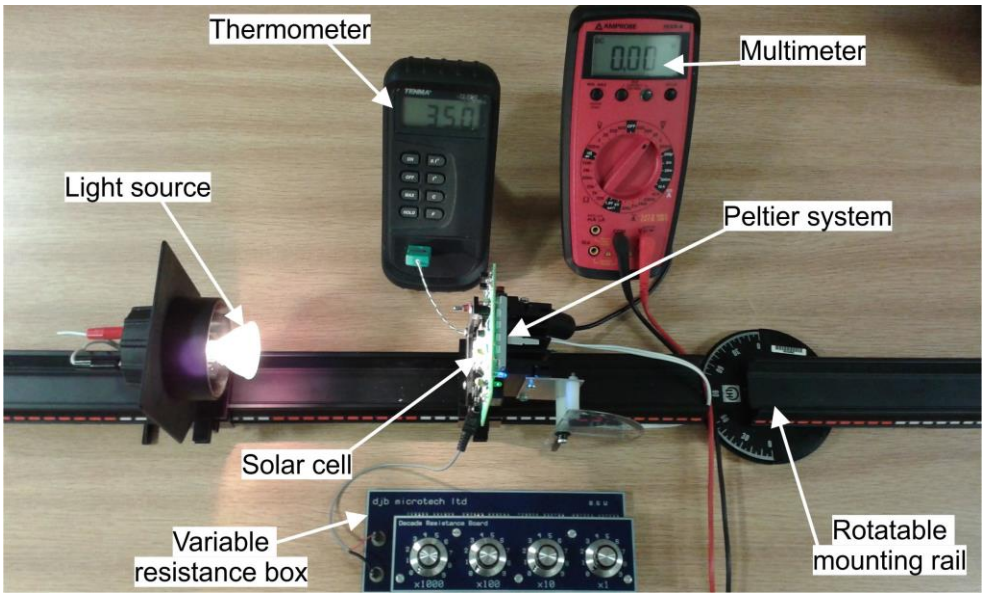
P1

Solar Cell Research Exercise (lab and coursework)

This contributes 15% of the marks for ELEC2201.

This is a research exercise in which you and your partner will explore the electrical properties of a silicon solar cell. You will be given one three-hour laboratory session and a number of weeks to prepare a report in which you evaluate the performance of the device.



Schedule

Preparation time	:	1.5 hours
Lab time	:	3 hours

Items provided

Tools	:	None Required
Components	:	Hook-up Wire
Equipment	:	Solar Cell Measurement Apparatus, Bench PSU, 2x Multimeters, Variable resistance box.
Software	:	Microsoft Excel, SigmaPlot, Mathworks Matlab.

Items to bring

Essentials. A full list is available on the Laboratory website at https://secure.ecs.soton.ac.uk/notes/ellabs/databook/essentials/

Before you come to the lab, it is essential that you read through this document and attempt to complete the preparation work in section 2. If possible, prepare for the lab with your usual lab partner. There is no objection to several students working together on preparation, as long as you all understand the results of that work. Before starting your preparation, read through all sections of these notes so that you are fully aware of what you will have to do in the lab.

> **Academic Integrity** – *If you undertake the preparation jointly with other students, it is important that you acknowledge this fact in your logbook. Similarly, you may want to use sources from the internet or books to help answer some of the questions. Again, record any sources in your logbook and reference them correctly in your submitted report.*

This exercise does not use the standard mark scheme because the lab is combined with a coursework exercise. You will not be awarded marks in the lab, rather the report you submit will be marked and contribute 15% of the total mark for ELEC2201. The **mark scheme** for this exercise is included at the end of the document.

1 Aims, Learning Outcomes and Outline

This laboratory exercise and coursework assignment aims to:

- Give you practical experience in characterising photovoltaic devices
- Show how illumination conditions affect solar cell performance
- Explore how this relates to real-world deployment of solar cells.

Having successfully completed the lab and coursework assignment, you will be able to:

- Measure the IV characteristics of a solar cell.
- Calculate key performance indicators for solar cells from their IV characteristics.
- Explain how and why the performance of a solar cell changes under different conditions.
- Demonstrate a detailed understanding of the many and diverse aspects that relate to the operation and exploitation of photovoltaic devices.

Outline

You will be provided with a $1cm^2$ crystalline silicon solar cell within an apparatus that will allow you to manually change:

- The *light intensity* by varying the distance between the light source and cell.
- The *angle of incidence* of light on the solar cell. Equipment will be provided that allows the angle between the light source and solar cell to be varied. You should simultaneously rotate the light source assembly **and** change the angle between source and cell so that the same region of light is incident on the cell.
- The *temperature* of the solar cell. The solar cell is mounted on a Peltier system for which the temperature range is ~15 to 45°C.

Within your assigned groups in the laboratory session, you will measure and plot the I-V characteristics of the cell under illumination and calculate various cell performance parameters. You will then investigate how changing the illumination conditions can affect the I-V characteristics of the cell. You will present these results along with further analysis and discussion in an INDIVIDUAL report to be submitted online for marking.

2 Preparation

Read through the course handbook statement on safety and safe working practices, and your copy of the standard operating procedure. Make sure that you understand how to work safely.

Read through this document so you are aware of what you will be expected to do in the lab.

To help you prepare for this lab, you should attempt to answer the following questions by referring to textbooks and other literature:

1. How do you extract the following parameters from the I-V characteristics of a solar cell?
    a. Open circuit voltage (V_{oc})?
    b. Short circuit current (I_{sc})?
    c. Maximum power point (V_{mp}, I_{mp})?
    d. Fill factor (FF)?
    e. Power conversion efficiency?
2. How can you extract additional parameters of a cell such as ideality factor n, dark saturation current I_0, series resistance R_s and shunt resistance R_{sh} from the I-V characteristics of a cell under different illumination intensities?
3. How do you expect the cell performance to change as you vary the temperature or angle of incidence?

Your preparation will not be marked but being well prepared for this lab will help you obtain all the results you need, understand the experiment and complete the report to a high standard.

3 Laboratory Work

3.1 Notes on safe use of equipment

You will be required to read and adhere to the control measures detailed in the general lab risk assessment.

When illuminated, the halogen bulb will become **very hot** along with any items in close proximity, which may cause mild burns. The solar cell will also become hot when the Peltier element is heating, and the heatsink will become hot when cooling the cell. Avoid looking directly at the light source whenever possible, due to its high intensity.

Do not touch the surface of the solar cells, fingerprints will degrade performance and cause impaired results.

3.2 General Method

Within the laboratory, the measurement apparatus must be configured so as to drive the voltage generated by the solar cell across the variable resistance unit, and the voltage across this resistance measured using the multi-meter. This will allow you to obtain the illuminated I-V characteristic of the photovoltaic module and enable you to collect the data required to complete the tasks in section 3.3.

The solar cell measurement apparatus can be varied by manually changing the distance between the lamp and the cell, by tilting the cell forwards and rotating the track sideways to vary the angle if incidence, and by adjusting the slider on the rear of the device to vary the temperature between approximately 15° - 45°C, which can be observed on the thermometer LCD unit.

1. Connect the solar cell output terminals directly to the variable resistance unit. Set the resistance to the maximum value.
2. Cut and strip two short pieces of wire to connect the terminals of the resistance unit to the multimeter crocodile-clips. Set the multi-meter range to max 2V DC.
3. Configure the solar cell apparatus to the baseline measurement state, which is suggested to be the lowest temperature, normal incidence and with the cell and lamp approximately 10cm apart. Remove the plastic cap from the solar cell.
4. Observe the open-circuit voltage on the multimeter display at the highest resistance. Record this resistance in your log-book alongside the voltage value.
5. Reduce the variable resistance, at first in blocks of 1KΩ until a significant change in the voltage is observed, then in finer steps of 100Ω, 10Ω and 1Ω. It is easiest to record the voltage in a Microsoft Excel spreadsheet alongside the resistance, and calculate the corresponding current flow within the spreadsheet from these values.
6. Once a resistance of 1Ω is reached, the I-V measurement is complete. The graph of voltage and corresponding current flow can now be plotted. Set the resistance box back to its maximum value.
7. When all required measurements have been taken, please leave the equipment in a safe and tidy state.

3.3 Tasks

Using the general method for IV curve acquisition from section 3.2, work through the tasks below. In the lab session, you should focus on collecting the required I-V curves for each task (part (a)). Following the lab, carry out further analysis of the results (parts (b) and (c)) and present your results, analysis and discussion in a scientific report.

Task 1- Baseline IV data acquisition and analysis

(a) Plot I-V characteristics of the cell in the baseline measurement conditions

(b) Calculate V_{oc}, I_{sc}, V_{mp}, I_{mp} and FF from the IV characteristics

(c) Assuming that at a distance of 15 cm, the power density of light from the lamp is 0.3 kW/m^2 and that the power density varies with the inverse square of the distance, calculate the power conversion efficiency of the solar cell.

Why would your efficiency value differ from that stated by the cell manufacturer?

Task 2- Variation in intensity

(a) Vary the intensity of incident light by changing the distance between the lamp and the solar cell. Plot IV characteristics for several different intensities.

(b) By using an equivalent circuit equation and plotting ln(I_{sc}) vs. V_{oc} for the different intensities, obtain estimates for the dark saturation current (I_0) and the ideality factor, n.

Can you also obtain series and shunt resistance values from the data?

Task 3- Variation in angle of incidence or temperature

(a) Plot I-V curves for the cell under different illumination conditions to investigate the effect of **one** of the following:

i) Angle of incidence

or

ii) Temperature (for temperature variations allow time for the temperature to stabilise. Note that the temperature will increase during measurements if the cell is in very close proximity to the lamp)

(b) Explain the variations in cell IV characteristics you observed in (a).

(c) Discuss the implications of your findings when considering practical deployment and operation of solar cells. Some factors you may wish to consider are:

- The location of solar cells on Earth
- Variations in illumination conditions with time of day or year
- Solar cell design and optimization for different illumination conditions
- Implications for concentrator solar cells
- Fixed vs. tracker systems
- Effects of encapsulation

Submission of coursework

Tasks 1, 2 and 3 should be written up into a report for submission.

The report should be no longer than **6 pages,** including figures.

For task 3(c), you may wish to make use of various online calculation tools (e.g. www.pvlighthouse.com.au, www.pveducation.org/pvcdrom) and refer to the literature to support your discussion.

You should only hand in an electronic copy of the report. This should be done through handin.ecs.soton.ac.uk. The deadline for submission is **4 pm on 23rd April 2015.**

Mark Scheme

The lab and coursework marking is carried out on the submitted report and will contribute 15% towards your total mark for the ELEC2201 module.

Task 1- Baseline IV data acquisition and analysis	
0	No evidence of task being attempted
5	Partially completed, no evidence of understanding
10	Partially completed, minimal understanding
15	Partially completed, good understanding *or* All completed, minimal understanding
20	All completed, good understanding
25	All completed, excellent understanding
Task 2- Variation in intensity	
0	No evidence of task being attempted
5	Partially completed, no evidence of understanding
10	Partially completed, minimal understanding
15	Partially completed, good understanding *or* All completed, minimal understanding
20	All completed, good understanding
25	All completed, excellent understanding
Task 3- Variation in angle of incidence or temperature	
0	No evidence of task being attempted
5	Results plotted, but no explanation or discussion
10	Results plotted, some explanation and discussion
15	Results plotted, good explanation, discussion and critical analysis
20	Results plotted, excellent explanation, discussion and critical analysis
25	Results plotted, outstanding explanation, discussion, critical analysis and evaluation
Writing, presentation and structure	
0	Poorly written, figures missing or not understandable
5	Adequately written but with significant errors, unclear presentation of figures
10	Well written but with some errors in grammar and spelling, reasonably clear figures
15	Well written and structured, with only minor spelling or grammatical errors, well presented figures
20	Very well written and structured, hardly any errors, very well presented figures with clearly written captions.
25	Extremely well written, structured and formatted, no spelling or grammatical errors, figures of a standard similar to published figures.
	TOTAL /100
	Mark out of 15