OCR ADVANCED SUBSIDIARY GCE
IN PHYSICS A (3883)

OCR ADVANCED GCE
IN PHYSICS A (7883)

Teacher Support: Coursework Guidance

This Teacher Support: Coursework Guidance booklet is designed to accompany the OCR Advanced Subsidiary GCE and Advanced GCE in Physics A for teaching from September 2000.

Contents

1 General introduction

This Coursework guide has been written to assist teachers in setting suitable coursework tasks and in assessing candidates' work. The guide should be read in conjunction with the specification itself. However, all sections of the specification relating to coursework assessment are included here.

While this guide is concerned with the assessment of coursework, it cannot be emphasised too strongly that before candidates are assessed on their experimental and investigative skills by coursework, these skills must be taught and candidates must have opportunities to practice and to develop their abilities.

Experimental and Investigative skills may be assessed either **internally** (by coursework) or **externally** (by a combination of an externally marked task and a practical examination).

Entries are made for Unit 2823 (in AS) or 2826 (in A2). In each of these Units, candidates must take two components - a written paper (Component 01) and the assessment of experimental and investigative skills by coursework (Component 02) or externally marked task and practical examination (Component 03). Both written paper and skills assessment component **must** be taken in the same examination session.

Centres may opt to enter candidates for:

- coursework in AS and in A2;
- the practical examination in AS and in A2;
- coursework in AS and the practical examination in A2;
- the practical examination in AS and coursework in A2.

In AS Unit 2823 Components 02 and 03, marks contribute towards Assessment Objective AO3: Experiment and Investigation.

In A2 Unit 2826 Components 02 and 03, marks contribute equally to Assessment Objectives AO3 and AO4: Synthesis of Knowledge, Understanding and Skills. There is assessment of AO4 because:

- candidates are required to use scientific knowledge and understanding from other modules of the specification in planning their experimental and investigative work, and in analysing evidence and drawing conclusions;
- in the assessment of all four experimental skills in Unit 2826/02, taken at the end of the course of study, candidates are expected to draw on their experience of such work throughout the course and, in particular, on the outcome of the assessment of these skills in Unit 2823/02.

Practical work provides many opportunities to develop key skills and to collect evidence that may contribute towards the assessment of key skills. Full details are given in Appendix A of the specification and links are identified throughout the content of the specification booklet. Teachers are advised to discuss such opportunities with colleagues and with the students concerned.

2 Coursework Assessment

Unit 2823 (Component 02) – Coursework 1 (60 Marks)
Unit 2826 (Component 02) – Coursework 2 (60 Marks)

In these components assessment of candidates' experimental and investigative work is made by the teacher (as coursework) and moderated externally by OCR.

Skills **P** and **A** are each marked out of 8 and Skills I and E are each marked out of 7. One mark per skill must be submitted for each candidate for Advanced Subsidiary (Unit 2823, Component 02) and for A2 (Unit 2826, Component 02). Hence, a mark out of 30 is initially calculated for each component. The marks are then doubled so that the final mark submitted for each component is out of 60.

When a skill has been assessed on more than one occasion, in Advanced Subsidiary or in A2, the better or best mark for that skill should be submitted. However, Centres are recommended not to assess the skills on more than two occasions in each of Advanced Subsidiary and A2 since this may take up time which might better be devoted to other aspects of the specification.

The skills may be assessed at any time during the course using suitable practical activities, based on laboratory work, related to, or part of, the content of the teaching course. The context(s) for the assessment of the coursework for Unit of Assessment 2823, Component 02, should be drawn from the content of Advanced Subsidiary Units 2821, 2822 and 2823, Component 01; the context(s) for the assessment of the coursework for Unit of Assessment 2826 Component 02 should be drawn from the content of A2 Units 2824 and 2825, in which the level of demand of the related scientific knowledge and understanding is higher.

In Advanced Subsidiary and in A2, the skills may be assessed in the context of separate practical exercises, although more than one skill may be assessed in any one exercise. They may also be assessed all together in the context of a single 'whole investigation' in which the task is set by the teacher, or by using individual investigations in which each candidate pursues his or her own choice of assignment.

A similar set of mark descriptors is used for both Advanced Subsidiary and A2. These descriptors have been written to provide clear continuity from the assessment of Sc1 in GCSE Science. The difference in standard of Advanced Subsidiary and A2 is a product of the level of demand of the related scientific knowledge and understanding expected and the complexity and level of demand of the tasks set. Also, the mark descriptors for Skills **P** and **A** at A2 include synoptic elements.

Marks submitted for coursework assessment must have been generated from candidates' individual work. Group work is not suitable for assessment unless the work of the individual candidate can be quite clearly identified both by the teacher and the moderator. In some cases it is necessary for candidates to work collectively in order to collect sufficient data for analysis; in these circumstances, planning and implementing should not be assessed but the work of candidates may be assessed in analysing and evaluating their results, when they are working independently.

The submission of proposed coursework tasks for approval by OCR is not a requirement of the scheme. However, Centres wishing to obtain guidance on whether a coursework task is suitable, should send details to OCR. Guidance may also be obtained on the marks awarded to candidates' work prior to moderation by sending details of the task set, any background information and marked examples of candidates' work to OCR. Teachers are asked not to send large quantities of material.

A programme of INSET meetings is arranged to provide detailed guidance on coursework assessment. Details are circulated to Centres and a contact number for OCR Training and Customer Support is given in Section 10.

The length of time to be devoted to the assessment of experimental and investigative skills is entirely at the discretion of the teacher. However, it is anticipated that between 5 to 10 hours class time should be sufficient in each of AS and A2.

2.1 Standards at AS and A2

A similar set of assessment descriptors is used for the assessment of coursework in both AS and A2. (The mark schemes for the practical examinations are also based on these descriptors).

Assessments at AS and A2 are differentiated by the complexity of the tasks set and the contexts of the underlying scientific knowledge and understanding. In A2, candidates will be required to apply knowledge, understanding and skills from the AS and A2 parts of the specification in planning experimental work and in the analysis of results to reach conclusions.

At AS, experimental and investigative work is likely to be qualitative or require processing in a context that is familiar to candidates.

- **Planning** exercises, although novel, focus on apparatus and techniques which have previously been encountered, based on knowledge and understanding from a limited part of the AS specification.
- **Implementing** involves the manipulation of simple apparatus and the application of easily recognised safety procedures.
- **Analysing and concluding** involve simple data handling, reaching conclusions based on a limited part of the AS specification.
- **Evaluation** expects recognition of the main sources of error and direct methods for improving accuracy.

At A2, assessments will expect a greater level of sophistication and higher levels of skill.

- **Planning** exercises require research to provide a satisfactory solution to a problem, which can be addressed in more than one way. The underlying knowledge, understanding and skills are likely to be drawn from several different parts of the AS and A2 specifications.
- **Implementing** involves a detailed risk assessment and the careful use of sophisticated techniques or apparatus to obtain results that are precise and reliable.
- **Analysing and concluding** involve sophisticated data handling and the synthesis of several strands of evidence. In developing conclusions, candidates will have the opportunity to demonstrate their skills in drawing together principles and concepts from different parts of the AS and A2 specifications.
- **Evaluation** requires recognition of the key experimental limitations and other sources of error as well as an understanding of the methods that may be used to limit their effect. The evaluation is likely to draw together principles and concepts from different parts of the specification.

2.2 Assessment and Moderation

All coursework is marked by the teacher and internally standardised by the Centre. Marks are then submitted to OCR by a specified date, after which postal moderation takes place in accordance with OCR procedures. The purpose of moderation is to ensure that the standard for the award of marks in coursework is the same for each Centre, and that each teacher has applied the standards appropriately across the range of candidates within the Centre.

Coursework submissions should be clearly annotated by the Centre to support the marks awarded to the candidates.

The sample of work that is submitted to the Moderator for moderation must show how the marks have been awarded in relation to the marking criteria.

2.3 Minimum Coursework Requirements

If no work is submitted by a candidates for a coursework component, the candidate should be indicated as being absent from that component on the coursework mark sheets submitted to OCR. Any work submitted by a candidate should be assessed according to the mark descriptors and marking instructions and the appropriate mark awarded, which may be 0 (zero).

2.4 Authentication of Coursework

As with all coursework, the teacher must be able to verify that the work submitted for assessment is the candidate's own. Sufficient work must be carried out under direct supervision to allow the teacher to authenticate the coursework marks with confidence.

2.5 Special Arrangements for Coursework

For candidates who submit some coursework but are unable to complete the full assessment, or whose performance may be adversely affected through no fault of their own, teachers should consult the *Inter-Board Regulations and Guidance Booklet for Special Arrangements and Special Consideration*. In such cases, advice should be sought from OCR as early as possible during the course.

2.6 Differentiation

In coursework, differentiation is by task and by outcome. Candidates will undertake assignments which enable them to display positive achievement.

2.7 Some definitions

Hypothesis

An hypothesis is a model, based on scientific knowledge and understanding, proposed to explain a particular problem or a set of observations or measurements. Having devised an hypothesis, it is possible to make predictions based on it, and these can be tested by experiment.

The 'scientific method' is based on the idea that an hypothesis can be disproved by experiment (when predictions are found to be untrue) but can never be proved (since an experimenter may, in the future, disprove it). Thus, an hypothesis which is not disproved remains in place and, when it has general acceptance, may come to be called a theory or law.

Accuracy

The accuracy of an observation or measurement is the degree to which it approaches a notional 'true' value or outcome.

The accuracy of an observation or measurement depends on the experimental techniques used, the skill of the experimenter and the equipment (including measuring instruments) used. Removing or minimising sources of error improves accuracy and the degree of accuracy can be estimated by evaluating sources of error (either qualitatively or quantitatively as appropriate).

Precision is here taken as being that part of accuracy which is wholly in the hands of the experimenter. So, having devised an experimental technique and selected the apparatus, the experimenter may choose to take observations or measurements to different degrees of precision (or may do so through lack of skill or carelessness). Decisions about the precision with which observations or measurements are made may take into account the nature of the investigation and an assessment of the sources of error. There may be little point in measuring a quantity to four significant figures if other quantities are measured to two significant figures.

Reliability

Reliability is a measure of the confidence that can be placed in a set of observations or measurements. The closer a set of observations or measurements approaches to conformity with an underlying model, process, structure etc. (which may be known or unknown), the more reproducible it is likely to be.

If the underlying model, process or structure is known, or a suitable hypothesis can be drawn up, reliability can be judged by reference to this. So, for example, the distance between data points and the line of a graph may provide evidence of reliability and statistical techniques may be used to provide a quantitative assessment of reliability in such cases. If observations or measurements are replicated, then the closeness of the replicates provides another way of judging reliability.

The reliability of a set of observations or measurements depends on the number and accuracy of the individual observations or measurements. Replicating observations or measurements increases the reliability of the set.

Validity

The validity of a conclusion is a measure of the confidence that can be placed in it. The validity of a conclusion depends upon factors such as the range and reliability of the observations or measurements that underpin it, any assumptions made in developing hypotheses or planning the investigation, and the nature of the investigation itself.

A conclusion may relate to whether or not a proposed hypothesis can be rejected or accepted. In such cases statistical techniques may be used to place a value on the reliability of data by generating a probability that the data do conform with the hypothesis. Such techniques should be used where appropriate.

3 Introduction to each skill

The experimental and investigative skills to be assessed are:

Skill P Planning

Candidates should:

- identify and define the nature of a question or problem using available information and knowledge of physics;
- choose effective and safe procedures, selecting appropriate apparatus and materials and deciding the measurements and observations likely to generate useful and reliable results;

For candidates to be able to achieve the highest marks for this skill, tasks set must be sufficiently open-ended to allow more than one solution. The tasks must provide opportunities for candidates to gather information from a variety of sources (including perhaps text books, the Internet, preliminary experiments) to inform their plans and the scientific knowledge and understanding underpinning their work should be of a high standard.

For each task, it is suggested that candidates are asked to complete a preliminary plan which is assessed by the teacher, primarily to ensure that it is practicable and safe. The final mark awarded for planning should, however, take into account any additional work done during the implementation of the plan, i.e. to include any modifications or additions. Planning must be carried out individually and experience shows that candidates achieve higher marks if they carry out their plan.

Skill **P** may be assessed as part of a 'whole investigation' or with Skill **I** and/or Skills **A** and **E**.

At A2, there are additional statements that relate to synoptic assessment to take into account in the assessment. Thus, to achieve the highest marks, the tasks set must offer opportunities for candidates to make use, in their planning, of scientific knowledge and understanding from both AS and A2 modules.

Skill I Implementing

Candidates should:

- use apparatus and materials in an appropriate and safe way;
- carry out work in a methodical and organised way with due regard for safety.
- make and record detailed observations in a suitable way, and make measurements to an appropriate degree of precision, using IT where appropriate.
- respond to serious sources of systematic and random error by modifying procedures in order to generate results which are as accurate and reliable as allowed by the apparatus.

For candidates to achieve the highest marks for this skill, the techniques used should be familiar and well understood. The tasks set should involve techniques that require precision and skill and that make sufficient demands on a candidate's ability to manipulate apparatus.

Skill **I** may be assessed as part of a 'whole investigation', in isolation, or in combination with Skills **P** and/or **A**.

Skill A Analysing Evidence and Drawing Conclusions

Candidates should:

- communicate scientific information and ideas in appropriate ways, including tabulation, line graphs, histograms, continuous prose, annotated drawings and diagrams, using IT where appropriate.
- recognise and comment on trends and patterns in data;
- understand the concept of statistical significance;
- draw valid conclusions by applying scientific knowledge and understanding.

For candidates to achieve the highest marks in this skill, the tasks set must provide sufficient data or information to make the analysis demanding, and allow them to relate their results to scientific knowledge and understanding of a high standard.

Skill **A** may be assessed as part of a 'whole investigation', in isolation, or in combination with Skills **I** and/or **E**.

At A2, there are additional statements that relate to synoptic assessment to take into account in the assessment. Thus, to achieve the highest marks, the tasks set must offer opportunities for candidates to make use, in their analysis, of scientific knowledge and understanding from both AS and A2.

Skill E Evaluating Evidence and Procedures.

Candidates should:

- assess the reliability and precision of experimental data and the conclusions drawn from it;
- evaluate the techniques used in the experimental activity, recognising their limitations.

For candidates to achieve the highest marks in this skill it is advisable that they either carry out the investigation themselves or have seen the techniques demonstrated. Only in this way will they be able to evaluate experimental procedures effectively. The tasks set should be sufficiently complex to allow detailed analysis and the data or information collected should permit evaluation of error and reliability. There should also be the opportunity to suggest realistic changes to the procedures used that would improve the quality of the results.

Skill **E** is best assessed as part of a 'whole investigation', or together with Skill **A**, in which case the experimental procedure should have been carried out by the candidates themselves, or demonstrated to them. Where the experimental procedures are such that individual working is not possible, candidates could carry out the investigation working in groups but then be assessed for Skills **A** and **E** on their individual work.

4 Notes for Guidance on Coursework Submission and Assessment

These notes are intended to provide guidance for teachers in assessing experimental and investigative skills, but should not exert an undue influence on the methods of teaching nor provide a constraint on the practical work undertaken by candidates. It is **not** expected that all of the practical work undertaken by candidates would be appropriate for assessment.

It is expected that candidates will have had opportunities to acquire experience and develop the relevant skills before assessment takes place.

4.1 The Demand of an Activity

The demand of an activity is an important feature of the assessment. From the bottom to the top of the mark range in a skill area the activity should involve increasing demands of associated scientific knowledge and understanding, manipulation, precision and accuracy and complexity.

The difference in standard of Advanced Subsidiary and A2 is a product of the level of demand of the related scientific knowledge and understanding, together with the complexity and level of demand of the tasks set. In A2, candidates will be required to apply knowledge, understanding and skills from the AS and A2 parts of the specification in planning experimental work and in the evaluation of data (synoptic assessment).

Teachers should appreciate that the choice of an activity that is comparatively undemanding (primarily in terms of the level of the scientific knowledge and understanding that can be linked to the activity, and in the range/complexity of the equipment/techniques used) may prevent access to the highest marks.

Teachers should be aware of this feature of the assessment so that, when considering the award of higher marks, the activity should require a sophisticated approach and/or complex treatment. Higher marks must not be awarded for work that is simplistic or trivial.

One of the factors that determine the demand of an activity is the level of guidance given to candidates. The use of a highly structured worksheet, for example, will reduce the number of decisions and judgements required by the candidate and will limit the range of marks available.

4.2 Marking Candidates' Work

A similar set of mark descriptors is used for Advanced Subsidiary and A2. The descriptors should be used to make a judgement as to which mark best fits a candidate's performance.

The descriptors have been written to provide clear continuity from the assessment of Sc1 for GCSE. This should ensure an effective continuation of the development of candidates' skills from GCSE to Advanced Subsidiary GCE and Advanced GCE.

The mark descriptors within a skill area have been written to be hierarchical. Thus, in marking a piece of work, the descriptors for the lowest defined mark level should be considered first and only if there is a good match should the descriptors for the next level up be considered. Therefore, if a teacher is considering awarding a high mark for a piece of work, the work must have demonstrated a good match to all the lower mark descriptors.

For each skill, the scheme allows the award of intermediate marks (between the defined mark levels). An intermediate mark may be awarded when the work of a candidate exceeds the requirements of a defined mark level but does not meet the requirements of the next higher defined mark level sufficiently to justify its award. Thus, an intermediate mark could be awarded if the work meets only one of the two descriptors at the higher defined mark level, or provides a partial match to both descriptors, or provides a complete match to one and a partial match to the other.

In Skills **P** and **A**, a mark above the highest defined mark level should be awarded for work which meets all the requirements of the descriptors for the highest defined mark level, and is judged to be of exceptional merit in terms of originality, depth, flair, or in the use of novel or innovative methods.

A mark of zero should be awarded where there has been an attempt to address the skill but the work does not meet the requirements of the lowest defined mark level.

The marks awarded should be based on both the final written work and on the teacher's knowledge of the work carried out by the candidate. In assigning a mark, attention should be paid to the extent of any guidance needed by, or given to, the candidate.

4.3 Synoptic Assessment

Synoptic assessment involves the explicit drawing together of knowledge, understanding and skills learned in different parts of the Advanced GCE course. Assessment Objective AO4 relates specifically to synoptic assessment and marks from Component 02 of Unit 2826, contribute to the assessment of AO4.

During experimental and investigative work, synoptic assessment:

- allows candidates to apply knowledge and understanding of principles and concepts from different parts of the specification in planning experimental work and in the analysis and evaluation of data;
- allows candidates to apply skills and techniques learned during the course.

All practical work assessed internally by Centres for the **A2** Unit 2826, Component 02 should draw on the range of experience that the candidate has acquired during the AS and A2 courses. It is particularly important that an exercise used to assess planning skills should involve an element of research which goes beyond the repetition of an experiment that simply reflects the use of ideas or techniques met within the module currently being studied. Likewise, an assessment involving analysing evidence and drawing conclusions must require a candidate to use knowledge and understanding acquired outside the confines of a standard experiment recently practised. During the process of moderation, evidence will be sought that such breadth has been achieved.

The assessment descriptors for the skills of Planning (**P**) and Analysing Evidence and Drawing Conclusions (**A**), include statements that relate specifically to synoptic assessment. These are shown in bold and should be applied only when assessing A2 work. Thus, in A2, a candidate will not be able to achieve more than 2 marks in each of Skills **P** and **A** without demonstrating aspects of synoptic assessment. Candidates will also bring to the assessment of Skill **I** (Implementing) their experience of practical and investigative work from throughout the course. In Skill **E** (Evaluating Evidence and Procedures), aspects of Skills **P** and **A** are evaluated. Overall, in A2, approximately 15 of the 30 available marks can thus be identified as contributing to an assessment of AO4 (synoptic assessment).

4.4 Quality of Written Communication

Coursework must include an assessment of candidates' quality of written communication. At Level 3 within the Key Skill of Communication, candidates are required to:

- select and use a form and style of writing that is appropriate to the purpose and complex subject matter;
- organise relevant information clearly and coherently, using specialist vocabulary when appropriate;
- ensure the text is legible and that spelling, grammar and punctuation are accurate, so that the meaning is clear.

The mark descriptors for Skills **P** and **A** have been written to include these aspects, and these skills carry an additional mark each in recognition of this.

4.5 Annotation of Candidates' Work

Each piece of assessed coursework must be annotated to show how the marks have been awarded in relation to the relevant skills.

The writing of comments on candidates' work can provide a means of dialogue and feedback between teacher and candidate, and a means of communication between teachers during internal standardisation of coursework. The main purpose of annotating candidates' coursework should be, however, to provide a means of communication between the teacher and the Moderator, showing where marks have been awarded and why. The sample of work, which is submitted for moderation, **must** show how the marks have been awarded in relation to the marking criteria.

Annotations should be made at appropriate points in the margins of the text. The annotations should indicate both where achievement for a particular skill has been recognised, and where the mark has been awarded. It is suggested that the minimum which is necessary is that the 'shorthand' mark descriptors (for example, **P**.5a, **I**.3b) should be written at the point in the text where it is judged that the work has met the descriptors concerned.

For Skill **I**, Implementing, more detail is necessary and the Moderator will require evidence concerning candidates' use of practical techniques and safe working practices. This evidence could take the form of checklists or written notes.

4.6 Health and Safety

In UK law, health and safety is the responsibility of the employer. For most establishments entering candidates for Advanced Subsidiary GCE and Advanced GCE this is likely to be the education authority or the governing body. Employees, i.e. teachers and lecturers, have a duty to co-operate with their employer on health and safety matters.

Various regulations, but especially the COSHH Regulations 1996 and the Management of Health and Safety at Work Regulations 1992, require that before any activity involving a hazardous procedure or harmful micro-organisms is carried out, or hazardous chemicals are used or made, the employer must provide a risk assessment. A useful summary of the requirements for risk assessment in school or college science can be found in Chapter 4 of *Safety in Science Education* (see below). For members, the CLEAPSS guide, *Managing Risk Assessment in Science* offers detailed advice.

Most education employers have adopted a range of nationally available publications as the basis for their Model Risk Assessments. Those commonly used include:

Safety in Science Education, DfEE, 1996, HMSO, ISBN 0 11 270915 X;

Safeguards in the School Laboratory, 10th edition, 1996, ASE ISBN 0 86357 250 2;

Hazcards, 1995, CLEAPSS School Science Service*;

Laboratory Handbook, 1988-97, CLEAPSS School Science Service*;

Topics in Safety, 2nd edition, 1988, ASE ISBN 0 86357 104 2;

Safety Reprints, 1996 edition, ASE ISBN 0 86357 246 4.

* Note that CLEAPSS publications are only available to members or associates.

(Other publications have sometimes been suggested, e.g. the SSERC *Hazardous Chemicals Manual* or the DES *Microbiology, an HMI Guide for Schools and FE,* but both of these are now out of print).

Where an employer has adopted these or other publications as the basis of their model risk assessments, an individual school or college then has to review them, to see if there is a need to modify or adapt them in some way to suit the particular conditions of the establishment. Such adaptations might include a reduced scale of working, deciding that the fume cupboard provision was inadequate, or that the skills of the candidates were insufficient to attempt particular activities safely. The significant findings of such risk assessment should then be recorded, for example on schemes of work, published teachers guides, work sheets, etc. There is no specific legal requirement that detailed risk assessment forms should be completed, although a few employers require this.

Where project work or individual investigations, sometimes linked to work-related activities, are included in specifications these may well lead to the use of novel procedures, chemicals or micro-organisms, which are not covered by the employer's model risk assessments. The employer should have given guidance on how to proceed in such cases. Often, for members, it will involve contacting the CLEAPSS School Science Service (or, in Scotland, SSERC).

When candidates are planning their own practical activities, whether in project work or for more routine situations, the teacher or lecturer has a duty to check the plans before practical work starts and to monitor the activity as it proceeds.

5 Mark Descriptors for Experimental and Investigative Skills

In defining the various mark descriptors, it is recognised that practical tasks vary widely, both in the experimental procedures used and in the nature of the observations and measurements which may be made by the candidate. The mark descriptors within each defined level are intended to provide guidance to teachers on how to recognise levels of achievement. It is acknowledged that the balance between the statements provided for a particular level of performance will vary with the nature of the activity. Whilst both statements for a particular level must be considered in awarding the marks, it is clear that teachers will need to judge for themselves the relative weightings they attach to each of the statements.

Both statements at a defined level must be satisfied in order that the mark for this level is awarded. All descriptors for lower defined levels must be satisfied before a higher mark is awarded. From the bottom to the top of the mark range the activity should involve increasing demands of related scientific knowledge and understanding, manipulation, precision, accuracy and complexity.

Skill P - Planning **Total 8**

Mark	Descriptor	
		The candidate:
1	**P.1a**	develops a question or problem in simple terms and plans a fair test or an appropriate practical procedure, making a prediction where relevant.
	P.1b	chooses appropriate equipment.
2		
3	**P.3a**	develops a question or problem using scientific knowledge and understanding **drawn from more than one module of the specification**; identifies the key factors to vary, control or take account of.
	P.3b	decides on a suitable number and range of observations and/or measurements to be made.
4		
5	**P.5a**	uses detailed scientific knowledge and understanding **drawn from more than one module of the specification** and information from preliminary work or a secondary source to plan an appropriate strategy, taking into account the need for safe working and justifying any prediction made;
	P.5b	describes a strategy, including choice of equipment, which takes into account the need to produce precise and reliable evidence; produces a clear account and uses specialist vocabulary appropriately.
6		
7	**P.7a**	retrieves and evaluates information from a variety of sources, and uses it to develop a strategy which is well structured, logical and linked coherently to underlying scientific knowledge and understanding **drawn from different parts of the AS and A2 specification**; uses spelling, punctuation and grammar accurately.
	P.7b	justifies the strategy developed, including the choice of equipment, in terms of the need for precision and reliability.
8		

The statements in bold represent additional requirements when assessing A2 work; they are not to be used at AS.

Skill I - Implementing **Total 7**

Mark **Descriptor**

The candidate:

1	**I.1a**	demonstrates competence in simple techniques and an awareness of the need for safe working.
	I.1b	makes and records observations and/or measurements which are adequate for the activity.
2		
3	**I.3a**	demonstrates competence in practised techniques and is able to manipulate materials and equipment with precision.
	I.3b	makes systematic and accurate observations and/or measurements which are recorded clearly and accurately.
4		
5	**I.5a**	demonstrates competence and confidence in the use of practical techniques; adopts safe working practices throughout.
	I.5b	makes observations and/or measurements with precision and skill; records observations and/or measurements in an appropriate format; recognises sources of systematic and random error which could affect accuracy and reliability of results.
6		
7	**I.7a**	demonstrates skilful and proficient use of all techniques and equipment.
	I.7b	makes and records all observations and/or measurements in appropriate detail and to the degree of precision permitted by the techniques or apparatus; responds to serious sources of systematic and random error by modifying procedures where appropriate.

Skill A - Analysing Evidence & Drawing Conclusions **Total 8**

Mark	Descriptor	
	The candidate:	
1	**A.1a**	carries out some simple processing of the evidence collected from experimental work.
	A.1b	identifies trends or patterns in the evidence and draws simple conclusions.
2		
3	**A.3a**	processes and presents evidence gathered from experimental work including, where appropriate, the use of appropriate graphical and/or numerical techniques.
	A.3b	links conclusions drawn from processed evidence with the associated scientific knowledge and understanding **drawn from more than one area of the specification**.
4		
5	**A.5a**	carries out detailed processing of evidence and analysis including, where appropriate, the use of advanced numerical techniques such as statistics, the plotting of intercepts or the calculation of gradients.
	A.5b	draws conclusions which are consistent with the processed evidence and links these with detailed scientific knowledge and understanding **drawn from more than one module of the specification**; produces a clear account which uses specialist vocabulary appropriately.
6		
7	**A.7a**	where appropriate, uses detailed scientific knowledge and understanding **drawn from different parts of the AS and A2 specification** to make deductions from the processed evidence, with due regard to nomenclature, terminology and the use of significant figures (where relevant).
	A.7b	draws conclusions which are well structured, appropriate, comprehensive and concise, and which are coherently linked to underlying scientific knowledge and understanding **drawn from different parts of the AS and A2 specification**; uses spelling, punctuation and grammar accurately.
8		

The statements in bold represent additional requirements when assessing A2 work; they are not to be used at AS.

Skill E - Evaluating Evidence and Procedures **Total 7**

Mark	Descriptor	
	The candidate:	
1	**E.1a**	makes relevant comments on the suitability of the experimental procedures.
	E.1b	recognises any anomalous results.
2		
3	**E.3a**	recognises how limitations in the experimental procedures and/or strategy may result in sources of error.
	E.3b	comments on the accuracy of the observations and/or measurements, suggesting reasons for any anomalous results.
4		
5	**E.5a**	indicates the significant limitations of the experimental procedures and/or strategy and suggests how they could be improved.
	E.5b	comments on the reliability of the evidence and evaluates the main sources of error.
6		
7	**E.7a**	justifies proposed improvements to the experimental procedures and/or strategy in terms of increasing the reliability of the evidence and minimising significant sources of error.
	E.7b	assesses the significance of the uncertainties in the evidence in terms of their effect on the validity of the final conclusions drawn.

6 Frequently asked questions (FAQs)

1. Can a single coursework exercise be used to assess more than one skill?

   Yes, skills may be assessed separately or in combination. All four skills can be tested at any one time, in a 'whole investigation'. However, it is the responsibility of candidates and their centres to ensure that it is clear where each skill is being covered. This should be achieved by the use of titles and sub-titles.

2. Is it advisable to test more than one skill in any one exercise?

   *This depends very much on the nature of the task and how it is set up. Generally, candidates achieve higher marks for planning if they are able to perform their investigation since this gives them opportunities to revise the plan in the light of experience. Thus, Skills **P** and **I** are often assessed together. Similarly, candidates who have not planned and carried out an investigation (or at least seen it demonstrated) will find it difficult to evaluate the investigation. Skill **E** may, therefore, be better assessed in a whole investigation. If all four skills are to be tested in one 'whole investigation', it is essential that it is clear to Moderators, by means of titles, subtitles, teachers' comments, etc., which are being tested where.*

3. Is there any size or word limit on coursework submissions?

   No, but there is absolutely nothing to be gained by submitting particularly large volumes of work for each assessment, especially where the same technique is repeated several times. Moderators will be looking at the quality of the work rather than the quantity and clear evidence that candidates have achieved the criteria listed under each skill.

4. Do Centres need to show evidence of marking on candidate's work?

   *Yes; the minimum requirement is that the 'shorthand' mark descriptors (e.g. **P**.3b or **A**.5a) are written in the margin of the script at the point where the work has met the descriptors concerned. However, the more comments clearly written on submitted work, the easier it is for Moderators to judge whether candidates have been fairly assessed.*

5. Do Centres need to submit copies of the worksheets, exercises and resources given to students?

   Yes; Moderators need to know exactly what candidates were asked to do, and what help they received.

6. Do Centres need to submit mark schemes?

   *The general descriptors given in the specification (and in Section 5) may be used directly by Centres to mark candidates' work. However, Centres may choose to develop specific sets of descriptors for particular tasks, to allow consistency of marking from year to year, and from teacher to teacher. If such 'contextualised' descriptors are used, they must be very closely based on the standard descriptors and they must be sent to the moderator with the sample of work. It should be noted that the moderator will mark using the general set of descriptors (given in the specification), to ensure that the standard of work is the same from centre to centre. For Skill **I**, teachers should provide details of the aspects of the work that were scrutinised, in the form of check lists or written notes.*

7. Some candidates find coursework very difficult. What advice can you offer which will increase candidates' prospects of achieving good marks?

   It is clearly important that candidates are taught the skills and given opportunities to practice, before being assessed. Candidates may find it helpful if staff go through a worked *exemplar showing how they themselves would tackle a particular topic, provided that candidates are not allowed to produce work on the same topic for submission. Candidates should be made aware of the descriptors used to assess their work, so that they can ensure that all aspects of the descriptors are addressed. Worksheets clearly give considerable assistance to candidates but, if they are too specific, the help which they give may prevent candidates making choices and so limit access to the highest marks, so they should be used carefully.*

8. Do all candidates have to do completely different topics for Skill **P** assessments?

   No; a single task may be set by the teacher for all candidates, but they must work individually.

9. In Skill **P** work, do candidates have to put their plans into action and examine the results in order to evaluate and modify their plans?

   No, but candidates who do not have the opportunity to carry out their plans and modify them in the light of experience will be at a disadvantage.

10. I am having trouble deciding whether my exercises properly address the demands of the skills listed in the specification. What advice is available?

    A proposed task may be submitted to OCR and a response on its suitability will be provided. INSET courses are provided each year; details are sent to Centres, and a contact address for the Training and Customer Support section is also given in Section 10.

11. None of my candidates have produced work that is as good as the best exemplars in this guide. Does this mean they cannot achieve full marks for their assessments?

    No. As long as candidates' work meets all the mark descriptors, including the top band, there is no reason why full marks should not be awarded. There can be a big range of performances within the top band. If you have one or two brilliant students, do not let this persuade you that those who are only 'very good' must be worth less than full marks. Conversely, if all your candidates are of more limited ability, do not be misled into giving the best of them full marks.

12. Can candidates use the Internet during their investigations?

    *Yes; there is some excellent material available and the highest mark descriptors for Skill **P** require candidates to draw together material from several sources. All URLs should be listed (with any other sources) in a bibliography. It should be noted that unless this information is processed or modified in some way and used in the development of the strategy, it is unlikely to be worthy of credit.*

13. Will candidates improve their chances of achieving high marks by making extensive use of Information and Communication Technology in their reports?

    Computer generated material is not in itself worth any more marks than hand-written work. However, if the use of ICT enables the mark descriptors for any of the skills to be more effectively addressed, then candidates could gain extra credit. It should be noted that many graph-plotting packages, if not used expertly, may not produce the most appropriate graphs.

14. Must there be hand drawn graphs?

    No, but computer generated material must be appropriate and not just rather simplistic bar charts etc.

15. Does all coursework have to be carried out under the direct supervision of the teacher?

    No; in order to meet the requirements of the descriptors, particularly for Skills P and A, candidates will need to carry out research which may require the use of library facilities, the Internet etc.. Also, it may not be possible to devote sufficient time in the laboratory/classroom to allow candidates to write up their work. However, sufficient work must be completed under direct supervision to allow the teacher to authenticate the marks awarded, and this is left to the discretion of the Centre.

16. How much help can I give students with their coursework?

    This is a difficult question to answer. In general terms, direct help in the form of suggesting to a student how to carry out an investigation, or how to interpret the results, is unacceptable, while it is acceptable to draw the attention of the student to aspects of the assessment descriptors that he or she has not addressed.

    In some circumstances it may be necessary to give direct help to students, for example to ensure that they are working safely or to get them through a difficulty. Such help should be taken into account in the award of marks and details must be provided to the moderator.

    If students are to be given the opportunity to choose their own coursework tasks, guidance should be given by the teacher to ensure that that the tasks are of appropriate demand and likely to generate results capable of analysis. In a whole investigation, or if students are to be asked to carry out an investigation that they have planned, it is suggested that the draft plans are submitted to the teacher for an initial assessment to be made of the suitability of the strategy. Such assistance is acceptable without penalty provided that candidates are not given direct guidance about what to do.

17. Can I take in the work of my students, mark it, and then give it back to them for any errors to be corrected before taking it in again for a final mark to be awarded?

    *No; once the work has been handed in for marking, the marks awarded should stand. Assistance can be given to students while they are carrying out their work provided that it is limited to the identification of aspects of the assessment descriptors that have not been addressed. However, it is suggested that work for Skill **P** should be collected in for an assessment of its suitability to be made before any practical work has been carried out, though Skill **P** should not be marked until the whole assessment has been completed.*

18. Can I use worksheets to set the tasks that my students are to carry out?

Yes; worksheets are very helpful, particularly if students are not being asked to plan the investigation themselves. However, a worksheet used to set a planning task which gives too much guidance as to the method to be used or the number of readings to be taken etc. may reduce the level of demand of the task and so limit the marks which can be awarded to candidates.

19. Where more than one skill is being assessed on a single piece of work, for example in a whole investigation, is it acceptable for the skills to be given widely differing marks?

If the level of demand of the task is limited, this will have an effect on all four skill areas. In this case the marks awarded for Skill ***P*** *are likely to relate closely to the other skill areas since it is unlikely that a poor plan will generate a good set of data and that such data can be analysed or evaluated to generate high marks. However, a good plan may produce good results but the analysis and/or evaluation may be poor. Where marks do differ widely, they should be scrutinised carefully and if a teacher feels that widely differing marks can be justified, information must be provided to the moderator to support the marks awarded.*

20. Can work completed in the AS year be submitted for assessment for A2?

Yes; though the work submitted for AS must be set in the context of AS modules and work for A2 must be in the context of A2 modules. This means that candidates will need to draw on the knowledge and understanding of the appropriate modules in order to plan and/or analyse the experiment/investigation. However, there are some topics that relate to work in both AS and A2 but teachers should be aware of the need to provide tasks of appropriate demand for A2.

21. If Units 2843 or 2846 are re-taken, can the coursework marks be carried forward?

Yes; an entry for one of these units is for the written paper and the coursework component. Entry options for these units are provided for coursework marks to be carried forward, but it should be noted that marks for the written paper may ***not*** *be carried forward.*

7 Suggested tasks

The following lists a number of topics, which may be used for the assessment of Practical Skills in AS and A2. It should be appreciated that the formulation of the task, based on each topic, determines which skills may be assessed.

AS

The effect of temperature on the bounce of a squash ball.

The effect of pressure of the air, in a football, on the bounce of the football.

Efficiency of thermal insulation.

Spring constant springs in series and parallel.

Characteristics of a bead thermistor thermometer.

Measurement of the acceleration of free fall.

A2

Efficiency of an electric motor.

Forced oscillations and damping of a mechanical system.

Specific heat capacity determination.

Use of a Hall probe.

Variation of resistance of an LDR with light intensity.

The effect on the smoothing of the load due to the capacitance of smoothing capacitors.

Resistive damping in an LC circuit.

Some very straightforward examples are shown below. They are full investigations covering all 4 assessment areas and have been chosen deliberately to emphasise that complex experiments are not needed to gain high marks.

It must be remembered that excessive time spent on coursework will not gain more than the 20% of the marks available for coursework in AS or in the full Advanced GCE. Each skill therefore is worth around 5% of the total.

The comments at each descriptor are what might reasonably be expected from the candidate and in turn might be used as a marking plan.

Example 1: The Deformation of Plastic Carrier Bags

A simple experiment where a force is applied to a specimen of carrier bag material and the extension measured.

Skill P

P.1a	Sets out simple force against extension experiment
P.1b	States what equipment will be used
P.3a	Looks at key factors, width, thickness, manufacturer/what plastic
P.3b	Repeats, comparability. Simple test to establish range
P.5a	Some theoretical background, text book information, safety tests, prediction
P.5b	Choice of equipment, how do you measure thickness? Precision available?
P.7a	Secondary sources CD-ROM, chemistry, internet, excellent quality of written communication throughout
P.7b	Loads to set extension or measures extension for each loading, good choice of plan with some backup
P.8	Mention of strain energy, molecular deformation, polymers, and comparison with metals. Problems with measuring e.g. compression of sample. (Some of these areas would be enough to award this top level)

Skill I (annotated marking is essential here)

I.1a	Simple measurements with safety
I.1b	Can manage working at level where some sensible records can be made
I.3a	Good technique e.g. “no parallax” observations, consistent methods
I.3b	Clear records, starts to tabulate results, consistent accuracy shown
I.5a	Real confidence in handling equipment, some thought given to sensible support system for top of sample, good safe handling e.g. no tipping of laboratory stand
I.5b	Tabulated results with repeats for anomalous readings, possible errors identified
I.7a	Skilful use of all equipment
I.7b	Consistent precision in observation, zero errors? Changes plan if needed

Skill A

A.1a Can change mass to weight

A.1b Identifies that extension increases with force applied

A.3a Averages results and then draws sensible graph with reasonable scales

A.3b Suggests proportionality and spots changes in gradient, uses terms like elastic, plastic, yielding in correct context

A.5a Good graphs with correctly marked axes and scales, identifies points at which changes in deformation occur

A.5b Some conclusions drawn perhaps between different manufacturers, uses area beneath curve for some mention of strain energy

A.7a Correct use of significant figures throughout, looks for similarities between samples and compares perhaps with metals or rubber-band extensions

A.7b Really clear conclusions, discusses on molecular level how these changes might be explained, excellent quality of written communication throughout

A.8 Relates conclusions to actual use of materials, talks about reinforcement of handles when looking at working loads. From secondary source perhaps considers costs versus carrying ability. (Some of these areas would be enough to award this top level)

Skill E

E.1a Was the experiment as performed suitable for the investigation?

E.1b Spurious readings noted and checked

E.3a Spots limitations in technique and makes some comment on their effect on the final conclusions e.g. measurement of thickness

E.3b Accuracy of observations noted by comment, error bars or percentage of observed value

E.5a Can any improvements be made e.g. in holding sample in clamp, attaching weights, cutting samples consistently?

E.5b Evaluates errors e.g. max/min gradients, reliability of yield points

E.7a Improvements suggested justified in terms of increased reliability of conclusions e.g. spreading of suspension point to give even loading of samples, maybe a little test to show the effect of snags when cutting samples

E.7b Bringing error assessment through to final conclusions with numerical effect on results shown. Does 10% uncertainty effect our final conclusion? Would it be advantageous to achieve greater precision when considering the use to which the work might be put?

Example 2: S.H.M. and Damping using a Simple Pendulum

A very simple experiment using an analogue stopwatch to time a given number of swings with thin cardboard shapes to achieve damping.

Skill P

P1.a Simple setting out of basic idea

P1.b Lists equipment to be used without any real comment

P.3a Some SHM theory showing key factors to consider, what effect will the shape of the cards have?

P.3b Sets out observations needed states number of swings to be measured and how to measure consistently

P.5a Some testing of proposals, considers safety, makes some predictions following on from simple theory

P.5b Choice of equipment considered e.g. digital watch, light gates, use of ICT. Considers more swings to be timed the shorter the length of the pendulum. Need for repeats etc.

P.7a Secondary sources, derivation of equations and not just a decaying amplitude measurement, excellent quality of written communication throughout

P.7b Justification of plan based on available equipment with some numerical analysis on increased numbers of swings etc

P.8 Talks about how to time accurately, reaction times, beating in, how to measure decay constant. (Some of these areas would be enough to award this top level)

Skill I (annotated marking is essential here)

I.1a Simple timing with safety

I.1b Working at a level where some sensible data is obtained

I.3a Good working, how to grip string in clamp stand for consistent working

I.3b Clear recording of data with some tabulation of results

I.5a Really competent technique shown with obvious regard to safety

I.5b Tabulated results with consistent precision, spots problems of rotation of cards during swing etc

I.7a Excellent handling of all apparatus used

I.7b Works at maximum precision capable with equipment in use, modifies experimental procedure if needed e.g. changes shape of card damper to offer consistent results

Skill A

A.1a Simple processing of results, maybe single calculations of predicted conclusion

A.1b Spots trend that period increases with length of pendulum and makes simplistic comments

A.3a Calculates average period, plots graph of square of period against length with reasonable precision

A.3b Draws attention to similar effects, corks bobbing, springs, oil damping etc

A.5a Good graph with well-marked axes, large scales, intercepts and gradients considered

A.5b Draws conclusions well with good consideration of damping, including some numerical analysis

A.7a Consistent use of significant figures with sound knowledge shown including calculation of damping constant by plotting log graph

A.7b Sensible, accurate conclusions drawn showing good knowledge of theoretical side of the experiment, excellent quality of written communication throughout

A.8 Uses for damping in car suspensions, range of everyday instants of damped SHM, decay in electrical circuits involving capacitor discharges. Effect of different shapes on damping of pendulum, is it just area? (Some of these areas would be enough to award this top level)

Skill E

E.1a Was experiment suitable?

E.1b Spurious readings spotted if present

E.3a Limitations in techniques commented upon e.g. shapes of cardboard dampers, wind

E.3b Notes accuracy of observations, some numerical analysis, error bars etc. Reasons for anomalous observations suggested

E.5a What improvements might be made in the techniques involved e.g. ICT instead of manual timing (does not need to be constrained by lack of available apparatus)

E.5b Numerical evaluation of error with max/min gradients, uncertainty in intercepts etc. and comments on how reliable the evidence appears to be

E.7a Improvements outlined in terms of the way they would increase reliability of procedures e.g. maybe a small test of the effect of wind on the results

E.7b Real assessment of errors brought through to final result, less than 1% uncertainty in damping constant? How much faith could be put into these figures if capital expenditure was involved in a project based in this area?

Note: The above are marked at A2 level.

The Simple Pendulum could easily be used at AS to establish a value for “g” with comparisons being made with other methods like dropping a weight through light gates or ticker timer or the use of strobe photography.

SOME OTHER INVESTIGATIONS

Whilst coursework should be based on the specification, there is no reason why other areas of interest should be excluded.

It is the quality of the Physics used that is important. Some of the full investigations below could help to stimulate candidates' interests outside the confines of the specification.

- Sweet spot of a tennis racket: - Is there one? Is one racket better than another?
- Viscous drag on golf balls: - Do the dimple patterns have any effect? Do different surface coatings make a difference?
- Bounce of squash balls: - What do those dots mean?
- Wear properties of floor coverings: - Does "Duralay" last longer than lino?
- Diffraction of sound or microwaves: - Does the size of the doorway have much effect?
- Which "AA" cell gives the best value for money? Are some cells really better for walkman use than others, if you work out the power per penny?
- Efficiency of sand traps in stopping vehicles: - How does speed of entry effect distance? Size of tyres? Mass of vehicle?
- The effect of lubrication on friction: - comparison of viscosity of different oils and their proposed uses. Try the impact test for heavier oils.
- What is the best size of pipe to transfer liquids? High pressure, small bore or low pressure, large bore? Economic considerations for, say, a Water Company?
- Do papers of the same density have different strengths? If so does the texture or colour have any influence?
- Effect of heat on mechanical properties of steel: - Three samples of thin rod- slow cooling, quenching and tempering (quenching and gentle heat), then bend until it fractures.
- Stokes Law with various sized tubes: - What happens when ball bearing is of similar diameter to tube? Where does the problem have so little an effect that it could be neglected and the normal experiment can be run?

Note: This should not be considered as a list of experiments to follow but simply as a few ideas that work.

8 Coursework forms

OCR is producing a Coursework Administration Pack for each specification containing coursework. This pack will contain all relevant forms and instructions for completion.

9 OCR Contacts

Subject Officer for Advanced GCE Physics A (specification queries only)

OCR
1 Hills Road
Cambridge
CB1 2EU

Training and Customer Support (INSET enquiries)

OCR
Mill Wharf
Mill Street
Birmingham
B6 4BU

Tel: 0121 628 2950
Fax: 0121 628 2940
Email: tcs@ocr.org.uk

OCR Information Bureau (other queries)

Tel: 01223 553998
Email: helpdesk@ocr.org.uk

Appendix 1: Exemplar Investigation

Investigation : Terminal Velocity of a Falling Object

Marks Awarded

Skill P Planning — Total 8

1/2	P.1a	√	Good theory, excellent analysis of problem and identification of
	P.1b	√	key variables
3/4	P.3a	√	Preliminary experiment carried out to assess suitability of method
	P.3b	√	(this alone could nearly stand as the full investigation)
5/6	P.5a	√	Multiple sources of information considered
	P.5b	√	
7/8	P.7a	√	
	P.7b	√	
Total		8	

Skill I Implementing — Total 7

1/2	I.1a	√	Clear table of results with repeats
	I.1b	√	Consistent accuracy used throughout experiment (IT use gives
3/4	I.3a	√	impression of far too great a precision for the techniques involved
	I.3b	√	but this is covered in later work on uncertainties)
5/6	I.5a	√	Proficient use of equipment
	I.5b	√	
7	I.7a	√	
	I.7b	√	
Total		7	

Skill A Analysing Evidence and Drawing Conclusions — Total 8

1/2	A.1a	√	Good graphical work with use of IT
	A.1b	√	Detailed numerical analysis of results
3/4	A.3a	√	Excellent conclusions drawn
	A.3b	√	
5/6	A.5a	√	
	A.5b	√	
7/8	A.7a	√	
	A.7b	√	
Total		8	

Skill E Evaluating Evidence and Procedures — Total 7

1/2	E.1a	√	Massive amount of good work on reliability of observations
	E.1b	√	and detailed analysis of improvements that can be made
3/4	E.3a	√	
	E.3b	√	
5/6	E.5a	√	
	E.5b	√	
7	E.7a	√	
	E.7b	√	
Total		7	

TOTAL 30/30

Contents

Planning

Implementing

Concluding

Abstract

I investigated the effect of changing the mass of an object falling through a liquid. I predicted that as the mass of the bob falling increased the terminal velocity of the bob will also increase. My results supported this prediction. However a linear relationship was not apparent. I therefore decided to extend my experiment to see if the mass of the falling object was proportional to the terminal velocity value squared. I modified my experiment by changing the counterweight mass rather than the mass of the falling object. This enabled me to decrease the chance of turbulent flow occurring. f(a)

Overall my results showed that the mass of the falling object was more likely to be proportional to the terminal velocity value squared especially when larger masses were used as the falling object (or when a smaller counterweight was used to oppose the motion of the falling object) as this caused a greater value for the terminal velocity. ✓

AN INVESTIGATION OF TERMINAL VELOCITY

Background knowledge

When an object falls through a liquid or gas, the fluid offers resistance to the motion. In general, the way in which this resistance changes with velocity is complex, but at low speeds, it can be assumed the resistive force, F is directly proportional to velocity v, i.e:

$$F = -kv$$

when k is a constant and depends on the viscosity of the fluid and the size and the texture of the bob. It is negative as the resistive force is opposing the motion of the bob.
A falling object through a fluid also experiences an upthrust.

An equation of motion from Newton's second law is produced:

Resultant force = Mg - U - kv.
Where the resultant force = mass x acceleration or mass x $\frac{dv}{dt}$

However in my experimental set up I needed to use a counterweight (this can be seen later in the method set up) to oppose the motion of the falling object. hence the above equation becomes:

$$(M + m)\frac{dv}{dt} = Mg - mg - U - kv$$

when U = upthrust, M = mass of the falling object and m = the mass of the counterweight opposing the motion of the object.
At the terminal velocity of a falling object there is no acceleration hence dv/dt = 0. therefore this implies that:

$$kv_t = Mg - mg - U$$

Therefore I can investigate how well my system fits the theoretical equation.

<u>Terminal velocity</u>

Definitions:
1. In water or another viscous medium a body will accelerate downwards only until the upthrust and the frictional resistance of the medium exert an opposing force equal to the force of gravity. The body will then fall with a constant velocity called the TERMINAL VELOCITY.

The forces acting on a falling mass are:

Upthrust and viscous drag upwards = U + kv

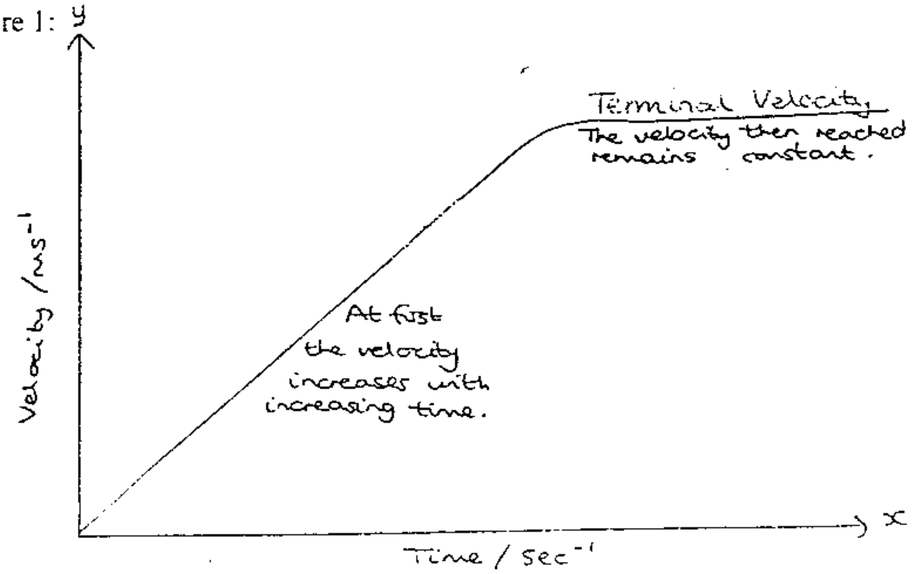
Weight of object = downwards = Mg.

However if a counterweight is opposing the motion of the bob, the force downwards = Mg - mg.
Where M = mass of falling bob, and m = mass of counterweight opposing the motion of the bob.

As k is a constant value for the same external nature and size of the falling object of mass M if the weight of the object M increases and the counterweight stays the same the velocity of the object must also increase, i.e. an increase in the weight of an object flowing through the liquid increases the terminal velocity reached by the object. The upthrust caused by the size and nature of the bob must also remain constant.

An object takes some time to reach terminal velocity. When first flowing through a liquid it will experience little resistive force. However as it travels through this liquid the resistive force opposing the motion of the bob will increase with velocity gradually causing the velocity to increase at a slower rate. Eventually when the forces acting up on the object are equal to those acting downwards on the object terminal velocity will be reached. This can be represented in a graph as shown below:

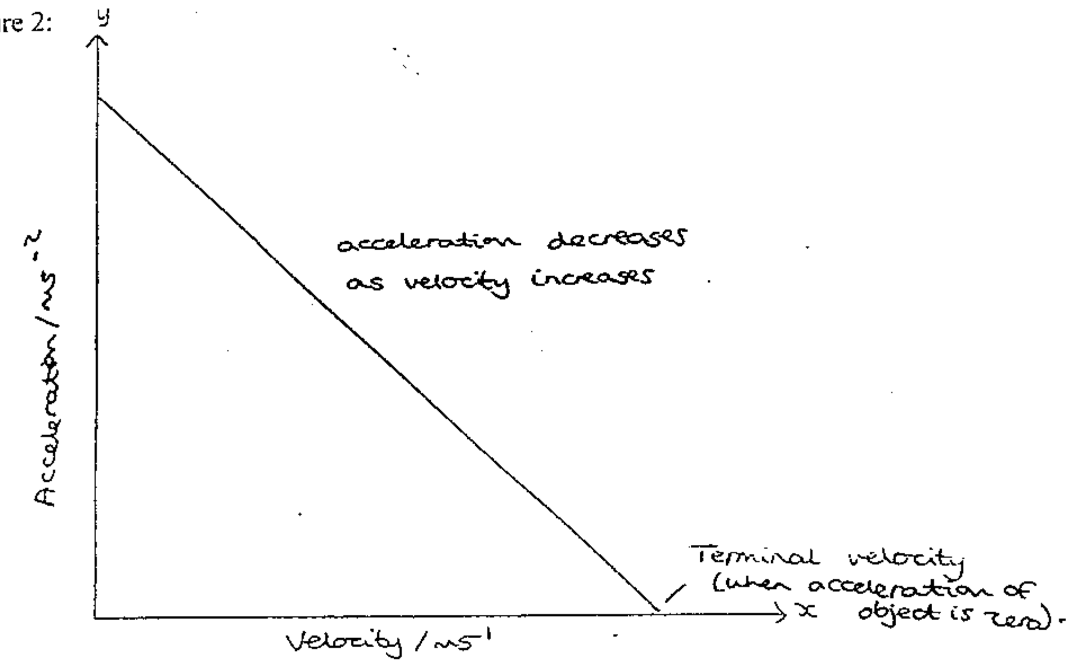
Figure 1:



When a sphere falls slowly through a fluid it pulls cylindrical layers of fluid with it. These exert an equal + opposite resistive force on the sphere.

As the velocity of the sphere increases and the viscous force increases, the acceleration decreases from its initial value of about g to 0. The way in which acceleration of the sphere varies with time can be seen below in figure 2. the way in which the velocity of the sphere varies with the time the sphere has been falling can be shown in figure 1.

Figure 2:



Stoke's equation is derived from the previous equation and states that:-

$0 = Mg - U - F$ or $0 = 4/3\pi r^3 g(p1 - p2) - 6\pi nrv$

This is Stoke's equation.
Where V = terminal velocity
g = acceleration due to gravity = $9.8ms^{-2}$
r = radius of sphere
p1 = density of sphere
p2 = density of fluid
and n = viscosity of fluid.

P(a)

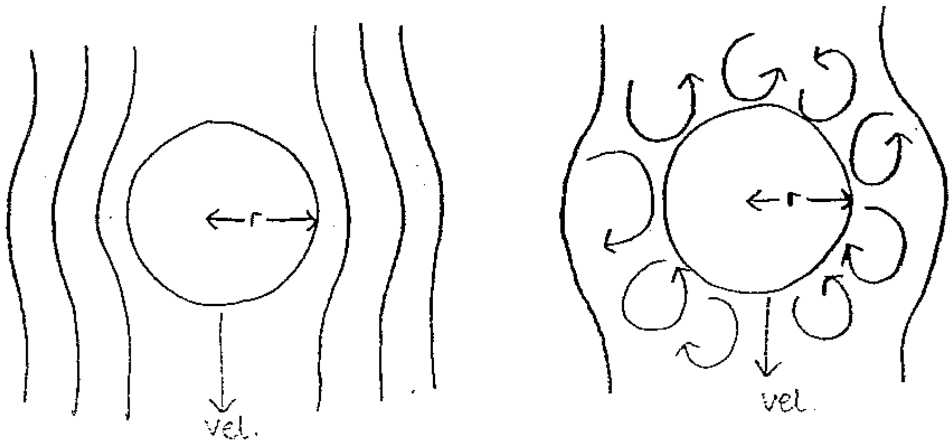
<u>This law only holds under certain conditions:</u>

- The falling object must be a regular sphere.
- The speed of the sphere falling through the liquid must be low.
- The tube in which the fluid is contained must be of large radius, at least twenty times greater than the radius of the sphere if the error is not to exceed 10%.
- The flow of the fluid past the sphere must also not be turbulent (see next page).

The movement of the fluid past the sphere

For Stoke's law to be obeyed the flow of the liquid past the sphere is streamline and not turbulent. The flowing diagrams show liquid layer lines for both streamline and turbulent flow of the liquid past a sphere.

Figure 3:
a) Streamline flow: b) Turbulent flow:



For an object falling through a fluid it is therefore more likely to have streamline flow if it is moving slowly and giving a minimal disturbance to the liquid around it. For an object moving quickly through the fluid it is more likely to have turbulent flow and Stoke's equation will not be obeyed.

Factors affecting terminal velocity

The factors effecting the value of the terminal velocity reached can be found from the equation of terminal velocity.

1. The value of k which is determined by:
The shape and size of the falling object. The larger the surface area of the sphere the increased viscous drag of the object when flowing through liquid. Therefore the terminal velocity reached will be lower.

2. The mass of the counterweight opposing the motion of the falling object. If the counterweight of the falling object is increased the force downward on the object will decrease. This will cause the terminal velocity reached by the falling object to decrease also.

3. The upthrust on the falling object which is determined by the fluid density. The more viscous the fluid the slower the speed of the object will be.

Problems identified

I have decided to investigate how the mass of a bob falling through a liquid will affect the terminal velocity reached by the bob.

I will change the mass of the falling mass by using a cylinder in which additional weights can be added without changing the shape or size of the mass. This therefore prevents two other variables from affecting the results.

The cylinder should travel slowly through the liquid so there is more chance of it reaching its terminal velocity therefore a viscous fluid should be used. Wallpaper paste made to a particular thickness should be suitable as it will be more viscous than water and will slow down the fall of the cylinder.

I shall set the rotating pulley so that as soon as the cylinder is released a lightgate will be blocked. This ensures that timing of the velocity of the cylinder is started as soon as possible after the sphere begins to fall. ✓

I will repeat each mass used in the cylinder to increase the accuracy of results.

Prediction

By increasing the mass of a cylinder falling through a liquid the terminal velocity will increase also.

This is because by increasing the mass of the bob flowing through a liquid I will increase the weight of the object. Using the equation:
$(Mg - mg - U) = -kv$, where k, m and U are all constants, by increasing the mass of the object, M the resultant force on the object will increase also and because k and u are constants, v, the terminal velocity reached by the object will also increase. ✓

Key variables

Dependent:
I will calculate the maximum or terminal velocity reached by the falling bob when there are different masses placed in the bob, the units will be m/s. ✓
Independent:
I will change the mass of the bob flowing through the viscous fluid.

Control variables:

P(b)

1. The position from where the bob is released.
2. The density of the wallpaper paste and its viscosity.
3. The mass on the counterweight opposing the movement of the bob through the viscous fluid.
4. The shape and size of the bob falling through the liquid.

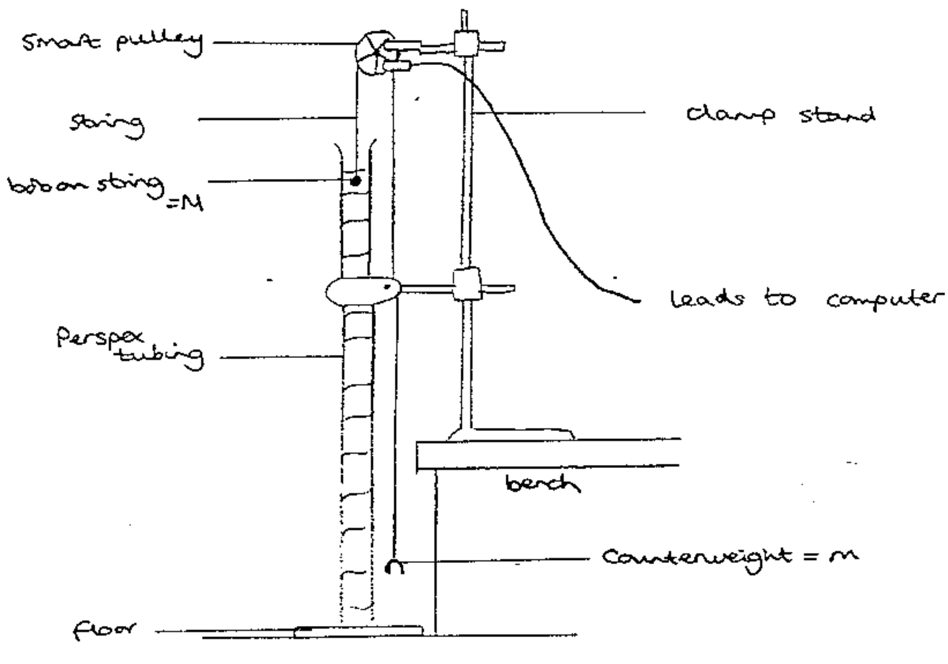
Appropriate apparatus and materials selected

30g wall paper paste powder
2.5 litres of water
A light gate pulley connected to the computer
Small masses to put into the bob of 1 gram, 2 grams and 5 grams
A bob
A counterweight of 50 grams
A long tube of perspex of diameter 7cm
String
Clamp stand

Appropriate method proposed

P(c)

I set up the apparatus as shown below:



Method:

1. Connect the bob and the counterweight by a long light string that passes over the smart pulley. Ensure the string is long enough to avoid any wet string passing over the pulley.
2. The counterweight ensures the pulley rotated uniformly as the bob falls through the liquid. Therefore it prevents the bob from hitting the sides of the tubing and either slowing down or speeding up.
3. Connect the pulley connected to the computer that is able to record how the velocity of the bob changes with time.

4. Select motion timer from the computer through the smart pulley program.
5. Position the bob just below the surface of the paste, this ensures no air bubbles are formed while flowing through the liquid.
6. Ensure the pulley is positioned so that the light is hitting one of the spokes of the pulley, therefore as soon as the bob is released one spoke will be blocked and timing will begin immediately.
7. Press return on the computer before releasing the bob.
8. Press return to stop timing just before the bob hits the bottom of the tube.
9. Repeat steps 1-8 with the same mass and then change the mass inside the bob and follow steps 1-9 again.

Constant measurements

I measured the mass of the bob and lid I was going to use this was calculated as 57.770grams. ✓

Potential hazards P(c)

The wallpaper paste contained fungicide to protect against mould growth, therefore I ensured I washed my hands after using the paste. ✓

Preliminary experiments to determine the order and scale of working

I decided to investigate the terminal velocity reached by the falling bob by finding the minimum and maximum mass I could use. The minimum mass would be when the bob no longer moved when it was released from its starting position. The maximum mass possible to use would be when the object only just moved slow enough to reach a terminal velocity. I therefore carried out the method described previously with different masses placed in the bob. I only repeated each mass twice to eliminate any inaccurate results.

I found the minimum mass it was possible to place in the bob was 12 grams, the maximum mass I could place in the bob was 38 grams. I used a 50 gram counterweight so the bob would not fall so quickly.

Time secs	Velocity m/s	Av. velocity m.s	Time interval secs	Velocity change m/s	Acceleration m/s/s
0.0394	0.1901				
0.1136	0.2158	0.2030	0.07416	0.02570	0.346548
0.1799	0.2380	0.2269	0.06630	0.02220	0.334842
0.2406	0.2567	0.2474	0.06070	0.01870	0.308072
0.2972	0.2735	0.2651	0.05660	0.01680	0.296820
0.3508	0.2865	0.2800	0.05360	0.01300	0.242537
0.4020	0.3002	0.2934	0.05120	0.01370	0.267578
0.4511	0.3107	0.3055	0.04910	0.01050	0.213849
0.4986	0.3214	0.3161	0.04750	0.01070	0.225263
0.5447	0.3298	0.3256	0.04610	0.00840	0.182213
0.5896	0.3380	0.3339	0.04490	0.00820	0.182628
0.6335	0.3457	0.3419	0.04390	0.00770	0.175399
0.6764	0.3539	0.3498	0.04290	0.00820	0.191142
0.7184	0.3598	0.3569	0.04200	0.00590	0.140476
0.7597	0.3659	0.3629	0.04130	0.00610	0.147700
0.8005	0.3695	0.3677	0.04080	0.00360	0.088235
0.8408	0.3741	0.3718	0.04030	0.00460	0.114144
0.8807	0.3769	0.3755	0.03990	0.00280	0.070175
0.9203	0.3798	0.3784	0.03960	0.00290	0.073232
0.9598	0.3798	0.3798	0.03950	0.00000	0.000000
0.9991	0.3827	0.3813	0.03930	0.00290	0.073791
1.0380	0.3817	0.3822	0.03890	-0.00100	-0.025707
1.0770	0.3837	0.3827	0.03900	0.00200	0.051282
1.1160	0.3817	0.3827	0.03900	-0.00200	-0.051282
1.1550	0.3817	0.3817	0.03900	0.00000	0.000000
1.1940	0.3779	0.3798	0.03900	-0.00380	-0.097436
1.2340	0.3732	0.3756	0.04000	-0.00470	-0.117500
1.2740	0.3695	0.3714	0.04000	-0.00370	-0.092500

where maximum velocity occured.

Table of preliminary experiment one
Results – produced from computer

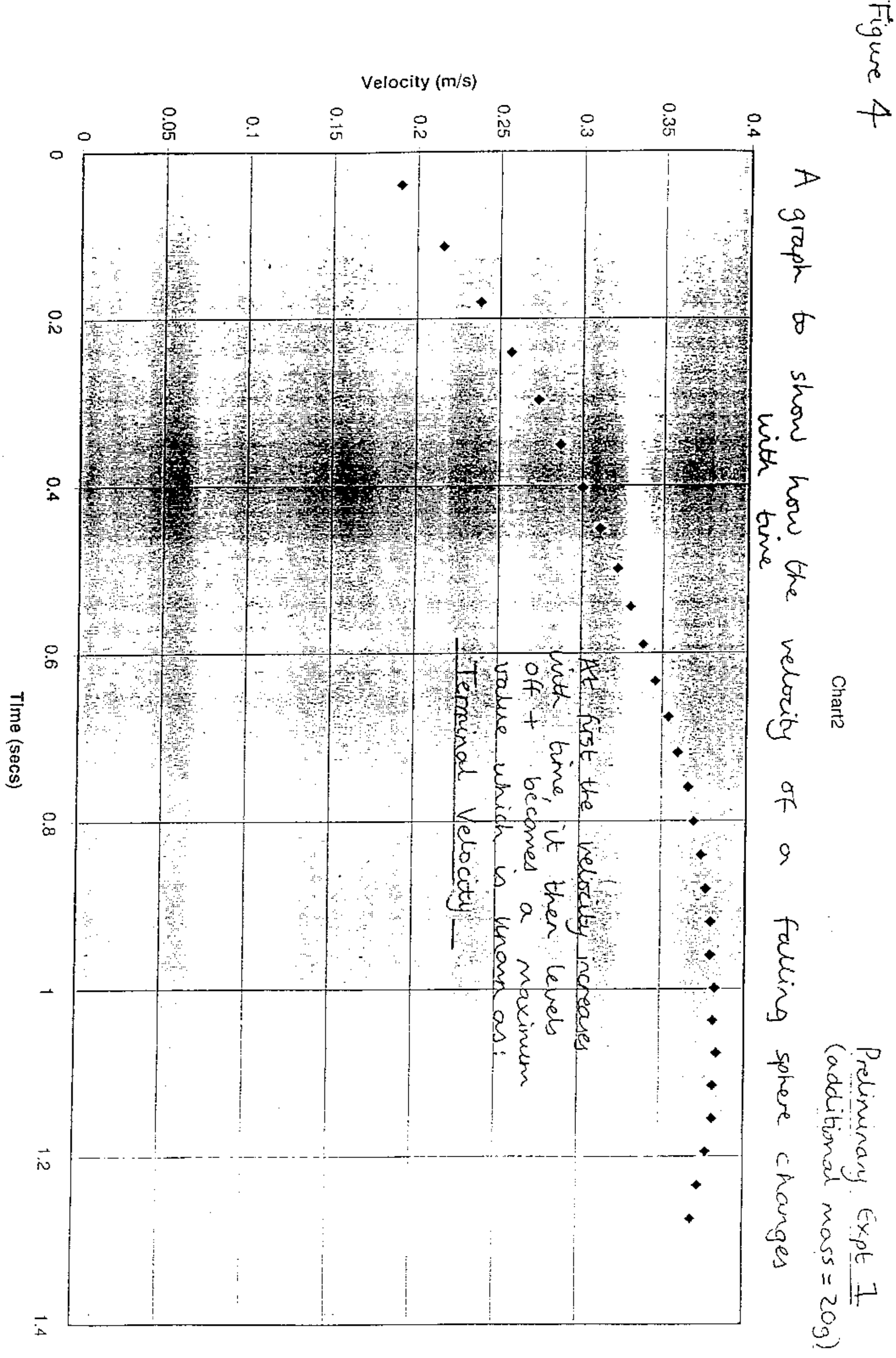


Figure 4
A graph to show how the velocity of a falling sphere changes with time
Preliminary Expt 1
(additional mass = 20g)
Chart2
Velocity (m/s)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Time (secs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
At first the velocity increases with time it then levels off + becomes a maximum value which is known as:
— Terminal Velocity —

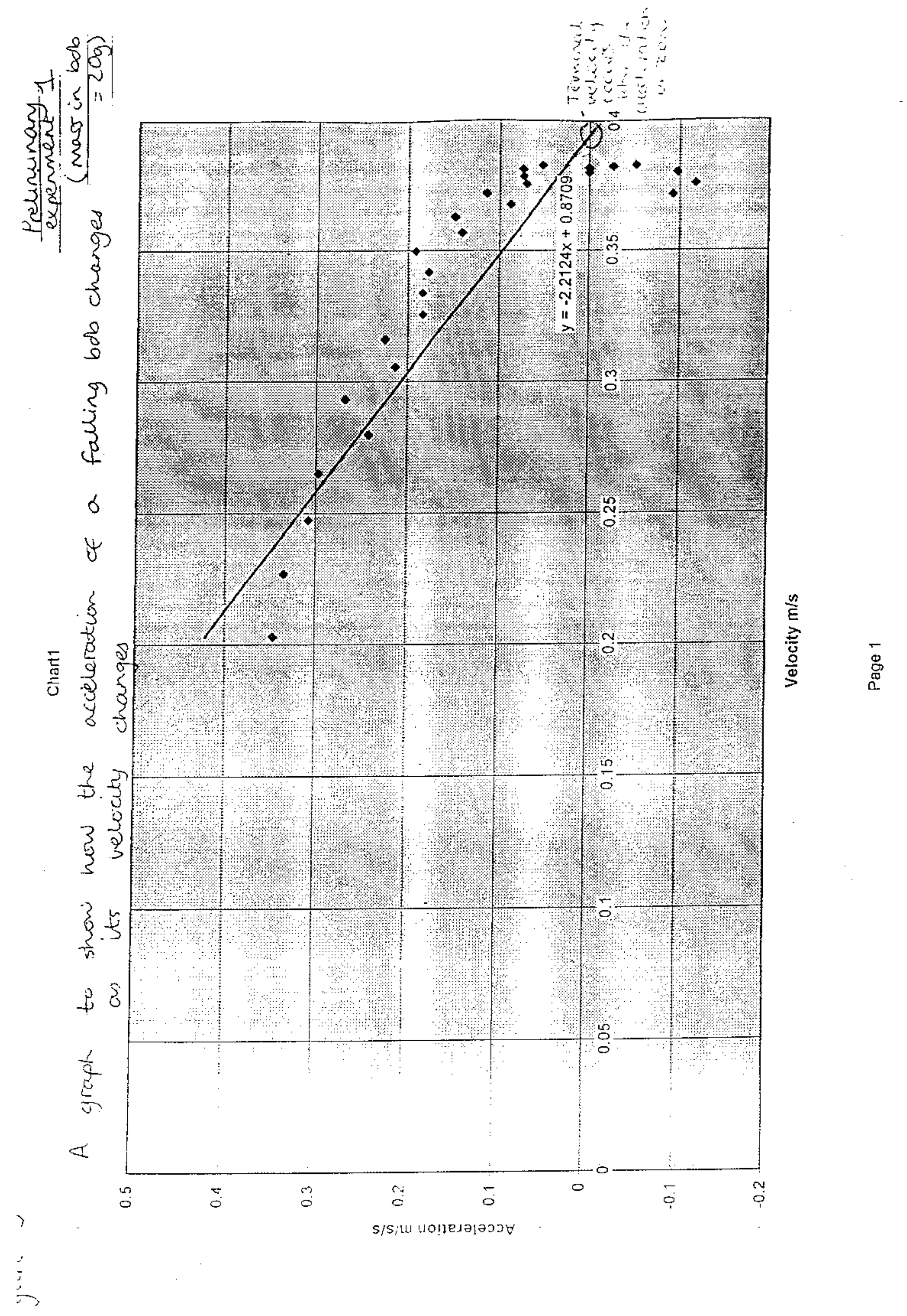


Chart1
A graph to show how the acceleration of a falling bob changes as its velocity changes
Preliminary experiment 1
(mass in bob = 20g)
y = -2.2124x + 0.8709
Velocity m/s
Acceleration m/s/s
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Page 1

Preliminary Results table:

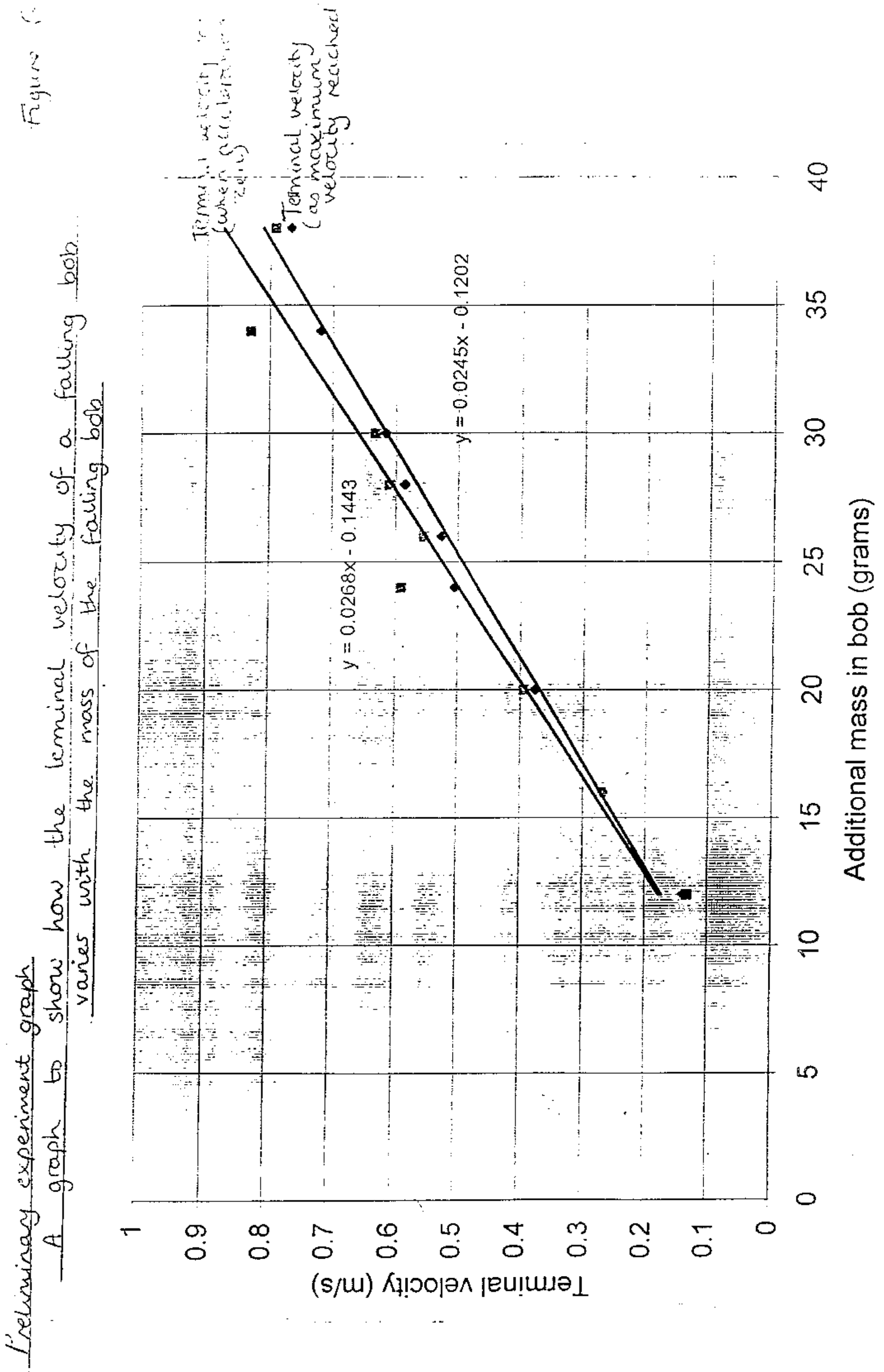
Experiment no:	*Mass in bob (grams)*	*Terminal velocity as maximum vel. reached (m/s)*	*Terminal velocity when acceleration is zero (m/s)*
1	20	0.3837	0.3936
2	20	0.3714	0.3961
3	16	0.2607	0.2642
4	16	0.2765	0.2757
5	12	0.1027	0.0973
6	12	0.1723	0.1672
7	10	n.a - as bob did not move	
8	11	n.a - as bob did not move	
9	24	0.5030	0.5915
10	24	0.5081	0.5903
11	26	0.4964	0.4980
12	26	0.5570	0.6123
13	28	0.5898	0.6328
14	28	0.5829	0.5864
15	30	0.6114	0.6108
16	30	0.6215	0.6548
17	34	0.7061	0.7762
18	34	0.7337	0.8844
19	38	0.7598	0.7590
20	38	0.7753	0.8251

A summary table of my preliminary results showing the mean terminal velocity values

For all the preliminary experiments a constant counterweight of 50 grams was used.

Mass in bob (grams)	*Average terminal velocity (max reached) (m/s)*	*Terminal velocity (when acc = 0) (m/s)*
12	0.1375	0.1323
16	0.2686	0.2700
20	0.3776	0.3949
24	0.5056	0.5909
26	0.5267	0.5552
28	0.5864	0.6096
30	0.6165	0.6328
34	0.7199	0.8303
38	0.7676	0.7921

I plotted a graph of these results to see if my method of collecting the data was reliable and if I could continue with the experiment. This can be seen on the next page.


Preliminary experiment graph
A graph to show how the terminal velocity of a falling bob varies with the mass of the falling bob
Figure
y = 0.0268x - 0.1443
y = 0.0245x - 0.1202
Terminal velocity (as maximum velocity reached)
Terminal velocity (m/s)
Additional mass in bob (grams)
0
5
10
15
20
25
30
35
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

To measure the value of the terminal velocity of a falling bob

There are therefore two ways of calculating the terminal velocity of a falling object:
1. By calculating the terminal velocity when the acceleration of the object is zero. Therefore I needed to plot a velocity against acceleration graph and produce a line of best fit on the graph. As Figure shows when a graph is produced and a line of best fit is drawn an equation of the graph can be obtained. This equation is in the form:

y = mx + c.
where m = gradient of graph and c = the y-intercept of the graph.
Therefore because I need to calculate the velocity of the sphere when the acceleration is zero I need to find x when y equals 0.
For the first preliminary experiment, figure 5 the equation of the curve is:

y = -2.214x + 0.8709.
When the acceleration of the bob is zero the value of y is 0 m/s/s.
Therefore we need to calculate the x value which is the velocity of the sphere.

Therefore 0 = -2.124x + 0.8709

and -2.124x = -0.8709

$$x = \frac{-0.8709}{-2.124}$$

x = 0.3936 m/s.

2. The other way of calculating the terminal velocity is determining the maximum velocity of the sphere reached. This can be either seen from the graph, see figure 4, or from looking at the tables produced from the computer showing how velocity varied with time for the falling bob and finding the maximum value of the velocity reached. From preliminary experiment one this value is 0.3837 m/s.

Therefore there are two values I can use in plotting a graph of mass against terminal velocity.

I calculated the two possible velocity values for each of the masses I used. I produced a table of my results. This can be seen on page 12. I found that the minimum mass I could place in the bob was 12 grams as the bob could not move freely when either 10 or 11 grams was placed in the bob. The maximum mass I could use was 38 grams as figure shows the bob only just reached terminal velocity when this mass was used.

I found the average terminal velocity for each mass used both using the maximum velocity reached method (in the third column of the table) and finding the velocity reached when the acceleration is zero (in the fourth column of the table). I then plotted a graph of mass against the two terminal velocity values. This can be seen on page 14. All my results and graphs of my results from my preliminary results can be seen in appendix A.

As the graph, figure 6 on page 14 shows the general trend is that as mass increases the terminal velocity of the falling bob also increases.

I could therefore conclude that my method was viable and I could continue with my actual experiment. I kept the counterweight constant at 50 grams. I decided to find the terminal velocity reached by 7 different masses in the bob. I chose to add the following masses to the bob:
13,17,21,25,29,33 and 38 grams. I plotted graphs of velocity against time and acceleration against velocity for each of the masses at all the attempts made. I also decided I would repeat the experiment three times and then find the mean value for both the methods of determining the terminal velocity value. All my graphs for my actual experiment can be seen in appendix B. I produced a table of my results, this can be seen on page 18. I decided to plot a graph showing the average terminal velocity for both ways of measuring against the total mass of the bob – the mass of the counterweight. The mass of the bob without any additional weights was 57.77 grams, and the mass of the counterweight was constant at 50 grams.
Therefore taking the additional mass of 25 grams as an example:
Overall mass = 57.77 + 25 – 50 grams = 32.77 grams.
Therefore by producing a scattergraph I can add a line of best fit for both the values of terminal velocity when a different mass is used. The graph of my main results can be seen as figure 7.

Additonal mass in bob (grams)	*Attempt no:*	*Terminal velocity as maximum velocity reached (m/s)*	*Terminal velocity as velocity when acceleration is zero (m/s)*
13	1	0.0858	0.1462
	2	0.1298	0.1372
	3	0.1570	0.1607
17	1	0.2760	0.2945
	2	0.3002	0.3155
	3	0.3207	0.3360
21	1	0.4273	0.4963
	2	0.4517	0.5230
	3	0.4571	0.5110
25	1	0.5315	0.5591
	2	0.5430	0.5550
	3	0.5807	0.6505
29	1	0.6040	0.6286
	2	0.5898	0.6006
	3	0.6346	0.7126
33	1	0.6539	0.7146
	2	0.6597	0.7144
	3	0.6597	0.7152
38	1	0.8086	0.8267
	2	0.8086	0.9493
	3	0.8043	1.0778

Main results table

The mass of the cylinder was 57.77 grams.

Additional mass in bob (grams)	*Total mass of bob - mass of counterweight (grams)*	*Mean terminal velocity as max. vel. reached (m/s)*	*Mean terminal velocity as vel. when acc. is zero (m/s)*
13	20.77	0.1242	0.1480
17	24.77	0.2990	0.3153
21	28.77	0.4454	0.5101
25	32.77	0.5517	0.5882
29	36.77	0.6095	0.6473
33	40.77	0.6578	0.7147
38	45.77	0.8072	0.9513

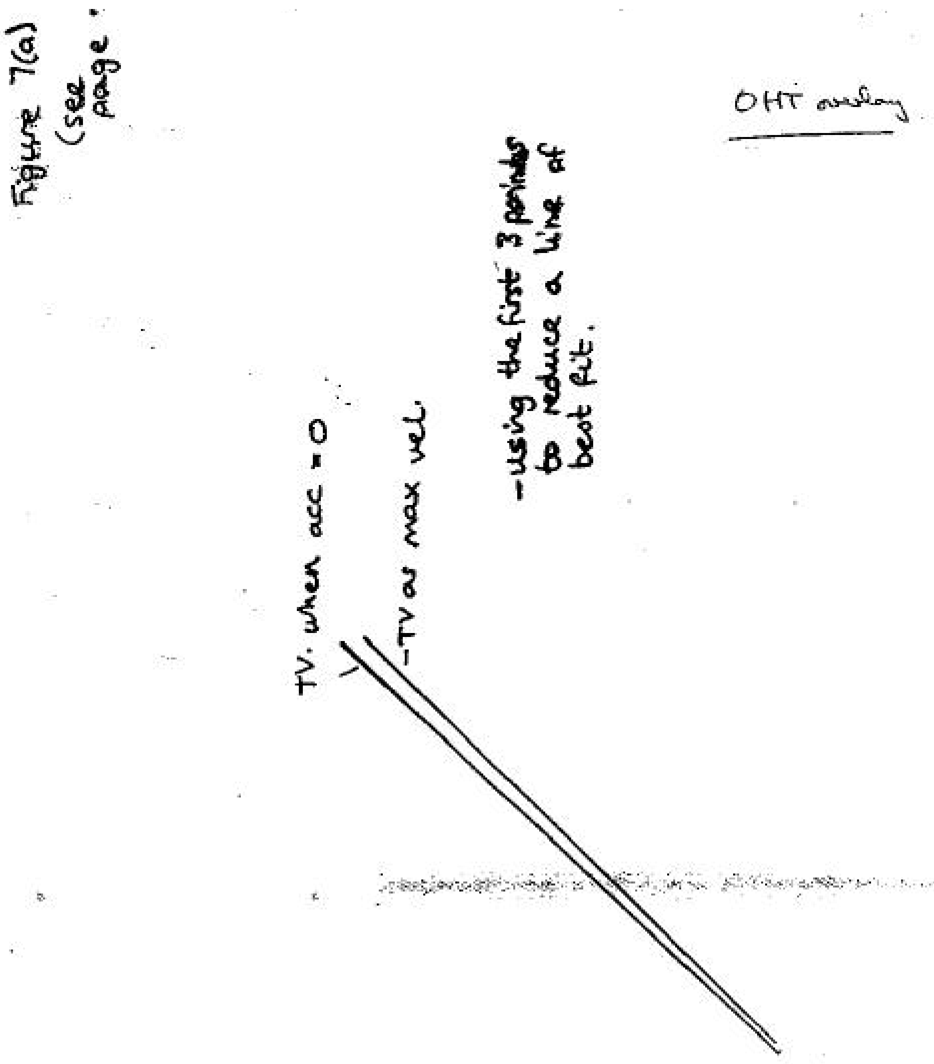
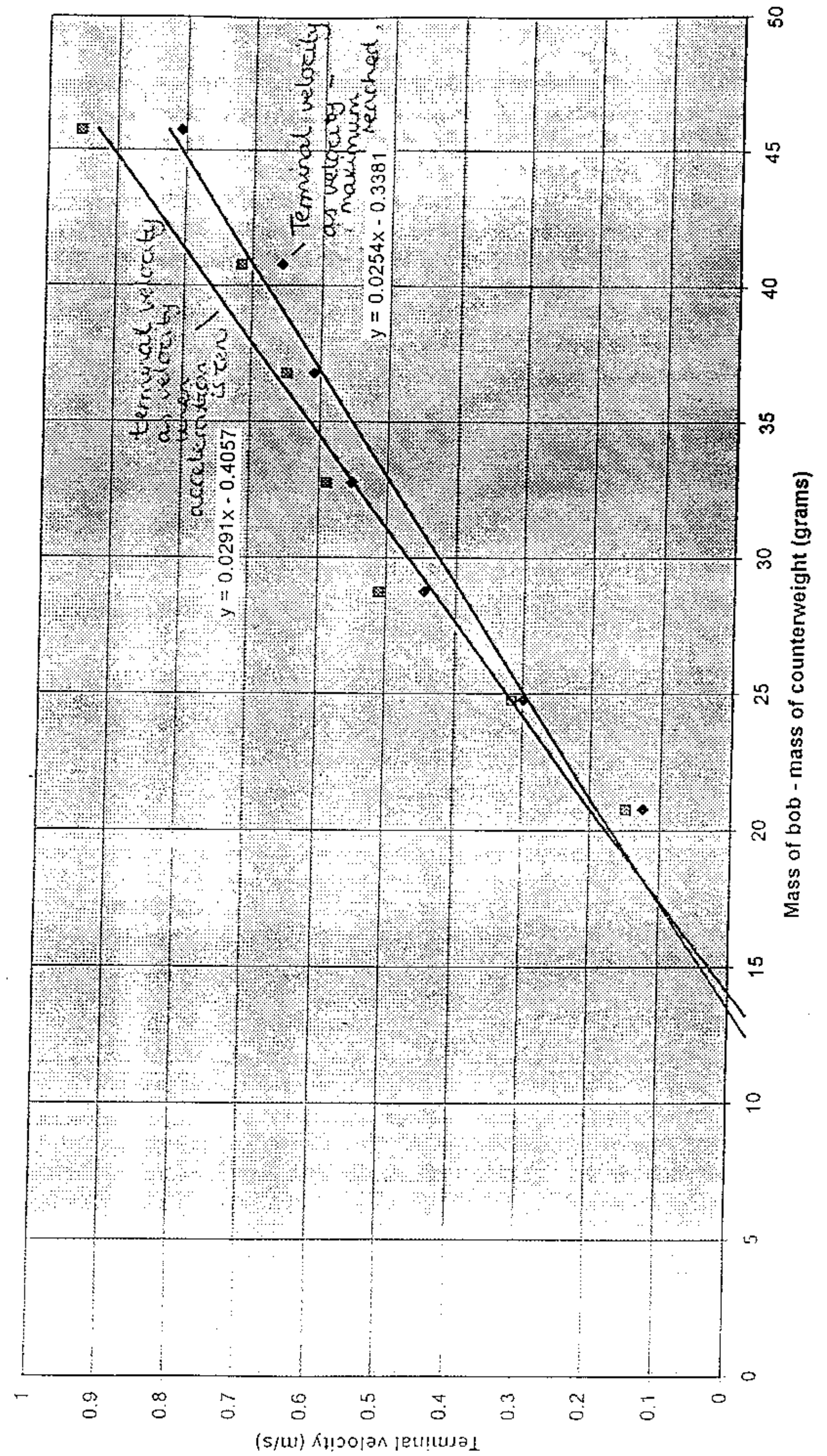


Figure 7(a) (see page
OHT overlay
-using the first 3 points to reduce a line of best fit.
TV. when acc = 0
-TV as max vel.

A graph to show how the mass of the bob affects the terminal velocity reached by the bob



Page 1

Operation of apparatus checked

I ensured that I was collecting reliable and accurate results by doing the following:

1. Dropping the bob in the centre of the tube so it would not hit the sides of the Perspex tube and cause fluctuations in velocity.
2. I ensured the lightgate was just about to be lit after the bob was released from rest and therefore velocity was measured straight away.
3. Measurement of the velocity of the cylinder was stopped just before the bob hit the bottom of the tube where it would bounce back up and down and cause velocity fluctuations.
4. I kept stirring the wallpaper paste to ensure a uniform viscosity of the fluid so the bob did not experience a higher resistance to flow nearer the bottom of the tube where the paste was settling out.
5. Making sure the cylinder was placed just below the surface of the wallpaper paste before released from rest ensured no air bubbles formed to alter the velocity of the bob.
6. That any water collected as it travelled down the tube was emptied before releasing the bob again.

Problems identified

After undertaking I discovered the following problems:

1. The bob was not watertight and as it travelled down in the wallpaper paste liquid sometimes entered the bob despite all my efforts to make it watertight by using Vaseline around the seal of the bob. Therefore this would have altered the mass of the bob and caused it to increase in velocity as it flowed further down the tube.
2. It was not possible to make the bob descend uniformly without rotating around the string. This could cause the flow of the liquid past the bob to become less streamline.
3. Although I ensured the wallpaper paste was stirred well before each measurement it was still possible that the paste may have settled out slightly during each reading and have caused some disturbance in the flow of the bob. However I considered this error to be very minimal.
4. For Stoke's equation of terminal velocity to be obeyed the flow of the liquid past the falling object must be streamline and not turbulent. A sphere also must be used. by using a cylinder I am increasing this error because there is an increased chance of turbulence due to the shape of the cylinder. The flow will also only be streamline if the velocity of the sphere is low. Therefore when a large mass was used in the bob it may be likely that the speed of the cylinder at its terminal velocity was too high for the flow of the fluid past the sphere to remain streamline.

Modifications proposed – Experiment two

From my first experiment I have seen how if a larger mass is in the cylinder the cylinder falls faster. This therefore could imply that the flow of the fluid past the sphere is more turbulent and Stoke's law would not hold. Therefore the theory behind the increasing terminal velocity at larger masses breaks down.

In experiment one I considered the resistance flow to be proportional to the terminal velocity. However above a critical velocity value it is considered that the drag is proportional to the square of the velocity of the falling object, this implies that

$M \propto K v_t^2$

Therefore as an extension to this project I decided to see whether this theory supports my results. I decided to modify my experiment by using a ball bearing as the falling object to minimise the error due to the edge effects of the falling object, which will increase the chance of Stoke's law holding. However this means I will be unable to alter the mass of the falling object, instead I will change the mass of the counterweight opposing the motion of the falling sphere.
Therefore the force downwards on the sphere will be:-
The weight of the sphere - the weight of the counterweight.
This means the greater the mass of the counterweight the slower the speed of the falling sphere through the liquid.

I will release the sphere from the same position in the fluid each time to ensure no air bubbles collect which will slow down the speed of the bob. I shall set the rotating pulley so a lightgate is just about to be blocked therefore the velocity of the sphere will be measured as soon as it starts to fall.

I decided to use water instead of the wallpaper paste as this meant there was no error due to the liquid not being a uniform concentration.

Prediction

The square of the terminal velocity of the falling bob will depend on the mass of the counterweight used. Therefore my proposed equation of motion is:
$mg = -kv_t^2 + Mg - U$. The square of the terminal velocity will decrease as the mass of the counterweight increases.

This is because as the mass of the counterweight increases the overall force downwards of the bob through the fluid decreases. Since this force determines the terminal velocity value, as the counterweight mass increases the terminal velocity value will decrease.

The resistance to the flow is more likely to be proportional to the square of the terminal velocity value when the bob is flowing at relatively high speeds, i.e when smaller counterweights are used.

Key variables:

Dependent:
I will calculate the terminal velocity of the sphere. I decided I would calculate the terminal velocity of the sphere by finding the maximum velocity reached from the tables of data (see appendix C) instead of using the acceleration against velocity graph to find the intercept.

Independent:
I will change the mass of the counterweight used. this will therefore change the terminal velocity of the bob falling through the liquid.

Control variables:

1. The mass of the sphere falling.
2. The position in the fluid from where the sphere is released.
3. The fluid through which the sphere falls.

Appropriate apparatus and materials selected

I will require the same materials as before except for the bob and additional small weights will not be needed.
Additional apparatus:
A small ball bearing.
10 grams weights to add to the counterweight of the sphere.
A screwgauge to measure the diameter of the sphere.

Constant measurements

I had to make the following measurements as part of this experiment:
1. The diameter of the ball bearing by using a screwgauge. I took three values of 20.03, 20.35, and 20.39 mm. This averaged to a value of 20.26mm.
2. The diameter of the tube was 70mm.
3. The mass of the ball bearing was 30.916 grams (to +/- 0.0005 grams).

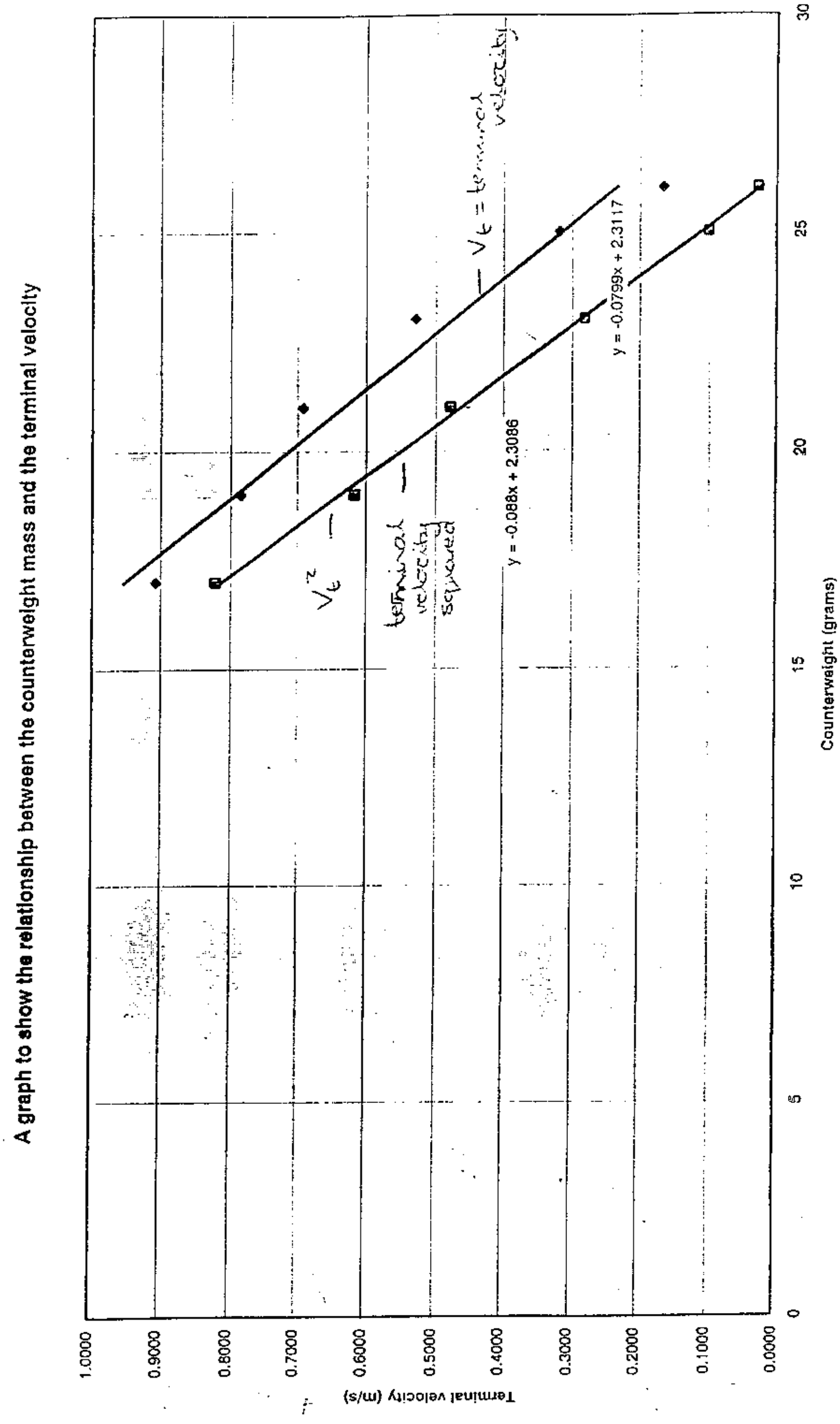
Method

I carried out my method as before, however instead of changing the mass in the falling bob I changed the mass of the counterweight instead. I repeated each mass of the counterweight three times. Again I experimented to find the minimum and maximum mass I could use for the counterweight when the bob still achieved terminal velocity. I found the minimum mass was 17 grams and the maximum mass was 26 grams. I chose six different weights within these limits to carry out the experiment on 17,19,21,23,25 and 26 grams.

To test my prediction I decided to plot a graph of the counterweight mass against both the terminal velocity value and also the square of the terminal velocity value to see which produced a most linear line on the graph. **See page 57.** ✓

A table to show the terminal velocity values when different counterweights are used

Counterweight (grams)	*Terminal velocity (m/s) = v_t*	*Mean v_t (m/s)*	*v_t^2 (m^2s^{-2})*
17	0.9006		
17	0.9342	0.9065	0.8217
17	0.8847		
19	0.7753		
19	0.7793	0.7849	0.6161
19	0.8000		
21	0.6655		
21	0.7128	0.6915	0.4782
21	0.6963		
23	0.5240		
23	0.5410	0.5303	0.2812
23	0.5259		
25	0.3173		
25	0.3207	0.3180	0.1011
25	0.3160		
26	0.1653		
26	0.1675	0.1662	0.0276
26	0.1658		


A graph to show the relationship between the counterweight mass and the terminal velocity
Terminal velocity (m/s)
1.0000
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
0
5
10
15
20
25
30
Counterweight (grams)
y = -0.088x + 2.3086
y = -0.0799x + 2.3117
V_t^2 — terminal velocity squared
V_t = terminal velocity

Concluding

Reliability and accuracy of data – experiment one

I can look to see how reliable my results from experiment one are by seeing how similar all the results for the terminal velocity values are for each mass used.

For the terminal velocity value as calculated by the maximum velocity reached:

The percentage error in the results is:

$$\frac{\text{The maximum difference between a terminal velocity value and the mean terminal velocity value}}{\text{The mean terminal velocity value}} \times 100\%$$

For example for the overall mass of 20.77grams (M - m) the three terminal velocity values are:
0.0858 m/s
0.1298 m/s
0.1570 m/s
Therefore to start with I need to find the maximum difference between one of these three values and the mean terminal velocity value which is 0.1242 m/s:
The maximum difference is between 0.1242 and 0.0858 m/s which is 0.0384 m/s.
Therefore I divide 0.0384 by 0.1242 and multiply by 100%:

$$\frac{0.0384}{0.1242} \times 100\% = 30.92\%.$$

✓

I repeated this for all my other masses and also for the second way of measuring the terminal velocity value - by using the velocity when the acceleration of the object is 0m/s.
I produced a table below with all my results:

Mass of bob - mass of counterweight (grams)	*Maximum percentage error (%) when TV = max vel. Reached*	*when TV = vel when acc. is zero*
20.77	30.92	8.58
24.77	7.69	6.59
28.77	4.02	2.70
32.77	5.26	10.59
36.77	2.51	10.09
40.77	0.39	0.07
45.77	0.36	13.30

C(a)

Therefore the reliability of my results varied greatly. With the first terminal velocity value the results seem to be more reliable as the mass increases. The maximum percentage error in the results occurred when the overall mass falling was 20.77 grams, the percentage error was 30.92%. This therefore suggests there may have been a problem with one of the readings such as the bob hitting the side of the tube. However apart from that one value the reliability of my results when using the maximum velocity reached is relatively high especially with the larger masses. For the second way of measuring the results by using the velocity value when the acceleration of the object was 0m/s/s the reliability also varied greatly. The most reliable was at 40.77 grams when there was just 0.07% error in the results. The largest percentage error was with 45.77 grams when there was a percentage error of 13.30%. For the second way of measuring the terminal velocity there does not seem to be any pattern of the results with the percentage error varying as the mass increased.

Therefore overall I considered my results using the maximum velocity reached were the more accurate except for the values at the lowest mass used.

Reliability of my results from experiment two

As before I calculated the maximum percentage error in my terminal velocity values. For example for the counterweight of 23 grams the three terminal velocity values are: 0.5240,0.5410 and 0.5259 m/s. This produces a mean value of 0.5303. Therefore the maximum percentage error is calculated by using the most extreme value for terminal velocity from the mean. This is 0.5410 m/s.
The percentage error is calculated by:
(0.5410 - 0.5303)/ 0.5303 x 100% = 2.02%.

I produced a table below showing all the percentage errors for each counterweight mass I used:

Counterweight (grams)	*Maximum percentage error in terminal velocity results (%)*
17	3.06
19	1.92
21	3.76
23	2.02
25	0.85
26	0.78

Therefore all my terminal velocity values were very reliable and the maximum percentage error was just 3.76 % when using a counterweight of 21 grams. The results suggest that by changing the counterweight instead of the mass of the bob my results were more reliable as the percentage errors from the first experiment were much greater than for this experiment.

Sources of error

I discovered that even after my second experiment there were still the following problems with the experiment:

1. In both experiments it was impossible to stop the rotation of the bob causing the flow of the liquid past the bob or sphere to be disturbed. This therefore was likely to slow the bob down and produce a too low value for the terminal velocity.
2. Due to the narrow tube the bob or sphere may not have always flowed directly down and may have experienced fluctuations in its velocity due to edge effects of the tube.
3. There would have been some friction between the string and the wheel of the pulley that would have slowed the falling bob or sphere down causing it to decrease in velocity.
4. For Stoke's law of terminal velocity to be obeyed the radius of the tube in which the sphere is falling should have a radius of at least 20 times the radius of the sphere. However the radius of the tube was 35mm and the radius of the sphere was on average 10.13 mm. Therefore the tube radius was only approximately 3.5 times that of the ball bearing. This may have proved a large error.

5. For both experiments there was a problem with the shape of the falling object. For experiment one the bob was not spherical, as I needed to add masses in the bob, therefore this would have interfered with the flow of the fluid past the sphere. For experiment two the ball bearing was not completely spherical as I produced three slightly different measurements for the diameter of the sphere. Again this may have affected the flow of liquid past the sphere.

Accuracy of results

1. The time was measured to the +/- 0.0005 seconds, and the velocity was measured to +/- 0.0005 m/s by the computer. Therefore my results should have been measured very accurately.
2. I repeated the measurements three times for experiment one and two. As my reliability assessment shows this may have sometimes not been accurate enough as there was a large percentage error in the three measurements in some cases. The reliability of the results is decreased due to the high accuracy of the readings produced by the printout direct from the computer. The figures were often to six decimal places therefore this accuracy caused by results to be more varied than if the measurements had only be to two or three decimal places.
3. For measuring the terminal velocity as the velocity of the falling object when the acceleration of the object is zero often may have produced an inaccurate value. This is because if one or two points do not fit the pattern of the expected line of best fit they disrupt the line and the intercept value.

Possible modifications to overcome errors

I therefore considered that if I were to carry out my investigation again there would be several factors I could improve on:

1. I could use a wider tube so the radius of the tube would be greater than 20 times that of the falling sphere. This would make the equation of terminal velocity more reliable and reduce the error of edge effects. This also would prevent any errors caused by the bob hitting the sides of the tube due to the rotation of the bob as it fell.
2. To increase the chances of the first experiment's results fitting the theory of terminal velocity I would need to find a falling spherical bob in which it was possible to add weights without changing the shape of the object (as this would alter the upthrust).
3. I could repeat both experiments more times using the same mass to increase the reliability of my results.

Conclusions from results of experiment one

By looking at equation:
kv = Mg - mg - U
I can see how well my results shown on figure 7 fit the theory suggested by the above equation. This is because the upthrust on the bob is constant because the size and the shape of the bob do not change throughout the experiment. From Archimedes prinicple I know that the upthrust is equal to the weight of fluid displaced.
The volume of the falling cylinder is $20cm^3$.
The density of the wallpaper paste

$$= \frac{\text{the weight of the fluid + the weight of the wallpaper paste}}{\text{the weight of the liquid used}}$$

$$= \frac{2500g + 30g}{2500g} = 1.012g/cm^3 \text{ or } 1.012\ kg/cm^3.$$

Therefore the upthrust on the bob is $1.012x10^3$ x $20m^{-6}$ x g = 0.198N

Rewriting the above equation: kv = (M - m)g - U, therefore for a graph of (M - m) against v_t a straight line should be produced. The intercept on the x axis occurs when the terminal velocity is zero. Replacing this in the above equation implies:
(M - m) = U/g
so when the terminal velocity value should be zero
(M - m) = 0.198/9.8
(M - m) = 0.0202 kg 0r 20.20 grams. C(b)

Therefore for the theory of terminal velocity to hold the intercept on the graph of (M-m) against v_t the intercept on the x axis should be at 20.20 grams.

From figure 7 I can see how the intercept values on the x axis are 13.31 grams when the terminal velocity value is the maximum reached, and 13.94 grams when the terminal velocity is the velocity when acceleration is zero.

Therefore there is some difference between the theoretical value and my practical value. However the similarity of the two intercept values suggest there is a consistent error causing an increased drag force on the cylinder. ✓

From figure 7 I can see how as the overall mass falling down the tube increased the mean terminal velocity value also increased. It is consistent that the terminal velocity calculated by the velocity of the bob when the acceleration is zero is always larger than ✓ that of the maximum velocity of the bob reached.

However the points on the graph seem to show more of a curved shape rather than being linear - this suggests that the mass is not directly proportional to the terminal velocity. Figure 7(a) shows that if I take the first three points of the graph (when the mass was 20.77, 24.77 and 28.77 grams overall) a straight line can be produced from which all the lines lie very close too. This produces an intercept value of approximately 17.5 grams. Therefore this is closer to the theoretical value I calculated, however it still suggests there was some additional drag.

Therefore although my prediction has been supported as the terminal velocity value did increase as the mass in the bob increased the terminal velocity the relationship is not linear. Figures 7 and 7(a) suggest that when ~~larger~~ smaller masses are used - i.e. smaller velocities the results support the theory more than at larger masses - at higher velocities.

Conclusions from experiment two

My second experiment investigated whether the mass of the counterweight was actually proportional to the square of the terminal velocity instead. figure 8 shows that as the mass of the counterweight increased the terminal velocity value decreased. From comparing the two lines it is clear that when the terminal velocity value is squared the graph is more linear than when terminal velocity alone is plotted against the mass of the counterweight. Therefore this tends to provide some evidence to support my prediction that the square of the terminal velocity depends on the mass of the counterweight used.

From simply looking at the line when the terminal velocity value was plotted although a curve is apparent the points still seem to follow a more similar pattern than that of figure 7 when the cylinder was used as the falling object. This suggests that by using a falling sphere as in experiment two my results were more accurate than when using the cylinder as the bob. This is because of the reduced chance of turbulent flow due to the edge effects on the cylinder. ✓

In summary:-

At lower masses or higher counterweights the resistive force seems to be proportional to the terminal velocity value directly. ✓

At higher masses or lower counterweight masses the resistive force is more likely to be proportional to the terminal velocity value squared.

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