LABORATORY PROJECTS

PHYS 1003 TEC
PHYS 1004 ENV
PHYS 1902 ADV

1 Junior Physics Laboratory Projects

So far all the experiments you have been performing in the laboratory have been carefully designed and provided with an aim, procedure, background theory and necessary equipment. This type of experimentation has served well to introduce you to various skills that are essential for carrying out a scientific investigation. By now you should be familiar with a diverse range of instruments and measuring techniques, have a good understanding of the relevance of uncertainties and how to estimate them, and have acquired some knowledge of computers and their use in analysing experimental data. All these skills will be called upon as part of your work in this final Module. During the last four weeks of lab you will be asked to conduct an investigation on a topic that interests you, and report on the results you find.

1.1 Objectives

This Project Module is designed to provide you with the opportunity to:

- Undertake independent research and encourage natural curiosity.
- Design and carry out a simple scientific investigation.
- Work effectively in a team.
- Improve your general experimental skills, including careful measurement, analysis of experimental data (including graphical analysis) and critical interpretation of your results.
- Gain experience in written and oral communication of your experimental procedures and findings.

1.2 Independent Research

No detailed aim, experimental procedure or relevant theory will be provided. It will be left to you to discuss as a group what it is you wish to investigate and how you intend to go about it!

Of course, your tutors will be available to make suggestions and help guide you **but they will not tell you what to do or how.** This means part of the work you do may include simply exploring and testing several methods to find a successful procedure. This is how most of the progress is achieved in scientific research. Rarely does a physicist write down an aim and procedure and then simply record data. A necessary part of any successful experiment includes designing the experiment, refining the experimental procedure and exploring unexpected or 'interesting' results.

1.3 Help!

To help you, a tutor will be assigned to your project group. You should think of this tutor as a member of your Group. Your session supervisor will also be available to offer advice. Some projects might require special equipment or requirements and you may need more technical advice than the tutor or supervisor can provide. In this case the project coordinator (Dr Richard Thompson, Physics Rm 226C, `r.thompson@physics.usyd.edu.au`) and/or the laboratory manager (Mr Barry Napthali) can assist you.

Lines of help for students, tutors and supervisors:

Project Group

⇒ Assigned Tutor

⇒ Session Supervisor

⇒ Laboratory Manager (Mr Barry Napthali, Carslaw Rm 406)

⇒ Laboratory Director (Dr Richard Thompson, Physics Rm 226C)

1.4 Design of experimental procedure

Turning a general idea into a specific proposal with all procedures outlined is essential to the successful completion of your investigation. One of the most important aspects of the project is to specify exactly *what* physical quantities you are going to measure and *how*. Planning of the method of analysis of results to show relationships between particular quantities is also important. Although you are encouraged to propose your own project on any topic, for practical reasons you are largely limited to investigations that can be performed using the equipment available in the First Year laboratories or which you can 'scrounge' yourselves.

You will be given a list of potential projects. You do not have to choose only from this list. Some other ideas for projects and an indication of the equipment readily available can be found by going to

`http://www.physics.usyd.edu.au/teach_res/projects/projects.htm`

or following the link from the Experimental Physics Lab page on the eLearning page for this unit. In any case, you must discuss your choice of project with your tutors and your lab supervisor.

1.5 Working as a team

Throughout the year you have been working in teams of 2 or 3. For this last Module two such teams will amalgamate to form a group of 4 to 6. To make effective use of everyone's time you will have to carefully plan the various tasks and responsibilities of each group member. For example, in a group of 6, you may decide to split into 3 pairs. One pair may head to the library and do some background reading and research on your topic. Another pair may procure the experimental equipment and the final pair could be responsible for analysing the data and writing the report. All the team members should participate in planning the experimental procedure and making some of the measurements.

All members of your group can access your results from home to work on their aspect of the experiment. To do this, save your work to directory (E:\STUDATA) after your lab session. It will be available for downloading from the Laboratory Download Site at the end of the day. This can be accessed by following the link from the Experimental Physics Lab page on the eLearning page for this unit. You can then work on the data at home and mail it to your University account which can be read from computers in the lab.

1.6 Presentation skills

Another aim of this Module is practice in presenting experimental work using two approaches. Firstly, the work performed will be written up in a ***Report.*** This report should follow the guidelines given below. In addition to this, your work will also be presented as a ***talk*** in front of your lab class during the final week of the module.

2 Timetable for Project Work

To be able to commence work on your project after the first Module requires some preparation and decision making. In the 1st week of laboratory (week 2 of semester) you will be placed in your Project Group and a tutor will be assigned to supervise you. You will have two weeks only in which to discuss any topics that may interest your group. The outcome from these discussions will be written up as an ***Initial Proposal*** and submitted to your tutor for consideration and marking. It will be returned the following week with comments. A more detailed ***Final Proposal*** will then be submitted. In this you will indicate both the experimental procedure you plan to follow and the various roles and responsibilities of all the group members. Working as a team will require group members to briefly meet on a number of occasions outside of normal lab hours to discuss the Project work. Tutors will be available during the weekly lab sessions for advice and guidance.

Since the final week is devoted to the talks, you really only have 3 laboratory sessions to complete your experiment, prepare the (Powerpoint/Keynote) presentation and write your report.

In that time you will have to set up your apparatus, test your procedure and collect the relevant data. You should aim to do as much of this as possible during the first two sessions to allow analysis and writing in the third session.

Project timetable for second semester:

Semester Week	**Activity**
Week 2	Placed into **Project Groups** and assigned a tutor
Week 3	Preparation of Project Proposal
Week 4	Preparation of Project Proposal (continued)
Week 5	**Final Proposal due**
Week 6	Final Proposal returned
Weeks 9, 10# & 11	Lab sessions for project work
Week 12	Oral Presentation
Week 13	Submission of Report

#Monday 7rd October is a public holiday, so Monday classes (but not the report submission deadline) are delayed by one week.

3 Assessment

A total of 28 marks is allocated to the work in the Project Module. This represents 14% of the total assessment mark for the entire semester. The marks are based on the written Report, the Oral Presentation, a mark given by Tutors, your Project Proposal, and your Weekly participation in the Project work during the lab sessions. All group members will receive the same mark for work handed in and the oral presentation (provided they have signed the appropriate forms and made a contribution) but not necessarily the same mark for laboratory work.

Each week your Project Group will be required to fill out a ***Progress Report*** that summarises what you have accomplished and the contribution of each member. It should also contain your plans for next week.

The ***Progress Report*** has to be pasted into your logbook and signed by each member of your Project Group. Your assigned tutor will check and discuss your Progress Report with your Group.

Project mark allocation:

Activity	**Mark**
Project Proposal	4
Weekly Progress Reports (3)	3
Project Mark	5
Oral Presentation	6
Written Report	10
Total	**28**

3.1 The Project Proposal

Submitting proposals for work you intend to carry out is a very important and necessary skill that will be called upon throughout your working career, whether that be in scientific research or not. The purpose of a proposal is to demonstrate to a supervisor or funding body that you know what you want to do and have a good understanding of how to achieve this. You should also be able to argue why it is desirable or important that you carry out such work. These are issues you will have to consider in writing a proposal.The Project Proposal Form must be signed by each Group member for them to be awarded any marks. Sample forms are shown at the back of the lab manual. The actual forms you need to complete will be distributed during your laboratory classes.

As part of everyday research (and in fact all types of work) money, equipment and labour will be required to carry out some proposed investigation or task. In order for these to be supplied you must convince the person(s) in charge of funding that the task you have proposed is worth carrying out, that you know what is required to complete the task and that you are capable of carrying it out. These are just some of the aims of the project proposal that you should keep in mind when completing it. To help us provide you with the equipment necessary to conduct the investigation you have chosen, you must complete this form carefully.

- Please give the complete details of all students in your Project Group. Marks will ***only*** be awarded to members of the team who have signed the forms.

- ***You*** must clearly indicate your project team number eg 6TECB (you must know this number to identify your team).

- ***You*** have to make sure that the tutor who is mentoring your team has signed the form.

- ***Project Title*** — gives us some idea of what you are going to investigate. Do not leave it blank. The title should clearly indicate what your project is about.

- ***Equipment*** — in order to carry out your investigation you will have to determine exactly what equipment you will require. There will not be sufficient time to find other more suitable equipment or build some special apparatus as it is needed. If the equipment exists in the laboratory, refer to it. If you require a voltmeter, how sensitive and accurate must it be, to measure millivolts, or to 1%? Check the various models of multimeters that exist in the lab and ask for the particular model appropriate for your measurements. The School of Physics will be able to supply certain equipment e.g. tubes suitable for standing wave experiments. However, you must tell us what you want, the shape and dimensions of the tube (or range if particular values are not crucial) and the material. Clearly indicate what equipment you will provide e.g. mobile phone (the School of Physics will not provide any mobile phones). You are then responsible for bringing this equipment when the Project begins.

- ***Summary*** — give a clear and precise summary outlining your project.

- ***Description*** — descriptions of measurements to be made and how they will be made should be clear and concise (for example, ...the voltage supplied by the various batteries will be measured as a function of time for constant load resistance; the service time and power supplied will then be calculated using the equations...; the voltage across the battery terminals is to be measured by a Yokogawa DMM Mode17532-02 using the circuit shown below...). Use diagrams to clarify what you are doing. Indicate what is interesting about the work you will perform, basically the motivation for carrying out the investigation. Assuming all goes to plan, what do you hope to learn? What questions or puzzles do you want to answer? Remember you are to work as a team and share the workload evenly. There are many tasks to be completed as part of the Project. Apart from actually designing and performing any experiments there will be data that must be analysed, research to compare with or justify your results, the written report and the oral presentation. Plan these carefully and everyone will do their equal share, e.g. divide the group into 2 teams, one responsible for the report and the other for the talk.

- ***References*** — to show that you are familiar with the relevant theory and know what you want to do, list any references you have used in designing your Project. These can include textbooks, journals, magazines, newspaper articles, the internet, etc.

3.2 Weekly Progress Reports

Your group must fill out a weekly progress report form on each of the three project weeks (weeks 9, 10 and 11). Forms will be provided in the laboratory. A sample of the form is on page P.33 of this lab manual; it's just a sample, don't use it.

Please note: The weekly progress report must be signed by each team member, pasted into your logbook and checked off by your tutor before you leave the laboratory each week. Only team members who have signed this form will be eligible for the weekly attendance mark.

3.3 Project Mark

Your tutors and supervisor will meet after the project presentations and will give you a mark out of 5 for your project. The tutor assigned to mentor you in your project will act as your advocate at this meeting.

Initially, the Project Mark will be given to the entire group. But the mark you are given as an individual will be scaled according to your participation in the project. If you contributed to the project proposal, contributed for the three weeks of project work, and attended the project presentation you will receive the full Project Mark. If you missed any of these your mark will be scaled in proportion to your participation. For this purpose the Project Proposal will carry double weight to the other elements. Please that it is very important that you complete and sign each of the forms during the project. It is presence of your signature on these forms that will be used to determine yourscaled project mark.

3.4 Oral Presentation

A maximum mark of 6 is awarded for your Group's Oral Presentation. YOU have to be present at the time of the talk to receive this mark.

Groups should use *PowerPoint* to prepare their talk. If you use *Keynote or OpenOffice* please Export your presentation as a PowerPoint file (.ppt or .pptx) and then *check* that it works correctly on a Windows PC before you give your talk.

We recommend that no more than three Group members give the talk. This will help the presentation flow. A talk should not be less than 8 minutes and no more than 12 minutes. You may be asked questions at the completion of the talk. It is advisable to present any information in point form. People are not likely to read large blocks of information and nor do you want them to, they should be listening to you. Use the points on the transparencies as cues for your talk. About 4-6 PowerPoint slides are all that you will require.

3.4.1 How to give a good oral presentation

Your results should be presented clearly and concisely. Assume the audience, your peers from the First Year Laboratory Class, know nothing about your work. Most groups will be doing a completely different topic. In order for them to understand your work you will have to:

- Clearly state the aims of your project.
- Describe the experimental apparatus and techniques used.
- Present the important results.
- State your conclusions.

3.4.2 Structuring your presentation

There should be a logical progression or structure in your talk. This is best achieved by dividing the material into separate sections.

Introduction A concise summary of the aims of the Project - what you intended to achieve during the course of the Project.

Theory A brief summary of the ***physics*** relevant to the Project.

Experimental A clear, brief description of the equipment and the techniques you used. Diagrams are ***essential*** here.

Results Keep this section short — it could be as simple as a graph or a value obtained from that graph. Large tables in Powerpoint cannot be read by the audience.

Discussion How good are your results? Why do they differ from what you expected? (Be prepared to say so if you don't know — this is much more convincing than waffling on). Could you possibly improve the experiment? Above all, keep this section short... it is easy to get carried away.

Conclusion A succinct summary of your results — a number (with associated uncertainty), an equation or a couple of lines of text.

3.4.3 Preparing PowerPoint slides

Nearly all students will use PowerPoint (or Keynote or OpenOffice).

- Slides should be clear and simple — avoid clutter. (Advertisers know how to get their message across: check out some billboards.)
- Use colour.
- Use LARGE letters — 24 point type is a good size. Never use less that 18 pt. type. Photocopies of printed text are too small.
- Use a **maximum** of 8 lines of text on each overhead — fewer lines are acceptable and point form is a good idea.
- Diagrams of equipment and graphs should fill the slide/overhead.

3.4.4 Speaking in public

- ***Look*** at the audience.
- Practice, practice, practice, in front of each other, your friends or family
- Keep to the allotted time, practice will greatly help, here. There is a strict limit of 12 minutes. DO NOT shorten the talk by speaking more rapidly, glossing over points or assuming "it will be OK on the day".
- Don't try to present ALL your results. It is much better to concentrate on what you found interesting or important.
- Avoid blocking the audience's view of the overhead screen or other visual aids.
- Point to information on the screen as you discuss it but spend most of your time looking at the audience.
- Memorise your talk. This is not difficult if you use your slides as prompts — they will give you clues as to what comes next.

- Remember you are communicating by speaking, not reading. Read presentations are painfully boring!
- Avoid speaking in a monotone — try to change the loudness and speed of your speech during the talk
- Do NOT use long words or sentences. Don't waffle, keep your talk crisp and concise.
- Do NOT speak too rapidly. Aim at speaking at HALF the speed you would in a normal conversation.

Presentation of the results of an investigation or research project is an essential skill to have acquired, no matter what your future career.

Here are a few words of advice from the experts. The editors of Nature probably have sat through more conference presentations than is good for them. Nature can lay claim to being the worlds most prestigious multidisciplinary scientific journal. Your project presentations should be just like what happens at a scientific conference. This editorial appeared in Nature Methods, vol. 5 no. 5, May 2008, p. 371.

"Talking Points

Presenting at a conference is a unique opportunity to broadly communicate your work.

Here are ten suggestions to make the most of it.

"I know this is a busy slide, but ..."

"You probably cant see this, but ..."

"Im gonna go through these last slides really quickly ..."

As editors, we attend many conferences. Having already heard these staples too many times this year, we decided to put together our top 10 list of presentation rules. We may not address an audience often, but we have plenty of opportunity to build up our pet peeves about presentation skills. There is of course more elaborate advice available, and this short list may sound like common sense to many. Nevertheless, we hope it helps beginner speakers get off on the right foot for the summer meeting season. Perhaps even some seasoned speakers may appreciate the reminder.

1. **Plan for the allotted time.** There are few things more annoying than a speaker who rushes through slides without leaving any lasting impression about the substance of the work. The key to a good presentation is to present the minimum amount of information that is necessary to make your point. A maximum of one slide per minute is a good rule of thumb, but the exact number should be determined by rehearsing.
2. **Know your audience.** There is no such thing as a one-size-fits-all speech. Knowing the level of specialty and diversity of your audience will help determine how much background and detail you need to present. Do not expect everyone to be an expert in your particular body of work but avoid patronizing the audience.
3. **Define your goals** . As you must limit your material, it is important to deliberately decide which points you want the audience to remember. Once this is clear, build your talk around these points and make sure that each slide has a purpose toward your goals.

4. **Structure your talk.** Whatever the audience, it is worth setting the stage by stating the general importance of the work and your specific objectives. To place the work in perspective, mention related efforts and what is unique about your approach. Only then, delve into experiments and results. An outline slide at the beginning is seldom necessary for short talks but it can help if you will be discussing substantially distinct topics. In contrast, there is no way around the summary slide; the all-important take-home message that should capture the key points in a way that both experts and non-specialists will remember.

5. **Keep your slides simple (content).** The slides should be a visual support for your talk rather than the talk itself; they should help convey the essence of your talk rather than the details. Prefer bullet points to paragraphs of text. Avoid complete sentences because the audience will not resist reading them, creating a distracting disparity with what you are actually saying. Such economy of text means you must choose the words judiciously, making sure you highlight key notions. Prefer schematics and cartoons to words but keep them simple, limiting them to the essential elements. Finally, prefer graphs to tables, and label them adequately.

6. **Keep your slides simple (design).** There is nothing wrong with a good old solid background and an appropriate colour contrast. Use a legible typeface for all text (do not forget about cartoon labels and graph axes) and make it large enough to be legible once projected. If you have to resort to a font size below 20 points, you have too much information on your slide. Sans-serif fonts (in which letters do not have little tails) tend to work best.

7. **Beware of animations and multimedia.** There are cases in which a simple schematic animation will convey a concept better than a still cartoon. But think twice and use animations sparingly as they can be awfully distracting if overused. As for dynamic data representations, such as live microscopy movies or rotating three-dimensional protein structures, they can be invaluable to convey critical observations. Our advice, however, is to keep them to a minimum and make sure they run properly. If you are using someone elses computer, chances are the movie will not play. So do not plan your talk around it, or else, have a contingency plan such as a few slides with representative still frames.

8. **Watch your delivery.** Be attentive to the speed and volume of your speech. If you are a non-native English speaker, pay particular attention to the pronunciation of key terms and use words on the slide to convey key concepts. If you are a native English speaker, keep in mind that many in the audience are not. In addition, using transition words and phrases between slides will help make the talk flow smoothly. To use them effectively, you must know which slide is coming up next.

9. **Choose your words.** Avoid jargon and acronyms. Uncommon abbreviations cannot always be avoided on the slides, but it is important to spell them out as you speak. As much as possible, match key words in your speech to the written words on your slides to maximize the visual support they offer. Explain the graphs and schematics as soon as you bring up a slide. If people do not know what is plotted against what, or what the red arrow is supposed to represent, they will not follow your explanation of the results.

10. **Rehearse!** Most of the points above will become apparent if you give a practice talk. With or without a friendly audience, the key to rehearsal is to make it real. Problems with timing, abrupt transitions and confusing explanations will become obvious only if you try it out loud and not in the comfortable environment of your own head. Some oral presentation instructors film their students giving mock talks in class, a potentially excruciating experience but one that is very informative about bad habits. For a real talk, practice runs will give you the opportunity to fix problems in the presentation design and to keep track of time effectively during the talk. Practicing is also the only proven way to reduce anxiety.

This is our advice, for what it is worth. Perhaps there is one more pet peeve that sums up all the others: **do not make excuses for things you could have addressed before your talk.** If you have prepared well, you will do a great job."

3.5 The Report

The Report will form the main basis for presenting your project work. Your report is worth one third of your project mark. It should not be a copy of your laboratory logbook. It should be a clear and concise presentation of the work you performed. Long tables of results and complicated calculations should not be included. Graphs should be used to present results and a clear explanation of how calculations were performed is more than adequate.

As a guide, the Report should be from 8 to 16 pages in length including diagrams and graphs.

We encourage cooperation between students and Groups in completing the Report. However simple copying is not acceptable, whether from other students or any other source (such as the web). Copying the work of another person or group without acknowledgment is contrary to University policies on Academic Honesty in Coursework (see `http://www.usyd.edu.au/ab/policies/Academic_Honesty_Cwk.pdf`). Allowing your work to be copied is unfair to other students and ultimately does not help the student copying your work.

The Report must be submitted with the ***Cover Sheet*** as the first page. The Report should be securely stapled and not submitted in any type of folder. If this is not done, marks will be deducted from your Report. All members of the Project Group **must** sign the Cover Sheet. Students who do not sign the cover sheet will NOT be awarded marks for the Report.

All Project Group members are expected to keep a photocopied version of the Report.

The Report must be submitted to the Physics Student Office, School of Physics, Room 210, before 5pm on Friday 1th November.

Reports may ***only*** be submitted to the Physics Student Office. The Report needs to be handed to an administrative assistant who will photocopy the Cover Sheet, sign it and give it to you as a receipt for your report submission. Reports should not be given to a tutor nor submitted in the laboratory.

The marking criteria for your Report are:

Criterion	**Mark**
Effort and presentation	3
Experimental data collected and Scientific presentation of data	3
Scientific analysis and conclusions drawn	4
Total	**10**

The style of a Physics Lab report is that of a scientific journal paper. Our intention is that you obtain some practice in the concise and accurate style of writing that scientists use. This is an essential skill for any science graduate.

To gain an idea of the structure of a scientific paper, we recommended you visit some journal webpages (preferably Physics, but Biology, Medical or Chemical journals are OK), and look at some recently published papers. Alternatively, have a look at recent journals in the SciTech library. Don't worry too much if you don't understand all of the article. For the purposes of this exercise we are more concerned with structure and style than content.

Using a University of Sydney account to do your web-browsing will give you access to papers from sources such as `http://www.sciencedirect.com/`. Physics enthusiasts could also check out `http://journals.iop.org/` and `http://journals.aip.org/`.

The following is the general structure of a paper, but as you will find from browsing the published literature there are wide variations that depend on the content of the paper. Use the following as a basis from which to work but remember that it's not a template. Your report should be understandable to a scientifically literate person, e.g., another junior physics student.

Abstract This is a paragraph at the beginning of a paper that summarises briefly the experiment, the main quantitative results and their implications.

Introduction This section is where the paper starts. It does not rely on the abstract. It usually includes some background or history to the area of research. It is very rare for an idea to arise by itself since there is always some precedent that has led to the ideas being tested in an experiment. It might also include some application of the principle behind the experiment.

Theory If there is some background mathematical theory or qualitative ideas that need to be introduced so that the experimental results can be understood, then this is the place to do it. The section itself doesn't have to be called "Theory". In many cases the theory is not extensive enough to place it in a dedicated section and is simply incorporated into the Introduction.

Experimental Procedure Since the paper is about an experiment or experiments, then there must be some description of the apparatus used. A reader can only gain confidence in the results if they are confident that you had appropriate apparatus and were able to describe its function and limitations (every piece of apparatus has its limitations, no matter how expensive it is!). In many cases you need to describe in some detail those parts of the apparatus that are critical to the understanding of the experimental results. A diagram goes a long way in helping the reader understand your description of the setup.

Results and Discussion A discussion of the results is best placed along with the presentation of the results. It breaks up the flow of a report to separate the results and discussion into two different sections. The analysis of your results should be quantitative (with uncertainties) and honest: attempt to explain discrepancies in physical terms, don't dismiss them.

Conclusions A conclusion is really an extended abstract, summarising the results in more detail and maybe suggesting ways this experiment or future experiments might be improved or extended.

References We expect you to read relevant material when preparing your report. All references, including web references, must be acknowledged. References should be cited by number, either as a superscript or within square brackets, with a numbered list at the end of your report. The extent of your outside reading can make a big difference to the scientific impact of your report.

Acknowledgments An *essential* part of the Acknowledgments section will be the team members' contributions, where the work of each member is outlined.

3.6 Common mistakes and helpful hints

- Remember to write in the *correct tense*. You have already completed the experiments that you are reporting about. So they WERE done . . . they are NOT being done now as you write the report.
- Do not write instructions as if you are writing a laboratory manual.
- Do not write in dot point format. The writing must be in a narrative style.
- Do not derive formulae or include intermediate steps in calculations.
- Equations and figures should be numbered, with symbols defined in equations and informative captions included for the figures. Figures should be referred to in the text, e.g., as shown in Fig X.
- Do not do join-the-dots plots for your graphs; they do not convey any extra information. However, if you have more than one plot on the same graph, then it may be appropriate to join the points or, better, use different plot symbols or colours to distinguish the points.
- Explain how you determined your uncertainties. There must always be a reason for an uncertainty estimate.
- Always compare experimental and accepted values. Examine the assumptions that may underpin an accepted or theoretical value before writing off your own results.
- Express discrepancies in terms of uncertainties, not as small, large or 5%!
- Exclude any waffle when trying to explain discrepancies. Show physical insight.

SAMPLE WRITTEN REPORT

TESTING COMMERCIALLY AVAILABLE BATTERIES

by

Albert Einstein, Max Planck, Marie Curie, Robert A. Millikan, Isaac Newton and Archimedes

Abstract

A large range of batteries is commercially available these days some claiming superior performance but at a significant cost. This report details tests conducted to measure the service time and rated capacity of 4 such AA batteries manufactured by Eveready under the names: General Purpose, Heavy Duty, Super Heavy Duty and Energizer. The alkaline based Energizer is shown to have a significant performance advantage but the best performance per cost was displayed by the General Purpose battery. Measurement of the open circuit voltage and internal resistance are shown to be good indicators of the battery condition.

Introduction

In recent years the market place has been saturated with various types and models of small electrical batteries. These range from the standard primary dry batteries to the high power alkaline primary batteries and the relatively new rechargeable secondary batteries. Despite their very similar appearance and apparent ability to fulfil most uses the prices per unit range from less than $0.25 for general purpose batteries to over $10 for rechargeable batteries. This means the comparison of performance per price and the question of appropriateness of the various batteries for particular uses are very important issues.

This report contains a description of experiments undertaken on various types of AA cells (the common Zn-C and newer alkaline batteries) to test their performance. The tests included simulated continuous use under high and low power demands. This allows not only a direct comparison of the various models and types of batteries but also their appropriateness for high and low power demands. The results obtained are also compared to the manufacturer's technical data where available.

Theory

All dry cells whether the common Zn-C, alkaline or rechargeable Ni-Cd cell produce a current by a series of electrochemical oxidation-reduction reactions. In the Zn-C battery a zinc can forms the anode and serves as the mechanical container for the cell. This is usually covered by protective and insulating layers of plastic and paper. The cathode consists of a mixture of powdered manganese dioxide and carbon moulded onto a central carbon rod. The anode and cathode are separated by an electrolyte made from a paste of ammonium chloride and zinc chloride. A complicated sequence of reactions occurs both at the cathode and in the electrolyte: the overall reaction can be considered as the oxidation of zinc at the anode and the reduction of manganese at the cathode.

In the case of alkaline cells the reactions can be thought of as similar and in fact both a zinc can and manganese dioxide are used. The main difference is the use of potassium hydroxide as the electrolyte. This is a much better conductor than the ammonium chloride and zinc chloride paste and allows the cell to generate much higher currents. It is usually recommended by the manufacturers for high power applications.

An ideal battery (or voltage source) can supply a given voltage independent of the load resistance. A real battery, however, has an internal resistance and hence the voltage measured across its terminals depends on the load. As such a simple model for a battery is an ideal battery with a resistor in series, as indicated in Fig. 1

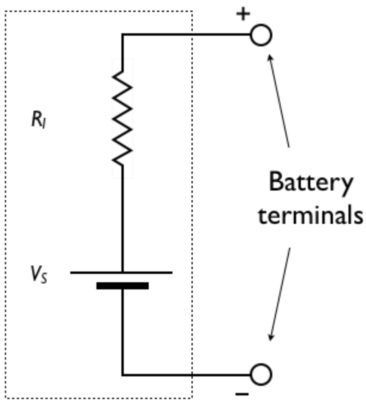

Figure 1: *Equivalent circuit for a real battery.*

Experimental

Tests were performed on a selected range of batteries. The following batteries were included in the tests. EVEREADY General Purpose, EVEREADY Heavy Duty, EVEREADY Super Heavy Duty, ENERGIZER Alkaline.

All the batteries were purchased brand new in packs of 4.

Two series of tests were conducted. In Series 1 the open circuit voltage (OCV) and internal resistance of each battery were measured using a voltmeter (Yokogawa DMM Model 7532-02) and a known resistor. The OCV was measured by simply placing the voltmeter across the terminals of the battery as indicated in Fig. 2.

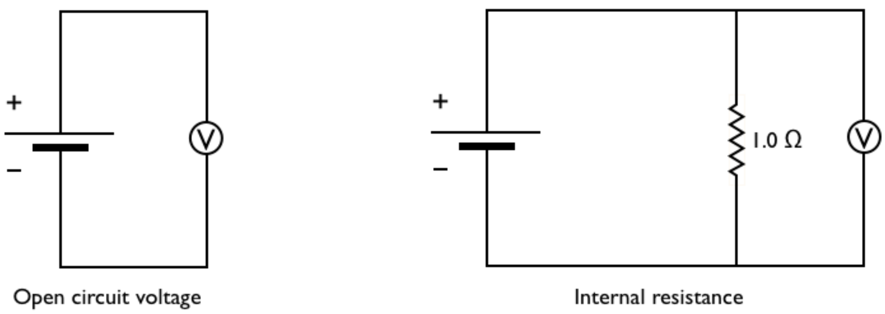

Figure 2: *Circuits used to measure the OCV and internal resistance of batteries.*

This measurement was used along with a measure of the voltage drop across a 1 Ω resistor to calculate the internal resistance of each battery. Considering the model of a real battery discussed earlier and the circuit shown in Fig. 2 we obtain the following relation,

$$V_s - IR_I - V = 0 \tag{1}$$

$$V = V_s - IR_I \tag{2}$$

where V_s is the ideal voltage of the battery, V the measured voltage drop across the resistor, I the current through the resistor and R_1 is the internal resistance. From the measurement of V

across the 1 Ω resistor the corresponding value of I was calculated while for the measurement of the OCV I was assumed to be zero (the internal resistance of the voltmeter was given as 11 $M\Omega$). The internal resistance of the battery was then calculated using the following expression

$$V = \frac{V_{OCV} - V_{1\Omega}}{I_{1\Omega}} \tag{3}$$

In the second part of the experiment, Series II, the batteries were tested under operating conditions. The voltage applied by each battery was monitored as a function of time for 2 different fixed load resistor values, 2 Ω and 100 Ω (corresponding to nominal currents of 0.75 A and 15 mA respectively). A different battery of each type was used for each test. The tests were designed to represent different power requirements, high and low respectively. The voltage was monitored until it dropped to 0.9 V. In the case of the high power tests the data was collected by hand using a voltmeter and wrist watch. For the low power tests the time taken for the voltage to drop to the required level meant that a computer controlled data acquisition system had to be used. This allowed the collection of data around the clock for long periods of time. The PC-26 data acquisition card was used and a program written in Pascal to collect and store the required data. This data not only allows a quick comparison between the various batteries but also a calculation of the ampere-hour capacity.

At the conclusion of the Series II experiments the OCV and internal resistance of the batteries were measured once again.

Results

The OCV for each battery used in the tests is shown in Table 1.

Table 1 : *Measurements of OCV for the various batteries.*

Battery	$V_{1OCV}(V)$	**Uncertainty** (V)	$V_{2OCV}(V)$	**Uncertainty** (V)
General Purpose	1.473	± 0.008	1.471	± 0.008
Heavy Duty	1.527	± 0.009	1.527	± 0.009
Super Heavy Duty	1.753	± 0.010	1.752	± 0.010
Energizer	1.581	± 0.009	1.579	± 0.009

Since 2 batteries of each type were going to be used for the Series II tests the results in Table l indicate the measurements for 2 batteries. The uncertainties indicated were calculated using the manufacturer's specifications for the calibration uncertainty in voltage readings.

Equation 3 was used to calculate the internal resistance of the batteries. The resistance was measured accurately using a Keithley 160B meter. The uncertainties indicated were

Table 2 : *Calculation of the initial internal resistance for the various batteries.*

Battery	$R_{1I}(\Omega)$	**Uncertainty** (Ω)	$R_{2I}(\Omega)$	**Uncertainty** (Ω)
General Purpose	0.49	± 0.02	0.47	± 0.02
Heavy Duty	0.51	± 0.02	0.52	± 0.02
Super Heavy Duty	0.47	± 0.02	0.45	± 0.02
Energizer	0.53	± 0.02	0.51	± 0.02

obtained by combining the uncertainties in the voltage measurements. The uncertainty in the resistance was neglected since it was so small. The results for the internal resistance are presented in Table 2.

The results for the Series II tests are indicated in Fig. 3 and Fig. 4 showing how the voltage supplied varies with time. Voltage readings from the PC-26 card have a resolution of 0.0025 V and calibration uncertainty of 0.5% of reading. The time was obtained from the computer's clock and is accurate to within a few seconds. Measurements were taken every 10 minutes. For quick reference the time taken to reach the cut-off voltage of 0.9 V is presented in Table 3 for both sets of graphs.

Table 3: *Service times for high and low power tests to end voltages of 0.9 V.* Cost of 4-packs also indicated.

Battery	**High Power Time(hrs)**	**Ratio**	**Low Power Time(hrs)**	**Ratio**	**Cost($)**
General Purpose	0.504	1	33.2	1	0.99
Heavy Duty	0.648	1.29	59.7	1.80	2.25
Super Heavy Duty	0.759	1.51	65.3	1.97	3.35
Energizer	2.64	5.24	160	4.82	5.69

The capacity in ampere-hours of the batteries during the tests was also calculated using the expression

$$\textit{Rated capacity} = \int I dt = \int \frac{V}{R} dt \tag{4}$$

This was obtained by taking the area under the graphs in Fig. 3 and Fig. 4 divided by the load resistance. The capacity for both high and low power uses is presented in Table 4. Typical uncertainties in the capacities are less than 0.5 %.

At the end of the Series II tests the OCV and internal resistance of the batteries was determined once again. The results are indicated in Table 5. Note that the batteries labelled 1 were used in the high power tests and those labelled 2 in the low power tests.

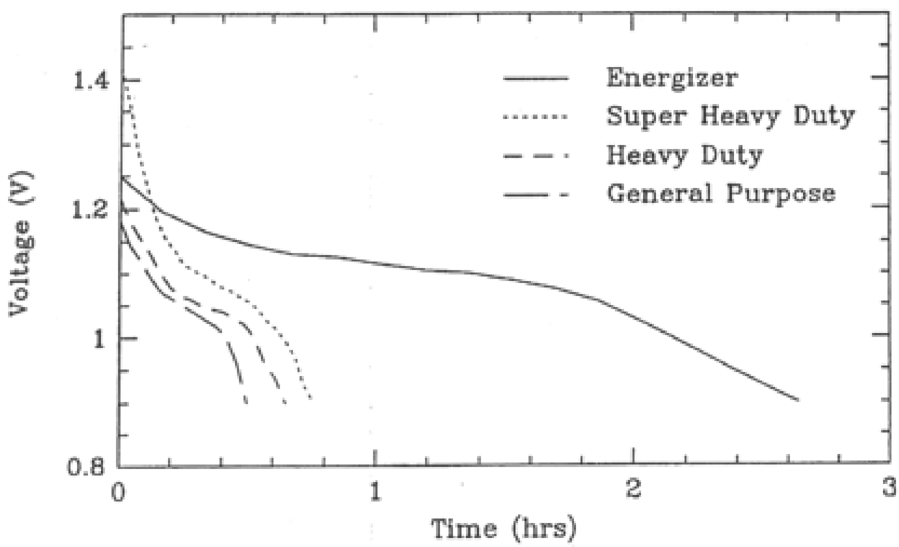

Figure 3: *Measurements of voltage supplied as a function of time for a constant load resistance.*

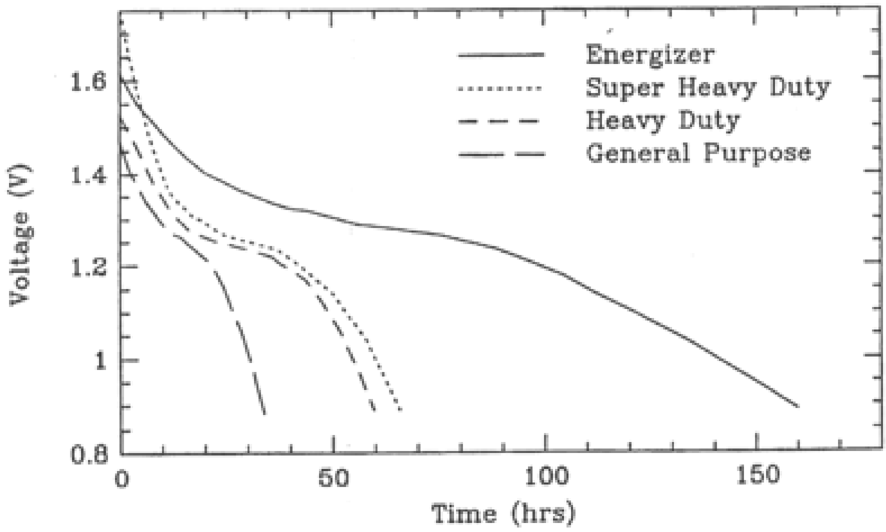

Figure 4: *Measurements of voltage supplied as a function of time for a constant 100 Ω load resistance.*

Table 4: *Calculated values for the capacity to a voltage of 0.9 V. for both the high and low power tests. Manufacturer's values are also included for comparison. The range indicates differences due to high and low power demands.*

Battery	**High Power Capacity ($mA.hrs$)**	**Low Power Capacity ($mA.hrs$)**	**Manufacture's values**
General Purpose	265	402	240-400
Heavy Duty	341	733	320-75
Super Heavy Duty	423	817	400-800
Energizer	1450	1890	1440-1850

Discussion

The AA batteries used in these tests are rated by the manufacturer at a nominal voltage of 1.5 V. Initial measurements of the OCV for the various batteries available indicate a significant range in values from 1.47 V to as much as 1.75 V. These values seem to be consistent between batteries bought in the same packets. One possible explanation for low readings could be deterioration of the batteries due to shelf life. Although they were purchased brand new the time and conditions under storage may vary. Such factors have been shown to influence battery characteristics (Cahoon and Heise, 1976). It has also been noted that the presence of artificial manganese dioxide tends to increase the OCV (Muller, Tye and Wood, 1965). Based on our measurements of OCV it is highly likely that the Eveready Super Heavy Duty batteries used had a significant proportion of artificial manganese dioxide. However, this is only one possible explanation.

The internal resistance of the various batteries also shows a significant variation and strong correlation with batteries from the same packet.

Comparison of the initial and final measurements of OCV and internal resistance clearly indicates that OCV drops with usage whilst the internal resistance increases. This means that together the OCV and internal resistance can be used to indicate the relative condition of a battery i.e. whether brand new or used for a significant time. The decrease in OCV can have

Table 5 : *Measurements for the OCV and internal resistance at the conclusion of the service tests.*

Battery	$R_{1I}(\Omega)$	$V_{1OCV}(V)$	$R_{2I}(\Omega)$	$V_{2OCV}(V)$
General Purpose	1.473	± 0.008	1.471	± 0.008
Heavy Duty	1.527	± 0.009	1.527	± 0.009
Super Heavy Duty	1.753	± 0.010	1.752	± 0.010
Energizer	1.581	± 0.009	1.579	± 0.008

significant consequences on the apparent battery life time in the case of devices that require a given minimum voltage to function e.g. logic devices. The increase in internal resistance implies battery efficiency decreases with usage and this effect is even more important for high power applications where the load resistance is comparable to the internal resistance.

Looking at the graphs from the Series II tests we can identify 3 main common features: an initial steady decrease in the voltage supplied; a plateau region of more gradual decrease in voltage; and finally an extended region of greater voltage decrease. The most significant differences are evident in the plateau region. The extent of this region and the voltage at which it occurs depends on the battery type and the application (high or low power demands). This can again influence the apparent life time of batteries depending on the minimum voltage or power required by a device.

In order to use the data collected in the Series II experiments to make a comparison of the various batteries we must select some criteria. Two results have been chosen, the time taken to reach a supply voltage of 0.9 V and the capacity available to that stage. The cut-off value of 0.9 V represents a significant drop in voltage and will probably produce noticeable deterioration in performance, signifying 'dead batteries'. Also since this value occurs well inside the final region of steady voltage decrease the conclusions drawn are equally valid for a range of similar cut-off voltages (0.8 - 1.0 V).

Table 3 indicates the times taken to reach a cut-off value of 0.9 V (the service time) for the various batteries in both the high and low power tests. For ease of comparison these times have been normalised to the smallest time. There is a significant difference evident between the alkaline Energizer and the other normal Zn-C batteries. In addition there is also a difference in relative service time between the high and low power tests. The Energizer clearly displays higher performance gains for high power applications. The cost of a 4-pack of batteries is also included in Table 3 to enable a cost-performance assessment. It is clear that the General Purpose batteries offer the best performance per dollar in both high and low power applications. The Energizer batteries, however, offer the convenience of significantly longer service with a single set of batteries. This means for some applications it will not be necessary to provide additional sets of batteries and no need to change them. It is this convenience that must also be considered. Certain applications require long service times without the possibility of changing batteries e.g. running an experiment in the field. In such cases the Energizer is the preferred choice. The calculated capacity is indicated in Table 4 and the manufacturer's values are also included for comparison. The manufacturer's values are represented as a range that includes results from high and low power applications, continuous and intermittent use. The notes provided state that the lower values correspond to high power demands while the higher values to low power demands. This corresponds very well with our results and indeed the actual rated capacity values also agree with the manufacturer's specifications. Again in terms of cost-performance the General Purpose batteries offer the best value for money.

Calculation of the internal resistance of the batteries after use shows a significant increase of resistance with usage. The batteries used during the low power tests have deteriorated more in that their OCV is much lower than those used in the high power tests. This accounts for their much higher internal resistance. Such measurements suggest that the OCV and internal resistance of a battery are good indicators of the condition of that battery.

Conclusion

In tests conducted to determine the rated capacity and service time of various AA batteries (Eveready General Purpose, Heavy Duty, Super Heavy Duty and Energizer) significant performance differences were evident. In both high and low power tests the General Purpose battery produced the best performance per cost. However, the significantly longer service time and larger rated capacity of the Energizer makes it more suitable for high power applications or where long service times are required. During the tests it was clear that the OCV of batteries decreases with usage while the internal resistance increases. Measurements of these quantities serve as good indicators of the condition of a given battery provided typical values are known.

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Albert Einstein and Max Planck	Wrote data acquisition program and set up apparatus for automated Series II experiments. Performed some calculations on rated capacity and internal resistance.
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Isaac Newton and Archimedes	Prepared report and talk. Responsible for research and obtaining manufacturer's data sheets.

Appendices

Pascal Program for data acquisition card Program listing (omitted for sample report). Manufacturer's data sheet - photocopy is sufficient (again omitted for sample report).