explored. This laboratory is specific to theoretical physics students, and introduces concepts, which will be fundamental in the later 4th year Phase Transitions course.

(WT) The Wetting Transition	***Dr Stephen Clark***

The behaviour of liquids at interfaces and in confinement is a fascinating and important area of study. For example, the behaviour of a liquid under confinement between two surfaces determines how good a lubricant that liquid is. The nature of the interactions between the liquid and the surfaces is crucial. Consider, for example, the Teflon coating on non-stick cooking pans, used because water does not adhere to "wet" the surface. In this theory experiment we will develop a discrete mean-field approximation for the behaviour of a fluid called density functional theory. The aim of this project is two-fold: (i) to derive DFT for an inhomogeneous lattice-gas fluid, whilst explaining the physics of the theory; (ii) To illustrate the types of quantities that DFT can be used to calculate, such as the surface tension of the liquid-gas interface, to study wetting behaviour and to answer the question ``what is the shape of a drop of liquid on a surface?''.

(LB) The Lattice Boltzmann Method	***Dr Alan Raynolds***

Accurate modelling of the fluid dynamics can be challenging even in simple setups, such as flow past a fixed, rigid obstacle. Conventional, macroscopic approaches attempt to numerically solve the Navier-Stokes equations, yet the non-linearity of the equations, complex geometries and the intricacies of turbulent flow can cause difficulties. A microscopic approach, tracking the position and velocity of individual molecules, clearly results in far too many degrees of freedom to feasibly handle. The lattice Boltzmann method is a compromise between the macroscopic and microscopic views. Space is discretised into a lattice, with the fluid at the lattice points described by a simple kinetic model. It is surprisingly easy to code, yet can reproduce complex fluid dynamics such as vortex shedding.

In this project, you will be guided through much of the implementation of the lattice Boltzmann method. You will then be encouraged to adjust and adapt the resulting code to enable an exploration of the features of fluid flow past a selection of obstacles.

Further details and experimental resources/ scripts for some of the experiments can be found on Blackboard: https://www.ole.bris.ac.uk/

Marking Scheme

Your work will be marked according to a 21 point marking scheme which is based on the University's generic marking scheme.

Mark	Criteria to be satisfied
20 19 18	➢ Work is close to publishable standard. ➢ Mastery of advanced methods and techniques at a level beyond that explicitly taught. ➢ Ability to synthesise and employ in an original way ideas from across the subject. ➢ Excellent presentation. ➢ Outstanding command of critical analysis and judgment.
17 16 15	➢ Excellent range and depth of attainment of intended learning outcomes. ➢ Mastery of a wide range of methods and techniques. ➢ Evidence of study and originality clearly beyond the bounds of what has been taught ➢ Excellent presentation. ➢ Able to display a command of critical analysis and judgement.
14 13 12	➢ Attained all the intended learning outcomes for this unit. ➢ Able to use well a range of methods and techniques to come to conclusions. ➢ Evidence of study, comprehension, and synthesis beyond the bounds of what has been explicitly taught. ➢ Very good presentation of material. ➢ Able to employ critical analysis and judgement.
11 10 9	➢ Some limitations in attainment of learning objectives, but has managed to grasp most of them. ➢ Able to use most of the methods and techniques taught. ➢ Evidence of study and comprehension of what has been taught. ➢ Adequate presentation of material. ➢ Some grasp of issues and concepts underlying the techniques and material taught.
8 7 6	➢ Limited attainment of intended learning outcomes. ➢ Able to use a proportion of the basis methods and techniques taught. ➢ Evidence of study and comprehension of what has been taught, but grasp insecure ➢ Poorly presented. ➢ Some grasp of the issues and concepts underlying the techniques and material taught, but weak and incomplete.
5	➢ Attainment of only a minority of the learning outcomes. ➢ Able to demonstrate a clear but limited use of some of the basic methods and techniques taught. ➢ Weak and incomplete grasp of what has been taught. ➢ Deficient understanding of the issues and concepts underlying the techniques and material taught.
4 3 2 1	➢ Attainment of nearly all the intended learning outcomes deficient. ➢ Lack of ability to use at all or the right methods and techniques taught. ➢ Inadequate and incoherently presented. ➢ Wholly deficient grasp of what has been taught. ➢ Lack of understanding of the issues and concepts underlying the techniques and material taught.
0	➢ No significant assessable material, absent, or assessment missing a "must pass" component.

Detailed assessment criteria

Below is listed in more detail what assessors will be looking for in your work. As stated above, the main criteria are: scientific content, quality of experimental work, and communication skills.

I. Scientific Content

An understanding of the theoretical background, the goals of the experiment, the function of the experimental apparatus and the data analysis technique should be demonstrated both in the report and the notebook. Excellent students will demonstrate a thorough understanding of the theory and the experimental methods, and will show evidence of extended reading around the subject, well beyond suggested further reading. An excellent report will include an original explanation of background/theory, with evidence of extensive reading and understanding of relevant literature. The data analysis will include a thorough error analysis, and there will be extensive and detailed conclusions drawn from the data, with references to prior results in the literature where appropriate.

- **Aims** – Understanding of the overall aims of the experiment.
- **Background reading** – Evidence of extended reading and an ability to relate it to the experiment.
- **Abstract** – The report should have a self-contained and concise abstract, with a clear statement of the results and conclusions.
- **Background & Theory** – The relevant background/theory should be identified and correctly explained. The key theoretical results pertinent to the data analysis should be derived or expressed, and the origins of relevant equations should be explained.
- **Apparatus & Methods** – All relevant experimental procedures and experimental apparatus should be described.
- **Discussion & Conclusions** – Good scientific arguments should be made when interpreting the quality and validity of results, and relevant literature should be used to support arguments and conclusions. Comparisons to other work should be cited properly.
- **Referencing** – Appropriate and relevant references should be identified, with excellent reports showing evidence of reading beyond the scope of that identified in the script. References should back up statements made in the text – rather than just be a list of things you have read.
- **Critique of methods** – Discussion of the limitations of the experiment and sensible suggestions for improvements to the experiment should be given were appropriate.
- **Evaluation of results** – A careful discussion of the results should be presented, including the relevance and significance the errors. A thorough comparison with other techniques or previous measurements should be made.
- **Creativity** – The experimental results and/or wider reading should be used to generate novel suggestions or explanations where appropriate.
- **Originality** – There should be evidence of independent thought and an effort to explain concepts in an original manner.
- **Wider context** – The wider relevance of the results and how they may affect or be important for other fields of work should be discussed.

II. Quality of Experimental Work

The experimental skill and diligence needed to obtain reliable results will be assessed. Allowance will be made here for major problems encountered due to equipment malfunction etc. and whether the student was working alone or in a pair.

Excellent students will produce extensive high-quality data with evidence of hard work and experimental skill.

- **Quality & Quantity of data obtained** – In cases where the experiment has not worked as expected there should be clear evidence that all reasonable steps have been made to get the results.
- **Data Analysis** – Should be accurate and checkable by the reader where possible. Results should be expressed in appropriate units.
- **Error Analysis** – Errors should be evaluated properly, quoted in the correct places and to the correct precision. Sources of systematic error should be noted.

III. Communication skills

Notebook and Organisation: An excellent notebook will contain a concise and well thought out summary of what is planned for each lab day and (at the end) what was achieved in each day. It will be very well organised, with extensive graphs and analysis embedded in the notes at appropriate points. This also applies to experiments which are either based on or make extensive use of computers. Primary method for keeping notes in the lab, is electronic notebook. If additional paper notes are used, they should be kept in a bound notebook, which needs to be digitised/scanned and transferred into images/text in the electronic book.

- **Clarity & Organisation** – The notes should be easy to follow, mistakes should be neatly crossed out (do not tear out pages) with a brief explanation as to what was wrong. Summaries should be written at appropriate points.
- **Theory / Experimental procedure** – Notes on theory and experimental procedures included. A concise description of all relevant parts of the experiment and a description of analysis methods used.
- **Data collection** – Experimental data should be in neat tabular form (where appropriate) with units, uncertainties and all relevant experimental conditions/settings noted. *In cases where data is collected by computer it is still important to note relevant conditions and also the names of the files in which the data is stored.*
- **Graphs & Diagrams** – Should be well formatted, readable, labelled, and embedded in the notes at appropriate points (not just dumped "en masse' at the end of the experiment.)

*Clarity and Fluency***:** The quality of writing and the flow of the report and how well the explanations and arguments are made will be assessed. An excellent report will be easy and engaging to read, with the material laid out in a coherent, logical and accessible manner.

- **Coherence** – The narrative should flow logically and easily from one section to another. There should be good links between the figures and the text.
- **Concise** – All information should be relevant and necessary. Unnecessary material, for example trivial or standard theoretical derivations, should not be included.
- **Explanations** – The objectives, theory, methods and data analysis techniques should be easy to follow, not simply a series of unconnected points.
- **Arguments** – The discussion and interpretation should be clearly expressed in a logical and thoughtful manner.

*Style and Presentation***:** the general layout and organisation of the report, the quality of the presentation of graphs, diagrams and tables. It also assesses grammar, spelling and the general literary style of the document.
An excellent report will have a professional appearance throughout with no errors in grammar or spelling. The size of the symbols and lettering used on all parts of a graph or diagram should be legible (this includes subscripts) as a guide a minimum size of 2mm is suggested. Lines should have sufficient weight (e.g. 0.5pt or 0.2mm). Normally titles for figures are not needed – rather the relevant information is included in the caption.

- **Formatting** – Should be consistent throughout (including use of bold or italics for labelling etc.). Figure captions and equations should be in the same font size as the text.

- **Layout** – The report should be well laid out with sections and subsections where appropriate. Content should be presented in the appropriate sections, and figures located in suitable positions throughout the report.
- **Language** – The report should be written in a professional scientific style, with the past, present and future tenses used appropriately. The passive voice should normally be used, although first person plural may be used where appropriate.
- **Spelling & Grammar** – There should be no spelling or grammatical mistakes.
- **Equations** – Should be clear with appropriate symbols, numbered sequentially and correctly cited in the text. All variables should be defined in the text (except standard symbols such as *e*, *h*, ⍰ etc) and should be in italic script.
- **Diagrams** – Should be used to illustrate concepts which are difficult to explain with text alone (e.g., the layout of the experimental apparatus). They should be clear, uncluttered and well labelled with a suitable caption. Original work is preferable as this may help to show originality. If figures are copied the source should be clearly identified (note this includes your partner's work).
- **Graphs** – Should be clear and correctly labelled, with appropriate axes, error bars, and font sizes. Suitable captions should be included.
- **Tables** – Should be clear with appropriate labels, units and a suitable caption. Data should not be presented in a table if it could be expressed better in a graph.
- **Internal referencing** – Figures, equations and tables should all be referenced correctly and consistently within the text. Any items not discussed in the text should not be included (e.g., graphs of data which are not described in the text).
- **Referencing style** – One of the standard referencing methods should be used consistently (Numerical [1] or Harvard (Smith 2010)).

University of BRISTOL

Physics Coursework Feedback
Retain this document as a record of development

Level 6 MSci Laboratory

Student:
Experiment:
Assessor/Supervisor:
Date:

Mark (0-20):

This mark is provisional and may be subject to moderation

Feedback

The letter grades below summarise the level attained in each category:
A=15-20, B=12-14, C=9-11, D=7-8, E=1-6, 0=0

Scientific Content (A-E)

Quality of Experimental Work (A-E)

Communications Skills (A-E)