THE APPLICATION OF WORKING MEMORY THEORY TO THE LEARNING OF PHYSICS

Thesis submitted for the degree of Doctor of Philosophy (Ph.D)

by

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Abstract

The first aim of this research was to replicate in physics work which had been done in chemistry by Johnstone and El-Banna 1987(52,85), in which Working Memory Theory had been used to account for student performance in traditional exams. This was carried out and the results in physics coincided well with the chemistry findings that Working Memory Theory space correlated well with exam performance and that a sharp fall in performance occurred when the demand of a question exceeded the Working Memory Space. An additional study was done to relate Field Dependence/ Field Independence measures to performance and to Working Memory Space. This was found to be of lesser importance. The second aim was to apply the insights gained in the first part of the study to help in the design of student laboratory and tutorial experiences. The laboratory work was carried out with undergraduates in Glasgow while the tutorial work was carried out with both Glasgow undergraduates and Algerian Baccalauréat students.

1. In the light of preliminary work, laboratory instruction manuals were redesigned so as to reduce information load by improved layout, by the use of diagrams and by the removal of extraneous and misleading information. We have evidence that the understanding and the attitudes of students in the laboratory have been improved.

2. Attention was also turned to problem solving;

tutorial problems have been designed in different forms to change the load in them and so minimise the psychological effects and the processing demand. The follow up of the findings has resulted in improved student performance. These findings should be generally applicable to the learning of physics.

Changes in education are often made on the basis of belief, fashion or necessity. In this study we had time to look carefully at a theoretical approach to change which enabled hypotheses to the raised and tested and which also suggested a mechanism for systematically improving learning in physics.

Chapter one

1-1 Piaget's theory of intellectual development

Studies of human mental growth indicate that children pass through several periods (stages) of cognitive development before reaching intellectual maturity.

The work of Piaget and his collaborators has been very largely devoted to examine how the basic concepts of science and mathematics (such as area, length) for the most part are in the stage of concrete operation. Piaget suggested that the child's development interacts with the environment surrounding him from birth up to 16 years of age. During this period he acquires new experiences and learns more about his environment, and he tries to grasp ideas about physical actions by applying the concrete experience which is vital at this stage, and attempts to increase his circle of knowledge.

Piaget[1] explains the intellectual development in terms of four main stages of cognitive development. These stages are:

1. Sensory stage, about the first two years of life
2. Pre- operational stage, from 2 years to 7 years on average.
3. Concrete operation stage, from 7 to 11 years old
4. Formal operation stage, from about 11 years of age.

These stages have contributed much to the application of Piaget's theory. Piaget has explained in detail the characteristics of each stage of cognitive development.

The two last stages are concerned with development at school. Let us now briefly discuss the characteristic of each of the last two stages; viz. concrete and formal operational. The concrete operational stage which is gradually built-up of the ideas of conservation of substance, (such as length, number, time. etc) leads to the ability to deal with properties of the immediately perceived world. The child often works by trial and error, and then begins to replace physical action by mental operation.[2] During this period the child develops his logical operations and increases his experiences.

In another investigation, done by Shayer[3], it was noted that 80% of 11-12 years old recognized multiplication problems.

During the formal operational stage, there is an increase in hypothetical reasoning and ability to handle abstractions. The child can plan ahead, make and test hypotheses, and become able to carry out an experiment.[2] By the end of this stage the value of logical thinking has reached a high degree of equilibrium.[4] In addition, the pupils are able to examine certain variables, to hold factors constant when investigating combinations. At this stage they have the ability to think in terms of combination of classes and understand complex concepts or abstractions.

Piaget[5] has focused his investigation almost completely on logical operations and their development. He explained the difference in performance of the tasks which were attributed to development in logical skills. In other words logical operation are necessary for success in solving problems.

1-2 **Implication of Piagetian theory in Education**

Piaget's work has been critized on points of detail; in particular, he used the "clinical" interview method, involving small numbers of children. Beard[6] and Boyle[7] have concluded that

Piaget's work does not always satisfy the requirement of scientific research. For example, Piaget's sample was small and could therefore not represent the majority of children, and his model does not provide illustration. On the other hand, Piaget conducted his investigations to illustrate his point of view rather than to gain new knowledge and define the characteristic of the education process. In fact, the results of these studies give unsatisfactory interpretations of mental development.

A great number of investigations have been undertaken to illustrate the relationships between the level of the students' cognitive development (which was measured by various standard Piagetian tasks) and their performance.

Inhelder and Piaget[8] have described a pendulum task that required several simultaneous variables to predict the motion of the pendulum. Lengel and Beull[9] used the triple pendulum problem and tested this using 20 science students in each of the three grades 7, 9 and 12. Their findings indicated that there is a gradual increase in their mean scores over three years. Only 30 % of the students' sample with age 12 years reached the formal operational stage, and more of these succeeded in quantifying their answers. In a similar study, Somerville[10] and Joyce[11] found a comparable level of performance.

Brown [12] has pointed out that, the nature of formal operations is not at the moment clearly defined. It is difficult to apply the Piagetian theory to examples of mathematical operations. On the same theme Shayer[13] showed clearly that, by 9 years of age only 30 % of the pupils are using the concrete operation fully, and at 14 years about 20 % are using early formal operation. Johnstone et al[14] have published collected data on pupils' recollections of the subjective difficulty of particular topics in the Scottish school chemistry and physics syllabus.

In a recent study, Shayer[13], and Ingle and Shayer[15] estimated the intellectual demands made on pupils by each topic in the Nuffield O-level, in both chemistry and physics.

In a subsequent study based on Piaget's theory Beistel[16] determined that not all first year University students in chemistry are at the formal operational stage. For this case, it should be useful to know whether the students made progress in intellectual development during laboratory work. This could be important to help students towards formal thought. According to the Piagetian approach, Mihkelson [17] emphasized that it could be possible to train students to become formal thinkers and help them to process difficult problems step by step. This was confirmed by testing first year students, using a series of tasks based on Inhelder and Piaget. These tasks required formal operation and a knowledge of chemical reactions. She found that only 1 out of 64 of the sample made sufficient observations, 21 out of 64 students made irrelevant observations, and 22 out of the same sample made 3 or more correct observations.

The concept of stage in Piagetian cognitive development has encountered criticism by Novak[18]; he agreed that Piaget's developmental psychological is a valid basis for analyzing secondary school students' performance, but he suggested that the Piagetian paradigm for cognitive development is not the most useful paradigm to guide research in teaching science. In the same way Ausubel [19] does not agree with the idea which Piaget puts forward; he asserts that the idea of "stage" gives a false impression. Intellectual functioning at any one stage has more explicit variation than the concept of stage would suggest.

1-3 **Ausubel's theory**

Education researchers have focused their attention on finding methods which help students to understand how to structure and produce knowledge.

West and Fensham[20] have suggested two factors influencing learning as:

(a) what the learner already knows (prior knowledge)

(b) his interaction in learning (motivation).

In this view, both factors are considered important in new science learning.

Ausubel's cognitive learning theory has been found to be a most useful guide for learning events. There are several key concepts involved in Ausubel's theory. These key concepts are a guide for the teacher for improving learning and teaching. The central idea in Ausubel's theory for cognitive structure is that " the most important factor influencing learning is quantity, clarity and organization of the learner's present knowledge. This present knowledge, which consists of facts, is available to him at any point in time, and is referred to as his cognitive structure"[21].

Ausubel's theory refers to the part played by prior knowledge in organizing new learning and building it into the cognitive structure[21]. In the same way, Novak[22] agreed that Ausubel's theory is considered more applicable and more powerful for science and mathematics education than the developmental psychology of Piaget.

It is useful to discuss briefly the five keys as they apply to instruction in physics.

1-3-1 **Meaningful learning**

The important idea in Ausubel's theory is that of meaningful learning which is defined as follows:

"meaningful learning takes place if the learning task is related in a nonarbitary and nonverbatim fashion to the learner's existing structure of knowledge"[21].

According to cognitive structure theory, it is a framework of knowledge stored in the learner's mind that grows and develops towards formal reasoning. For example, a student learns new knowledge on the *power* of a machine; it should be consciously related to what he already knows:.

Work done = Force x distance

and velocity = distance/time.

Power = Work done / time taken = Force x distance /time

Power = Force x velocity.

Therefore the learning occurs when the learner makes a conscious effort to determine the key concepts in new knowledge which relate them to other concepts.[22]

1-3-2 **Rote learning**

Rote learning is considered to be opposite of meaningful learning, "rote learning occurs when no such interaction takes place"[20].

Ausubel makes a strong distinction between rote and meaningful learning where rote learning results in a arbitrary, verbatim incorporation of new knowledge, but meaningful learning consists of the assimilation of the new knowledge, by relating that to existing knowledge in the learner's mind. It should be noticed that, the process in cognitive structure differs from Piaget's concepts of assimilation, but results from growing differentiation and integration of specifically relevant concepts in cognitive structure.[22]

1-3-3 **Discovery learning**

Discovery learning is defined as follows:

"the principal content of what is to be learned is not given but must be discovered by the learner before he can internalize it".[21] By this method, the concept should not be stated but the learner is given procedural instruction to discover the concept for himself.

1-3-4 **Reception learning**

In reception learning "the principle content of what is to be learned is presented to the learner in more or less final form".[21] The information is provided directly to the learner and it does not involve any discovery.

Ausubel distinguishes between these methods of reception and discovery learning, in that in reception learning the content is presented to the learner either by the teacher or by written instructional material in the final form. Ausubel considered that discovery and reception learning methods could be classified either as meaningful or as rote learning.[21]

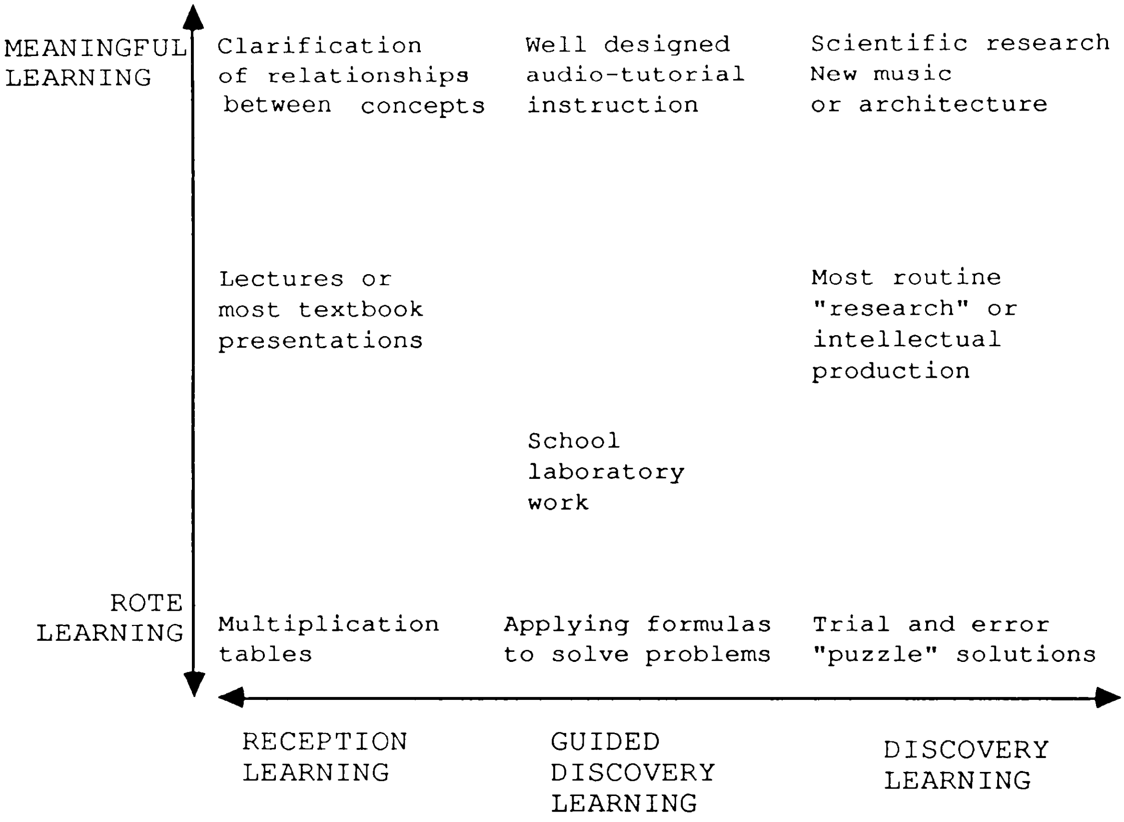


Figure 1-1. The comparison between methods of learning (Novak, reference 22)

Figure 1-1 shows the differences between the learning continuum (rote to meaningful learning) and the instructional continuum (reception to autonomous discovery learning) as well as the relation between these.

West and Fensham[20] have proposed that meaningful learning could occur by the following two processes:

(a) the use of relevant and irrelevant subsumers in the prior knowledge.

(b) the use of advance organizer subsumers.

1-3-5 **Subsumption**

Ausubel used the subsumers concept to represent the aspects of existing knowledge which provided the interaction of meaningful learning and the facts. A subsumers is defined as "any concept, principle or organizing idea that the learner already knows that can provide association or anchorage for various components of new knowledge".[22]

The process of subsumption differs from Piaget's concept of assimilation in that it does not occur in the basic stages of development but rather results from growing differentiation and integration of relevant concepts in cognitive structure:

(a) new knowledge is linked to specifically relevant concepts or propositions.

(b) this process is continuous and major changes in meaningful learning occur not as a result of a stage of cognitive development but rather as a result of growing differentiation and integration of specifically relevant concepts in cognitive structure.[22]

1-3-6 **Advance organizer**

In order to facilitate the incorporation of new knowledge into the cognitive structure, Ausubel has proposed a pedagogical strategy of using advance organizers. "This is a verbal statement, presented to the learner before the detailed new knowledge"[20] Novak's statement[23] that the organizer "is a small learning episode that is more general and more inclusive than the learning material that follows and that it is perceived by the learner to serve as a cognitive bridge between what he or she already knows and what is to be learned". The advance organizer facilitates new knowledge, when the material is completely novel and no relevant concept exists in the learner's mind.[24]

On the basis of psychological theories of cognition and learning as well as educational researchers' findings it can be concluded that

(a) learning by discovery method is not a necessary condition for meaningful learning in science .

(b) "The concrete experience must be represented in a context that helps to build conceptual framework. Then and only then, will the early learning form a base for the assimilation of experiences that come later, experience that may involve direct observation or the report of observations made by others".[25]

1-4 **Utilization of Ausubel's theory**

There have been several investigations of Ausubel's theory of cognitive structure. For example, Larkin and Reif[26], in a study of problem solving ability using university students, recommended that students should be taught to:

(a) integrate separate principles into a general coherent method suitable for many diverse problems.

(b) approach the problems hierarchically by a process of successive refinements.

Shavelson[27] in his investigation of cognitive structure, indicated that the cognitive structure of learners underwent change during instruction in physics. Key facts and concepts were interrelated more closely at the end of the instruction that at the beginning. The learner's cognitive structures and the content structures corresponded more closely.

Entwistle and Huggins[28] have reported that, when two closely related concepts are taught together, the student learns less about either concept than they would if the concept were presented separately or along side some unrelated concept. The close association between the concepts seems to interfere with the meaningful learning.

Several studies have dealt with expository teaching following Ausubel's model. Babikian[29] has investigated the effect of three methods of learning, viz discovery, laboratory and expository in teaching science concepts at the junior high school level. It was found that both expository and laboratory methods were significantly more effective then in the discovery method for overall achievement, verbalization and recognition of concepts and application of empirical problems. Furthermore the expository method was as effective as the laboratory method for overall achievement, verbalization recognition, transformation, application to numerical problems, discovery and retention of concepts. Moreover, all students found the three methods interesting, but most of them considered the expository method for teaching science the easiest, the clearest and the best method. Similar results were reported by Grabber[30] , in studying of the comparative effectiveness of the expository and discovery method, and no significant difference was found in terms of the students understanding of the concepts of science or their cognitive process skills.

1-5 **Neo-Piagetian theory of intellectual development**

A number of investigations have been undertaken to study the relationships between the level of student's cognitive development measured with basic Piaget's tasks, and their performance particularly in science and mathematics. Neo-piagetian theory was proposed by Pascual-Leone 1969.

The central idea in the Neo-Piagetian model is the size of the child's X-space (mental capacity) which grows gradually with age [40]. The Neo-Piagetian model was proposed to illustrate the mental-processing complexity of the various mapping operators.

According to Pascual-Leone[31] and Case[32], students' performance at any given cognitive task is a function of four parameters:

1 the mental strategy which he attempts to apply to a task.

2 the demand which, in attempting to apply the strategy puts on his mental capacity

3 the mental capacity which he has available (X-space)

4 disembedding ability (Field Dependence/Field Independence)

Neo-Piagetian theory has been used to give a sufficient interpretation of the intellectual development of children. Hence it could provide a satisfactory means of gaining prediction in science education.

Let us now discuss briefly these hidden parameters:

1-5-1 **Z-demand (task's difficulty)**

Information processing load in the Neo-Piagetian model is represented by Z-demand, a term defined as "the maximum number of schemes that the subject must activate simultaneously, through an attentional process in the course of executing a task".[31]

In this connection, Johnstone[33] explained Z-demand in terms of what student had to consider, recall and process before starting to tackle the question. The Z-demand is expressed as the number of thought steps in a process necessary to solve a problem for the least sophisticated students It should be noted that, in the same task a different Z-demand could be experienced by different solvers depending upon how they chunk the information given to them by the task, and the benefit of their prior experience.

Pascual-Leone has conducted task analyses in terms of the amount of information required by a task. For example, the Z-demand of conservation of weight[34] has four thought steps. However, it is difficult to determine the Z-demand of a task without knowing the strategy employed by the solvers. In addition Niaz[34] has suggested that, it is possible to change the Z-demand of an item without changing its logical structure. This could avoid overload on student's working memory space.

1-5-2 **Repertoire**

According to Pascual-Leone[31] and Case[35], the cognitive function can be explained in terms of the activity of "schemes" which is defined as a "technique" word to represent past and present states. In other words, the schemes are considered as responsible for producing behaviour. At any given time, there are a large number of schemes in a subject's repertoire in order to release responses or behaviour and effective responses.

In another study, Scardamalia[36] explained the "schemes as a psychological entity that accounts for organized pattern of behaviour".

The schemes could be represented in three states; a figurative scheme, an operative scheme, and an executive scheme. We shall now discuss briefly the function of each:

1 Figurative function which is defined as the internal representation of items of information or behaviour (store of knowledge). In other words, the schemes are presenting past or present states of acts.

2 Operative function. These schemes are representing a transformation in the previous cognitive experience and broad ideas have been adapted and extended to produce a new pattern of knowledge which comes into existence.

3 Executive function. Which is responsible for producing what figurative and operative schemes a subject activates. Therefore, mental efforts are required to activate or rehearse schemes by modification of old schemes and comparison of several schemes producing direct responses.

It should be noted that the amount of mental effort employed at any time during these process is limited. Therefore the number of schemes used in any mental effort could also be limited.

1-5-3 Mental capacity (working memory X-space)

According to Pascual-Leone[31], Case[32,37] and Scardamalia [36] the mental capacity is a limited resource that increases with the age throughout childhood. When measured behaviourally, maximal mental capacity is found to increase linearly every other year during normal cognitive development from capacity of mental one unit or scheme at 3 and 4 years of age to a capacity of 7 mental units at 15 years and older. The capacity of working memory is fixed at least from age 2 years, according to the following scale below:

Piagetian sub-stages	*age (year)*	*X-space*
1. Early pre-operational	3-4	e+1
2. Late operational	5-6	e+2
3. Early concrete operational	7-8	e+3
4. Late concrete operational	9-10	e+4
5. Early formal operational	11-12	e+5
6. Middle formal operational	12-13	e+6
7. Late formal operational	14-15	e+7

The symbol (e) is used to represent the process in space for the executive schemes, and the numbers represent the maximum number of schemes that can be successfuly coordinated at a given time.

Working memory space is defined by Pascual-Leone and Smith[38] as the maximum number of schemes or items of information a subject could store and retrieve without further processing. Here, the working memory function is assumed as well as short-term memory.

Case[39] has shown that students at the same age can have different working memory capacity and they can learn new strategies. In general students with large working memories learn more effectively, whereas those with working memories smaller than minimum for the Z-demand of the task generally fail to learn. As a consequence of increasing working memory, it becomes easier to acquire and employ more complex executive strategies.

1-5-4 Disembedding ability (Field Dependence/Field Independence)

There has been much work done in the light of cognitive style (Field Dependence/Field Independence). According to studies reported by Witkin[40] and Goodenough[41] the effect of this factor on student's performance has been investigated.

Field independent students seem to have the facility for attending to the essential information in a situation and are not deflected by irrelevant information. The get to the "heart" of a problem directly.

Field dependent students have difficulty in separating what is essential from what is irrelevant and so easily become confused and indecisive.

Most students are somewhere along a continuum between these two extremes.

Pascual-Leone [31] demonstrated that field independent subjects are higher processors and tend to use a functional X-space (X_f) close to or higher than their X-space (X_s) whereas field dependent subjects are lower processors and tend to use X_f much lower than X_s. For example, Frank[42] and Kenneth and Frank[43] found that the students' performance was affected by the particular learning note taking. During the lecture, students must chose one of the following three learning methods: personal notetaking, notetaking on a skeletal outline and provisional notes. They found that field dependent students increased their factual achievement between immediate and delayed testing, but field independent students decreased their factual achievement slightly. The field independent students in general, obtained higher results than field dependent students when lecture notes were taken, but both performed comparably with detailed notetaking.

In another study, Niaz[44] found evidence to support the hypothesis that the manipulation of the perceptual field dependence/field independence factor would effect students performance in two different tasks (water pouring and beam balance, in each of which there were two questions i e four items in all). He calculated correlation coefficients between the disembedding ability test and students' performance and found that the correlation coefficients between the GEFT (Group Embeddded Figure Test- for a description see page 48) and the four items remained significant before and after they had done the associated practical work.

Dovis and Frank[45] concluded that field independent students perform more effectively than field dependent students, and both employ different encoding strategies, or when they apply the same strategy the effectiveness of it could vary. In addition, Nummedal and Collea[46] have found a significant correlation between the field dependence/field independence test and students' performance in proportional reasoning where irrelevant-relevant information was presented, but no significant correlation between them when only relevant information was presented. Recent studies by El-Banna[47] and Al-Naeme[48] investigated the performance of chemistry students in problem solving. It was found that the students' ability was dependent on the extent to which they were distracted by irrelevant information.

There was a strong relation between the students' performance and their ability to select relevant information for the group of students with low working memory space. For students of medium X-space the relationship is less pronounced, and no relationship was found for students of large X-space.

1-6 **Utilization of Neo-Piagetian model**

Several factors affecting the ability of students to interpret a given problem have been examined.

In a recent study Scardamalia[36] has pointed out that X-capacity could not account alone for "horizontal decalage". She noticed that there were other factors, e g stimulus saliency and previous experience. She reported that the poor performance of students on a given problem could be due to their: (a) lack of logical competence, (b) low working memory capacity, (c) insufficient experience, and (e) inability to isolate irrelevant from relevant information.

Similar study is reported by Lawson[49] who determined that the condition of student's achievement is a function of the following cognitive variables:

(a) repertoire of information processing schemes, i e Piagetian development, (b) the size of working memory, (c) ability to select relevant information, (d) previous relevant knowledge, (e) prior beliefs.

Niaz and Lawson[50] have concluded that reasoning is required to use the trial and error method for balancing chemical equation:

(a) the more complex equations place an increasing Z-demand on mental capacity.

(b) mental capacity correlated significantly with only complex questions (high demand).

(c) field dependence/field independence factor plays little role in this study.

In another study supporting the Neo-Piagetian theory (Niaz[34,51]), confirms that the activity of schemes would be increased by cognitive operators. It was found that students' performance decreased as the Z-demand of the problem increased. Johnstone and El-Banna[52] have confirmed the importance of working memory overload when Z-demand of the question is greater than X-capacity of student. This causes a sharp fall in performance.

Ronning[53] suggested that problems could be considered to be at least three dimensional: (a) domain of knowledge, (b) problem solving method, and (c) characterstics of solvers (in this case, field dependence/field independence).

In addition, Case[32] concluded that, the Neo-Piagetian theory has the potential to make detailed explanations and predictions for interpretation between instruction and development.

Chapter two

2-1 Introduction

The important goal in this part of study is to get an idea how pupils learn and how the information is stored in memory, so it should be useful to know about the storage and the retrieval of information in problem solving.

Norman and Lindsay[54] described what characterizes the memory system as follows:

(a) the concept of memory system.

(b) the process whereby knowledge is stored, retrieved and utilized in learning and problem solving.

(c) the information processing model of memory postulates two aspects which are related to internal structure i.e. the brain.

We shall now briefly discuss what is happening between input stimulus and output responses.

2-2 Component of memory

According to Bourne et al[55] the basic component of the system memory are three memory stores called the sensory register, the short-term (S.T.M) store and the long-term memory (L.T.M) store. The three stores are structurally distinct, because they process information in different ways, for different purposes and for different durations. They also lose information in different ways. This is illustrated in figure 2-1.

2-2-1 Sensory register

There are a number of different sensory systems. The model suggested by Atkinson and Shiffrin[56] considered a separate

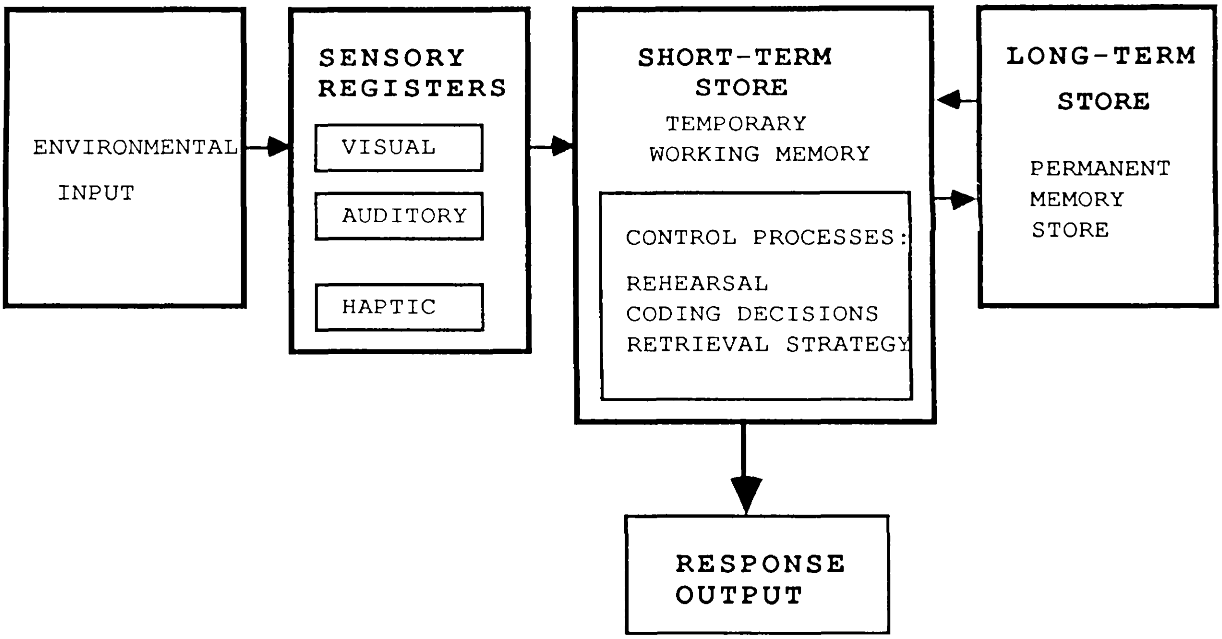


Figure 2-1. The component of memory (Atkinson and Shiffrin reference 62).

sensory system for each sense, each corresponding to a different sensory modality; visual information entering `the system through the eyes is initially stored in the visual sensory memory called the "iconic memory", while auditory information, entering the system through the ears, is initially put in a auditory sensory memory, called "echoic memory". We also note that there are other sensory systems.[55]

The external information enters the system through the sensory memories; it goes first to the sensory register which accepts all external information from any event, but it does not keep it a long time; most of the information might be lost from this store in less one second. Many researchers are agreed that the information in the visual sensory store persists for a duration of only 250 m.sec, whereas in the auditory sensory store the duration is at least 3 or 4 sec.

Atkinson and Shiffrin[56] concluded that" the information is lost from the sensory register rapidly by decay". It may be that not every item which enters this store is lost, but much can be transferred to the short-term memory store. In addition, the sensory memory is capable of registering a vast amount of information. Murdock[57] pointed out that the sensory system was assumed capable of having a large capacity for holding and storing a large information but for only a very brief period. Lachman et al[58] have indicated the function of the sensory register is to preserve meaningful information for a time long enough for it to be selectively transmitted further into the memory system.

2-2-2 **Short-term memory store (S.T.M)**

A large number of investigations have been carried out to explain the nature of the limitation of the short-term memory store. In many cases, the information passes through the sensory memory store to S.T.M store, and some passes into the long-term memory L.T.M store. During this corresponding interval, some of this information is lost from S.T.M.

The short-term memory store is found to have a very limited capacity, and the items of information can be held in it for only a short period unless they are transferred to long term memory.[59] Miller[60] demonstrated that the majority of people can hold only about 7 plus or minus two units or "chunks" in short-term memory store. He used the term "chunk" to refer to the items that can be stored in S.T.M at any time, but it is not easy to offer a precise definition of chunk. However, it refers to any familiar unit of information based on previous learning. Miller found that pupils are limited in capacity to the number of information processes which they can keep in memory, and this limited capacity influences their performance on a variety of tasks.

There is other evidence for the limitation of S.T.M to hold possibly seven items only. A well known test which is often used to measure the limited capacity of subjects is called a " Digit Span Test". This test requires that the person can recall a sequence of items in the correct order. The size of the groups is increased until the person can no longer give them back; this is taken to be a measure of short term memory. Most of us would find difficulty in remembering a 7 or 8 digit telephone number for few seconds before dialing. The fact that people can hold in their mind only 7 or 8 digits is taken as an estimate of the size of S.T.M store.[61]

Atkinson and Shiffrin[56] have concluded that as information is held in S.T.M storage, it is automatically transferred to L.T.M store. This transfer takes the form of copying the information in both stores. Another description of "the short-term store is a working memory where conscious mental processes are performed on information from both the sensory register and the long-term store". Atkinson and Shiffrin[62] explained in another study the process in terms of conscious manipulation. Information must be copied into the S.T.M. It should be noted that this transfer by copying does not remove the information from its source stores. They agreed that information cannot be consciously processed in either the sensory or the L.T.M store. Conscious processing is identified as a unique function of S.T.M. In addition, Peterson and Peterson[63] found that information is rapidly lost from S.T.M if the subject has to perform another task. They have agreed that items will be lost in S.T.M store unless they are immediately recalled, and a brief delay causes loss of information. Thus is due to trace decay.

2-2-3 **Long-term memory store**

A number of investigations have indicated that there are many ways to rehearse new information. For example Craik and Lockhart[64] suggested that there are at least two types of rehearsal:

"maintenance rehearsal" and "elaborative rehearsal". In "maintenance rehearsal" there is a repeat of the material without thinking about it. It should not cause any of the material to be transferred to L.T.M. While in the "elaborative rehearsal", the information is transferred to L.T.M, and it is considered to involve taking new information and doing some operation with it. For example, attempting to relate it to other things that are known.

The information can be transferred from a temporary store to a more permanent long-term memory store and perhaps also from the sensory register store. The long-term memory store contains an unlimited amount of information coded in many forms. The purpose of L.T.M is to keep information and all rules for its processing when they are not being used.[58]

In this connection, Child[65] has pointed out that the L.T.M store depends on several factors relating to the information. He focuses on four of those factors, namely the length, the content, the opportunity for initial learning and the activity. For example, long messages are less likely to be remembered then short ones. Atkinson and Shiffrin[56] emphasize the interaction between S.T.M and L.T.M, the rate of forgetting from L.T.M varying from a few minutes to many years, the decay rate of information in L.T.M is shown in comparison with the rapid decay rate from S.T M

A similar study by Lachman et al[58] has indicated the different ways of losing information from this store: by decay, by distribution from new input external information, and by efforts to retrieve the knowledge for recall.

In this model of information-processing, there are two vital processing stages; encoding processes and retrieval processes:

(a) in the encoding process, the physical characteristics of the stimulus by such a word as speed, force, time etc are processed and encoded as a memory trace. Some of these processes correspond to the sample processing done by the perceptual system in order to identify or categorize the stimulus input.

(b) in the retrieval process the memory trace is retrieved by operations designed first to access the correct memory trace, and than to devise useful information for stimulus items.[61]

Similarly a study by Melton and Martin[66] on encoding showed that this occurs when the information leaves the S.T.M and enters the L.T.M. This process is called encoding and the information that is stored is organized in various ways rather than being merely collected. Child[65] has explained the retrieval as the return of information to the S.T.M from L.T.M store.

Atkinson and Shiffrin[56] suggested several control processes that can be used in any attempt to learn a new piece of information. They pointed out that there are strategies employed to facilitate learning which include rehearsal, coding and imagining. These are the three primary ways for learning.

2-3 **Working memory**

Baddeley[67] proposed a model of working memory which allows the discrimination between storage and processing capability. He suggested that the working memory system contains a component which is used only for storage and a flexible "working space" (or central processor). He concentrated on the function of the short-term memory with its limited capacity of few items for a few seconds. In this connection, Sanford[68] explained that working memory can be thought of as working memory space which may be flexibly divided between data storage and data manipulation. The operation of working memory is conceived of as an interpretation/thinking memory space.

Working memory implies a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as, comprehension, learning and reasoning.[67] Again, Greene[69] has identified the working memory as being a memory in which new items can be received and necessary information can be retrieved from long-term memory and allowed to interact. Baddeley[67] agreed that working memory is necessary for cognitive functioning which depends on the interaction between old knowledge (stored knowledge) and new input information. Greene[69] also pointed out that the aim is to explain how new items can be interpreted in the light of old knowledge. In other words, the working memory works by retrieving necessary information from long-term store and preparing appropriate processes in working memory so that it is responsible for selecting input information and assessing knowledge from L.T.M, planning strategies for solving problems and for outputing appropriate responses.

Following this, Lachman et al[58] have explained that outputing responses to a question is arrived at by a manipulation of information in working memory space. Further, Cohen et al[61] pointed out that the retrieval of information from L.T.M could depend on how it was stored.

According to Baddeley's model, the working memory is assumed to have an important role in selecting learning strategies, manipulating and operating strategies for retrieval of the necessary knowledge from permanent store, while L.T.M is assumed to be capable of utilizing a range of control processes and strategies.

In this connection, Johnstone[70] described the working memory as that part of the brain where a person holds information, works upon it, organizes it and shapes it before storing it in the L.T.M for further use.

2-4 **Chunking**

Miller[60] in a very influential paper introduced the idea of "the magic number seven plus or minus 2." Miller introduced the magic number as a number of "chunks" that can be held in S.T.M store for immediate recall. In order to explain more precisely the meaning of "chunk", several researchers have been involved. For example, Simon[71] has explained that "a chunk of any kind of stimulus material is the quantity that short-term memory will hold five of". The chunk consists of individual items that have been learned and stored as a group in L.T.M[72]. Miller agreed that the capacity of S.T.M should be measured in chunks rather then in individual items. Atkinson and Shiffrin claimed that there is a S.T.M storage with a number of "slots" into which a chunk of information can be placed, and the limited capacity is due to the small number of "slots".

Miller's paper suggested that recording the information in the form of chunks can help one overcome the limited capacity of S.T.M. A person finds it easier to remember things when they are grouped into large chunks. "We must recognize the importance of grouping or organizing the input sequence into units or chunks".[72]

The best performance usually was found with groups of three or four items as a chunk. For example, Ryan[73] found the recall of sequences was optimal when groups of three or four were used. As a result, the number of bits of information could be increased by building larger and larger chunks when more information is involved than before.[60] Here Johnstone[74] has pointed out that the learner is able to chunk a lot of information into workable items, thus allowing him or her to reduce the load on the working memory. A problem may have several steps, but require much information for its solution, and if the solver has good cognitive structure for grouping the amount of information into a small number of groups (chunks) it is possible that overload could be avoided on working memory.

It has been found[74] that a common source of difficulty in tackling a problem is overload when the demand of the question is greater then student's capacity. Johnstone has suggested that it would possible to reduce the task's demand on working memory by helping the student to build a strategy. He described this strategy as a trick or technique for simplifying the difficulty of the task and for organizing his previous knowledge. In an additional study it was suggested[75] that the information content of a task is related to the existing conceptual understanding and the level of perceived difficulty. These are related in the following ways:

(1) the number of chunks represented by given information will depend on the conceptual understanding.

(2) when a large number of chunks are required at some stage in a given task, the more difficult the material is seen to be, and the poorer will be the results.

(3) if chunk capacity is exceeded, the following may result:

(a) the solver will extract no useful information when he attempts the whole problem.

OR (b) he will use memory conserving strategies which allow a sequential treatment, and will succeed in obtaining new information.

(4) conceptual understanding leads to an efficient (small number of chunks), organized (steps performed in efficient order) and converging strategy.

Let us study this statement "*the angular momentum of an isolated system is constant*" from the point of view of both teacher and student. The teacher could think of the communication, and reconstruct the statement as a small number of chunks. Thus (*the angular momentum*) *of an* (*isolated system*) *is* (*constant*). In this way Johnstone[70] pointed out that the teacher's working memory is already organized.

The students who have not learnt as much as the teacher, may hear it as rather more chunks as shown below:

the angular) (*momentum*) *of an* (*isolated*) (*system*) *is* (*constant*).

This could then lead to overload in working memory and failure to register the whole message. Hence it is important to separate the items, and form them into new, larger chunks, and so help students to form larger and fewer chunks.

Another example is where the teacher shows students Newton' rings apparatus, which is commonly used in school for measurement of wavelength. The teacher could see this equipment as a small number of units or chunks as he knows the function of each unit. These units are shown by circling symbols that served a common function in figure 2-2A, whereas the students are having to cope with 10 or more units or chunks as shown in figure 2-2B.

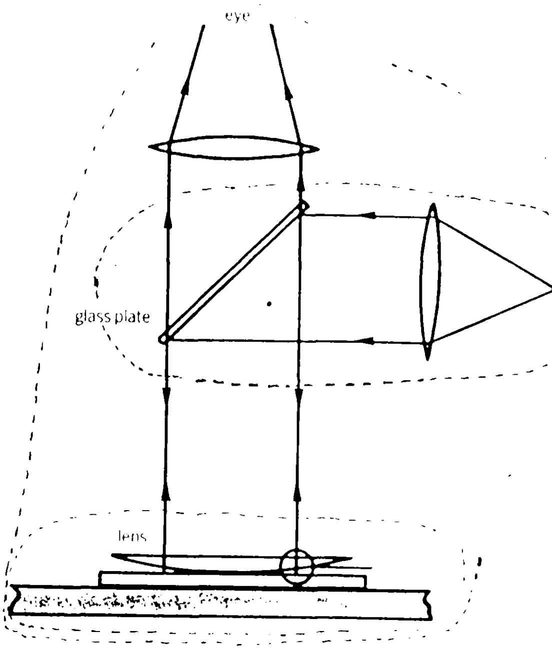


Figure 2-2A

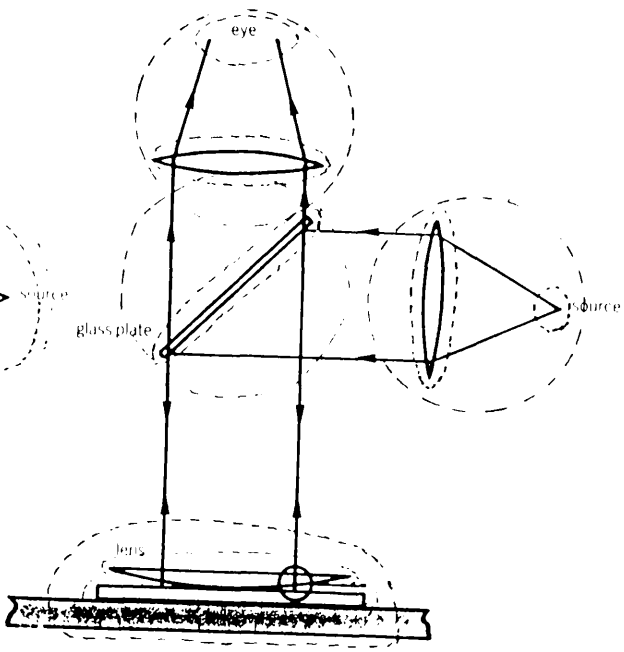


Figure 2-2B

The ability to chunk information is related to a strategy which has been learned. The number of chunks the student can hold will vary from one student to another depending on their characteristics. In fact, White[59] has reported that "the more you know about the topic the easier it is for you to chunk it."

It is important to distinguish between Miller's and Johnstone's theory about the short-term memory. Miller believed that the function of short-term memory is to hold information (7 ± 2) without manipulating it, and it could be possible to increase the amount of information per chunk. While Johnstone emphasized that the working memory capacity is smaller than short-term memory capacity because part of the working memory is a given over to operations, techniques, etc. so that our working memory is nearer to (6 ± 2) items. This perhaps leaves some space for processing and operations.

2-5 **Problem solving**

Problem solving ability has come to be regarded as an important part of any science course. In order to solve a problem, several components are required for both the problem itself and the problem solver.

The ability to solve physics problems involves recall of relevant knowledge (i.e laws, mathematical formulae, conceptual physics, etc) which had been previously learned and placed in long-term store, as well as processing and maintaining of current information in working memory, and employing certain strategies to minimize the load of processing. Both memories have a great effect on success in solving problems. In attempting any problem, it is interesting to identify firstly all the relevant information required to solve it. Some of this information could be given in the problem statement and part will have to come from the student's previous knowledge.

In fact problem solving was defined by Ausubel[76] as a form of discovery learning, bridging the gap between the learner's existing knowledge and the solution to the problem. Greeno[77] argues that problem solving is based on two types of knowledge: procedural knowledge of problem solving strategies and more elaborate conceptual knowledge. On the other hand, the best chance of success in solving physics problem depends on a mixture of large previous knowledge in physics, and employment of some strategies and tactics.

Cooper and Nason[78] have explained how problem solving ability is in general enhanced if the concepts and processes are stored in highly related chunks in L.T.M.

The limitation on a student's information-processing capacity can be attributed to several factors:

(a) The student will encounter a variety of difficulties in solving problems because of limited working memory capacity.

(b) An expert student might find certain problems easier because his or her expertise allows him or her to reduce the load on working memory capacity by chunking.

(c) The problem could be easily solved by employing certain strategies.

(d) Problem solving should be quite different depending on whether or not a students has a memory aid available.[55]

Wallas[79] has suggested four stages which are useful as an aid to success in solving physics problems:

(i) define the problem ; (ii) select approporate information

(iii) combine the separate pieces of information; (iv) evaluate.

On the same theme, Johnstone[33] believed that a student might respond correctly to a question when he interprets the question into his working memory and then has to add to this information from L.T.M store such as facts, method, strategies and still have space available. Therefore he suggested three things might result when overload takes place on working memory:

(a) the student would find the question impossible to solve.

(b) the student might find the best way to proceed by employing certain strategies such as breaking down the whole problem into sub-problems then solving each one separately while not exceeding the working space available.

(c) the student could use his strategies to help him to take short cuts by reducing the number of chunks through increasing the amount of information in the chunks.

We can list the common mistakes in solving physics problems. Many students simply proceed to calculate something from the data given in the problem statement by using different mathematical formula without asking themselves whether this calculation will get them close to the answer to the question. To reach the correct answer they must choose the best move. This would require more thinking to find which intermediate steps and physics laws are involved and then devising a plan for proceeding to the next stage. Thereby the problem space might be even further reduced. Although the students may have sufficient knowledge, they may be unable to recall the necessary information required to organize it. They may lack any strategies to guide them in applying such facts and principles, or they may not have had enough practice.

We believe that if a student has learned cognitive strategies and improved these by practice, he will soon be capable of transferring this experience to tackle different problems in different domains.

Evidence from Larkin[80] and Larkin et al[81] in general indicate that experts should have more large scale functional units available to them, whereas novices tend to have their knowledge stored in a less organized fashion. This work aimed to provide instruction to increase the student's chunking of appropriate physics concepts. When this group was compared to a control group it was found[80] that the experimental group:

(a) demonstrated striking improvement in difficult problem solving

(b) produced more drawings and diagrams.

(c) appeared better planners in tackling the problem.

(d) showed better use of necessary and relevant information

(e) spent less time wandering down blind alleys.

It is possible that the instructional method used with the experimental group could be a guide to help students to develop their abilities earlier.

Reif[82] and Larkin et all[26] reported on how a novice and an expert solved physics problems. The expert was a physics professor who had recently taught a mechanics course, while the novice was an excellent student who had recently completed his first University-level course in mechanics. Both solved five problems. On this basis the expert and novice differed only in the following important aspect: the novice began individually to construct a mathematical description of the problem. He identified principles and applied them individually to generate equations. On the other hand the expert applied principles not individually, but selected a general method and used it to work by successive refinements.

Another common difficulty of many students is associated with not being able to grasp the physical situation sufficiently clearly in the problem statement. They may also have difficulty in visualizing the description of the statement because the data may not be explicitly stated or because there is an actual difficulty in expressing the physical action clearly in words. In this research adding a diagram to the statement will be suggested. In other words, the part that language plays in the problem could be a very important factor in the performance of student in solving physics problems.

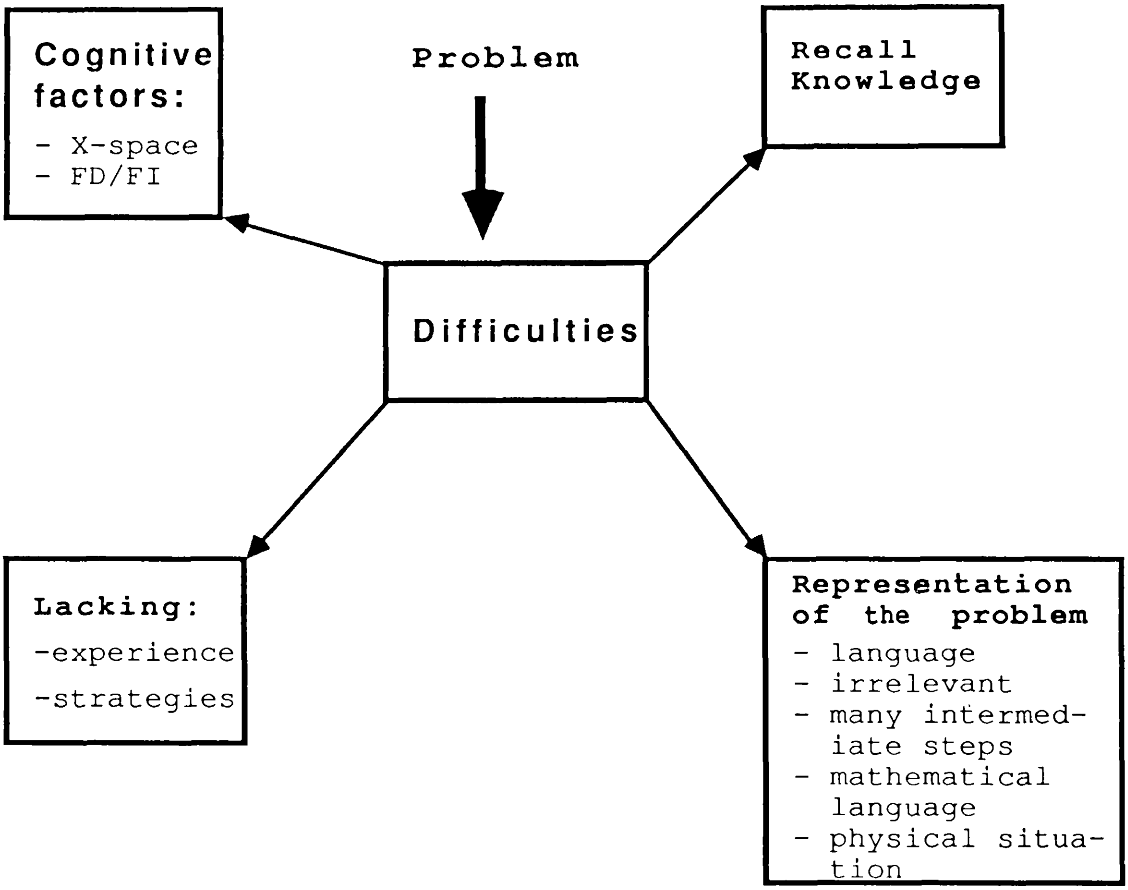


Figure 2-3. The cause of difficulties in solving physics problems.

For any physics problem there are two necessary factors:

(1) Dependent factors which relate to the characteristics of students, such as working memory capacity; disembedding ability (FD/FI): recalling principles and knowledge; experience, and employing strategies.

(2) Independent factors refer to representation of the problem itself: the language; negative questions; irrelevant and unnecessary information; hidden physical action behind the words; too much information, many intermediate steps, and mathematical language.

These are shown in diagram 2-3 above.

According to the above, it would seen useful to teach students some strategies such as those below. These might enhance their ability to devise a plan and organize their thinking to tackle any problem:

(a) to summarize the information and remove the relevant from irrelevant information and display this by drawing principal diagrams or tables showing all unknown quantities.

(b) how to break down the whole problem into small problems which are more readily attempted

(c) to identify the principal key or keys which might be necessary and then classify the problem

(d) which and how many mathematical formula are needed and what relation exists between unknown quantities (variables) in the question.

(e) identify the unknown quantities and give each one an algebraic symbol, then work through intermediate steps related to answering the question.

It is worthwhile for a student to be given many opportunities to practice solving small problems by employing certain strategies but the problem should be represented to the students in an effective way as defined in a later chapter. This ensures that the student leaves space in memory for holding and processing, thereby reducing or avoiding the problem of overload.

Reif[83] has also shown the manner in which students organize knowledge in cognitive structure and how this affects their performance in various tasks. He found that students who organized scientific information in a hierarchical manner performed better on recall and modification of an argument, as compared to those who organized the same information in a linear manner.

Reif et al[84] have showed that, it is possible to make progress in teaching some general skills necessary for effective learning and problem solving. In their investigation, they identified several abilities which were required for gaining a better understanding of any new relation. They taught some strategies for problem solving consisting of the following four important steps: description, planning, implementation and checking. Their results indicate the following effects of the special instruction designed to teach strategies:

(a) students who received such instructions exhibited a greater use of diagrams and also a more intelligent use of algebra before calculating numbers.

(b) such students showed more extensive planning, and also a greater success in attaining solutions than the student who have been given an ordinary physics course without special instruction.

In addition, when they compared the two groups of students they found that:

(a) most student after several weeks of ordinary instruction had not acquired the new physics relations given to them.

(b) special instruction in learning skills enhanced substantially the students' skill of gaining an understanding of the new physics relations.

2-6 **Working memory model**[52] **and hypotheses**

Based on a model of working memory, an attempt was made to explain the success and failure of students in learning physics in terms of the following three factors which influenced their achievements. These factors are:

(1) the mental strategy that the learner employs to tackle a question. This is related to schema, tricks and previous knowledge.

(2) the demand of the task (task difficulty).

(3) the capacity of working memory (X-space).

and in addition a fourth factor was considered

(4) the disembedding ability (FD/FI).

In a recent study, Johnstone and El-Banna[52,85] investigated a model for thinking/ holding memory capacity, as shown in figure 2-4.

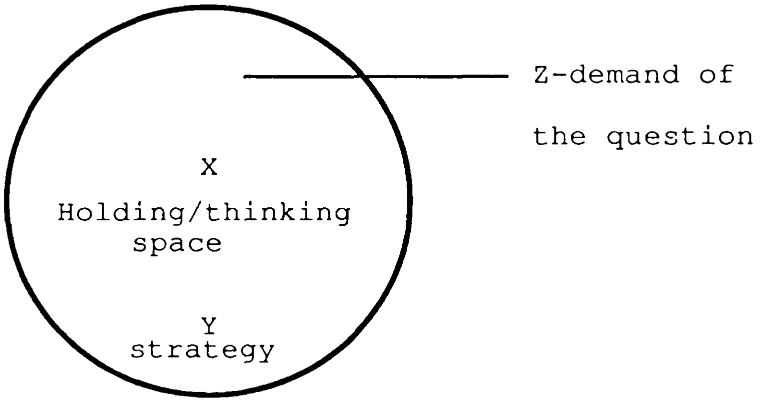


Figure 2-4. Simplified model (Johnstone and El-Banna, reference 85)

Here Y represents all functional strategies needed to process the given information.

X refers to the maximum number of items of information (chunks) that the student can hold in his working memory.

Z represents the number of thought steps or pieces of information necessary to solve a problem.

They have demonstrated that our working memory capacity can hold only a few items while we think about them. They suggested this by analyzing chemistry items into the number of thought steps (Z-demand) and by measuring the working memory of both secondary school and university students. The facility value (F.V) (which represents the percentage of the sample who solve a question correctly) was plotted against the number of thought steps (Z-demand) required. These results are presented in figure 2-5.

The results indicate that the students can succeed in solving problems if $X \geq Z$, but will fail if $X < Z$ unless they can operate on

Z-demand by applying certain strategies or techniques to allow the Z-demand to be organized and become less than X. This study has emphasized the role of the working memory in problem-solving.

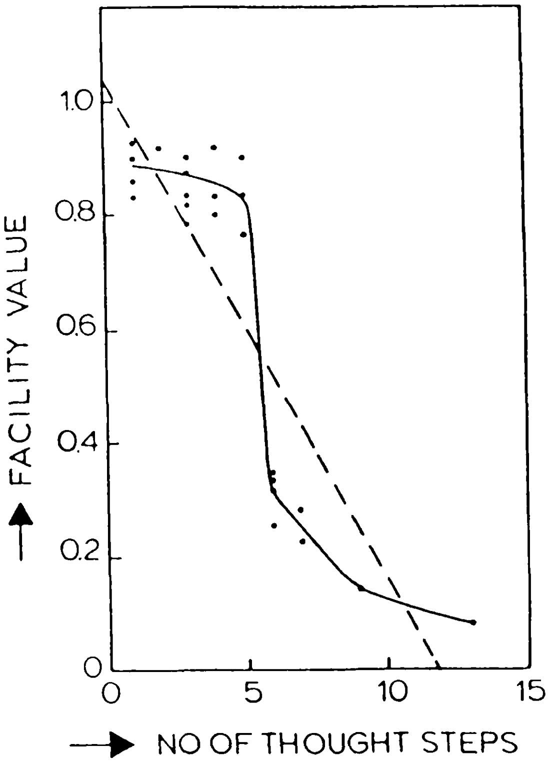


Figure 2-5. A plot of facility value against the number of thought steps required to solve the question (reference 52)

2-7 **Overload of working memory on practical work hypothesis**

Modern models of working memory may have relevance to learning in physics, particularly in areas which students perceive as difficult.

In laboratory work there are many factors which can cause student difficulty and even lack of success. This can be so if there are many steps in the practical process, with resulting heavy load of information. This causes high demand. As a consequence of this overload, the students may not understand the task in hand.

Participation in appropriate laboratory and practical activities could play a very important role in developing scientific concepts and problem solving skills. Practical activities are potentially one of the most important resources in facilitating learning /teaching physics.

The Z-demand of practical work can produce information overload on a student's working memory. When the students are doing practical work, they are actually under perpetual working memory overload[86]. Here the overload was estimated from different types of information received from different sources at the one time: written and verbal instruction provided; previous knowledge theory to be recalled; practical skills and experience to be remembered or acquired; manipulation of the operation of different equipment, and the processing of much information and dealing with the many steps required to be managed in an experiment.

In this connection, Johnstone[52] defined working memory as that part of the brain which holds items of information; where work is done upon them to organized them, and then transfers this information to permanent store in long-term memory for further use. He has explained that overload occurs if it leaves us no space for thought and operations. Once more, in practical work the overload of working memory seemed to appear when a student is not able to distinguish between irrelevant and relevant information stated in the experimental instruction. In other words, the student could not distinguish what is important and what is not. As a result, the student is lost through not understanding what he is doing. He may not have prepared for the experiment and have sufficient grasp of background concepts and technical skills to carry out an experiment.

Moreira[87] found that in many cases, the students perform an experiment without clear ideas about what they are doing or about

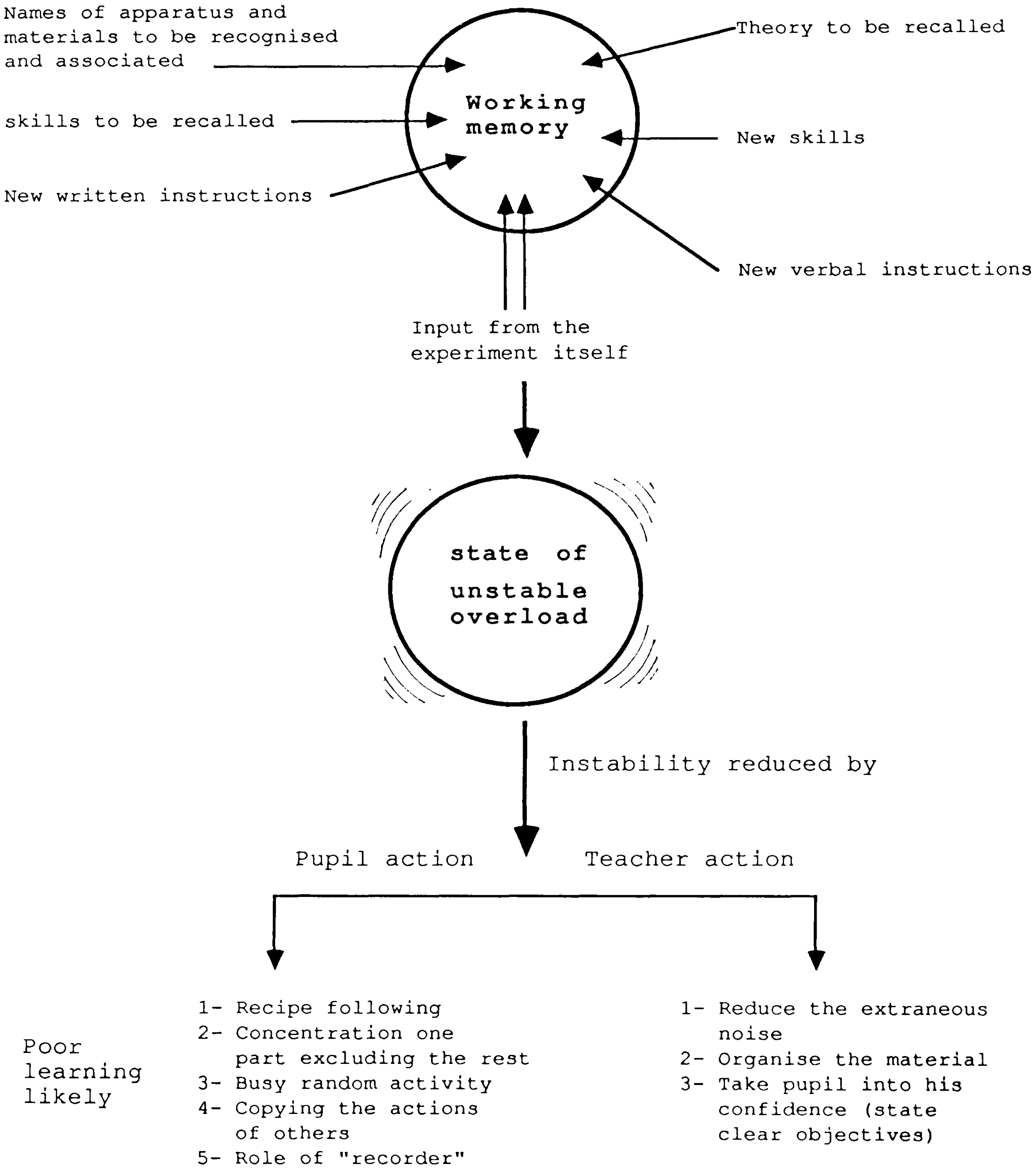


Figure 2-6. Unstable overload in practical work (Johnstone and Wham 1982, reference 89)

what lies behind the experiment. Many of them are not able to identify the physical concepts or basic phenomena. In which case if students do not know either the physical concepts or phenomena involved when they are dealing with the experiment, then the experimental instructions could hardly contribute towards their understanding of the experiment.

In this connection, Letton[88] has explored practical work to gain ideas about the process of experimental work. She demonstrated that second year chemistry students have not enough experience to discriminate between signal (which teacher consider important information) and noise (which the teacher considers unimportant), and as a consequence students suffer overload.

Another source of difficulty is that students in an introductory course may not be physics majors, for example, coming from a wide variety of programmes (different levels). They may be not be interested a priori in physics and perhaps they may even dislike the course forced upon them as a necessary part of their programme.

A number of investigations have suggested that the common factor which seemed to appear in practical courses in physics which students perceived as difficult is that of overload of working memory. During the practical course, the student is unable to distinguish between the signal and noise, because he lacks experience to be able to group the information flooding into his working memory.[86] The very principle which the lab is trying to establish may be the key the student needs to separate signal from noise. For this example, it has been suggested[52] that it is essential to remove unnecessary information and the noise from the laboratory instruction. This instruction must be rewritten to allow the students to decrease the number of chunks by decreasing amount of information involved. This would leave room for thought and operations.

As a consequence Johnstone and Wham[89] suggested four steps to avoid the possible overload and to reduce noise, as shown below:

(1) enhance the signal by giving a clear statement of the main points involved in an experiment.

(2) suppress the noise by stating clearly what is preliminary, peripheral and preparatory.

(3) redesign of the experiment.

(4) teach the important manipulative or interpretive skills before using them.

Another general source of information on overload in teaching science is the effect of language: unfamiliar vocabulary; negative forms, and long sentence. Here Cassels and Johnstone[86] showed that some English words in chemistry presented difficulties for novice students, who also experienced more problems in comprehension of written tests.

In addition to the difficulties arising from technical terms, most difficulties are derived from the use of non-technical words in books and by teachers. These word are by no means all familiar to the pupils. This becomes apparent in learning /teaching physics. These difficulties are caused by terms such as three dimensions: quantity; concept and correspond, for example. A large population of pupils in fundamental and secondary school in Algeria have difficulties in choosing an appropriate explanation for such words in Arabic and have even more difficulty when asked to give their own interpretation of the meaning of these words. These words are often used in books, in experimental instructions and by teachers.

It could be possible to avoid the language load on working memory by using both familiar vocabulary, familiar equipment and short sentences in the experimental notes which could contain certain added diagrams to enhance the grasp of the physical understanding. Since in each new practical the learner is a beginner, it is necessary to reduce or eliminate the noise, and have a clear statement in the text of the experimental notes so that students are able to separate necessary from unnecessary information. It is important to get students to optimize their short-term memory and to filter out the noise.[90]

Our working memory cannot work with more than (6 ± 2) separate pieces of information at any one time. If more information has to be handled, the result is mental overload. As an example which illustrates the idea of overload in working memory in doing practical work consider the experiment to measure the index of refraction of a prism using a spectrometer- an experiment which the students found demanding in our investigation. During the performing of this measurement the student has constantly to use the fine adjustment, to adjust the light source, to turn the telescope right, left and back. He will retrieve from his long-term memory information for a meaningful interpretation of what is observed. When working with a spectrometer for the first time at least 11 pieces of information are required to handle the instrument, and the student may be uncertain of the sequencing of the eleven operations required, thus leading to a potential overload. A further 6 pieces are required in the physical measurement, as shown below. This could create an overload if the students did not know how to sequence them.

1 collimator:

(a) how to adjust the slit.

(b) how to fix the collimator.

(d) how to focus the collimator.

(e) where to place the filament lamp.

2 Prism table:

(a) how to place the prism on the prism table.

(b) how to rotate the prism table and clamp it.

(e) how to read the vernier scale.

3 Telescope:

(a) how to rotate the telescope.

(b) how to focus the telescope.

(c) how to measure the rotation of the telescope.

(d) how to focus both collimator and telescope for parallel light.

4 Physical measurement:

(a) how to set cross-wires on the line spectrum.

(b) how to get minimum deviation

(c) how to measure the angles of deviation for different wave lengths.

(d) how to measure the angle of the prism.

(e) how calculate the dispersive power.

(f) how to calculate the observational errors in the index of refraction.

The names and the functions of the different parts of spectrometer have to be remembered as well. For this example it should be noted that repeated working with a spectrometer results in the manipulation of the different parts becoming routine, and all the different skills are subsumed. Only three pieces of information (instead of the 11 detailed steps) are needed at the beginning and consequently all of the attention of the student can go to perception and the physical measurements. (i) Collimator (ii) prisim table (iii) Telescope.

As a result, if the student has to hold a great deal of information there will be no space left for processing and interpretation during practical work. In this connection Johnstone[71] has pointed out that working memory space is severely limited in size. Any overload of it leaves us no space for thought and organization and so faulty or no learning takes place.

It has been shown in the proposed model that the important point is that the information to be held and the processing have to share the same limited space. To provide memory space to carry out an experiment, the students should have (or be given) a plan, should organize and sequence the steps required to manage the experiment in order to group larger bits of information per chunk.

The general aim of the present research was to find a method of evaluation and assessing the behaviour and the attitudes of the students in practical work in physics, Our hypothesis was that practical work potentially gave rise to an overload situation which affected the efficiency of learning that took place in the laboratory. We attempted to find out what overload situation existed and in which experiment, and then decide what steps could be taken to improve this situation in the light of our guidelines proposed. The objective was to develop attitudes and increase the achievement of students in practical courses and so make the experiment worthwhile. Thereby the students would be able to gain a greater understanding of what they were doing and with more motivation.

Chapter three

University class examination analyses

3-1 Introduction

Our aim was to present a model in terms of working memory (Johnstone and El-Banna[52]) for learning in physics, with a view to improving teaching and learning. This model was based on the three measurements and the relationships between them:

I working memory capacity (X-space).

II disembedding ability (degree of field dependence/field independence) (FD/FI).

III Z-demand of an item (task difficulty).

I Working memory capacity: This was measured mainly by Digit Span Backwords test, but an attempt was also made to use another test for comparison. This was L T

(a) Digit span Backwards Test (DBT).

(b) Letter Test (LT).

II Disembedding ability. A test of the degree of field dependence/field independence was made by using the Group Embedded Figure Test (GEFT) Witkin et al[91], in which the identification of a simple geometrical shape, hidden in a complex pattern, is taken as an indication of the ability of the students to isolate relevant from irrelevant information.

III Z-demand (task difficulty): The Z-demand was formulated by Case[39], Niaz[51] and Scardamalia.[36] Johnstone and El-Banna[85] approximated the Z value to the number of steps in the solution procedure of the problem for the least talented but ultimately successful students. A study of students' actual answers to examination questions was made to determine the Z demand of each question or each part of question and many examinations scripts were read. The subjective element in such decisions leads to an uncertainty of about ± 1 in the value of Z taken.

Relationships among the above parameters: It is useful to look at the role of the three factors cited above in how students interpret and deal with problems. The students' responses were classified depending either on their working memory X-space or degree of FD/FI. Then, relationships were sought between these parameters.

3-2 Hypotheses investigated

In an attempt to find out a way of interpreting the data obtained, four hypotheses were formulated:

1 Hypothesis one: The performance of students in solving physics' examinations questions should decrease as the Z-demand of the problems increases.

2 Hypothesis two: There should be a difference in performance between students of different working memory capacity for a question of given Z demand

3 Hypothesis three: For a group of students having the same X-space, field independent students should perform better in solving physics problems than field dependent students.

4 Hypothesis four: For a group of students who have the same X-space and disembedding ability (FD/FI), it should be that the performance in solving different problems decreases as the Z-demand increases.

An investigation was carried out on first year physics students at Glasgow University over a period of two terms during the academic year 1987/88. In order to confirm the findings obtained for testing the validity of these hypotheses cited above, the investigation was carried out again with a "terminal mathematics class" at Lycée Amara Rachid, Ben-Aknoun in Algeria over a period of three terms during the academic year 1988/89. The factors introduced above can be shown in the form of the following diagram in figure 3-1.

The questions were analysed into thought steps to give the Z-demand. Then a comparison was made between the performance of students and both their psychological tests scores of working memory capacity and their field dependence/field independence ability.

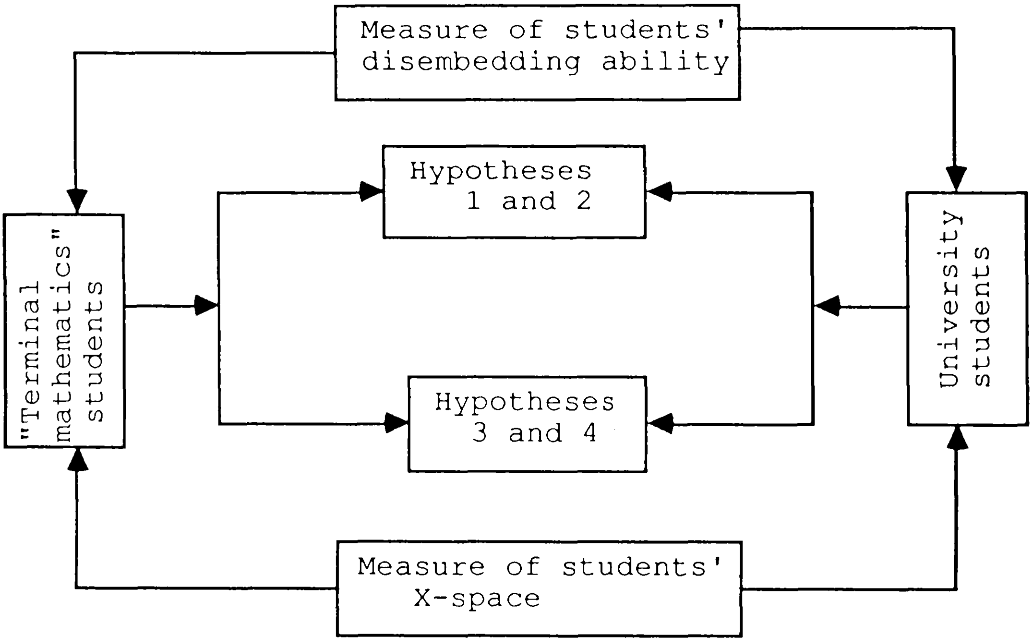


Figure 3-1

First year examination of University Students

The sample on which this work was based was 168 first year physics students at Glasgow University during the academic year 1987/88. The students were tested at the start of the first term to determine the following cognitive predictors:

3-3 **Working memory space:**

Thus was estimated by two kinds of psychological test:

(a) Digit span Backwards Test (DBT).

(b) Letter Test (LT).

In these two tests, groups of digits or letters are given to be memorized, and then the students were asked to give these back in reverse order. The size of the groups was increased till the students could no longer give them back. A sample of this test is to be found in Appendix 3-1. DBT is the normal test quoted in the literature (Scardamalia[36] and Case[32]). Where there was a difference between DBT and LT, the DBT score was used. (Group 2 Table 3-1).

The sample which is considered to be used in this investigation was composed of the students:

(a) who obtained an identical score on both tests stated above.

(b) who obtained plus or minus one either in DBT or LT, relative to DBT.

(c) who sat only DBT.

Table 3-1. Comparison of students scores on both psychological tests.

Performance on both DBT and LT	N
1- Identical score	37
2- Differences plus or minus one	52
3- Only DBT test	42
4- Difference >+1	32*
5- Misunderstood the instruction	5*
Total	168

Note,* indicate that, these students were not included in the sample study.

As can be seen in table 3-1, the sample of 131 students (in groups 1, 2 and 3 in table 3-1) had a range of X-space between 4 and 8. This was put into categories of:

(a) 63 (48.1 %) of students who had X-space =7 and 8, called X=7

(b) 41 (31.3 %) of students who had X-space =6.

(c) 27 (20.6 %) of students who had X-space=4 and 5 called, X= 5.

The sample was therefore divided into three categories: students with capacity X=7, students with capacity X=6 and students with X=5.

It was assumed that those X space parameters remained constant during the period of testing of the students.

3-4 **Group Disembedded Figure Test:**

A further test, of degree of field dependence/field independence, was administered to the same sample of students above, using the Group Embedded Figure Test (GEFT Witkin et al[91]). A sample of this test is to be found in Appendix 3-2.

According to GEFT, the distribution of the total score was divided into the following categories:

a) 41 (28.87%) students scored from 13 upwards and were classified as field independent (F.I)

(b) 84 (59.16 %) students scored from 7 to 12 and were classified as field intermediate (F.Int).

(c) 17 (11.97 %) students scored from 2 to 6 and were classified as field dependent(F.D).

3-5 **December examination**

3-5-1 **Question analysis**

In December 1987, the twelve questions of the class examination were analyzed into their thought steps, by using the attempts of the students (see below). Then they were classified according to the number of steps: three questions had an Z-demand 3; two questions had an Z-demand 4; one question had an Z-demand 5; four questions had an Z-demand 6 and two questions had Z-demand 7. All 12 items had been allocated different marks with a maximum total of 90 marks for the examination. Distributions of these questions by Z-demand are presented in table 3-2. This table shows the facility value, mean score and maximum mark for each item.

Two examples are used to illustrate how the thought steps which are required to solve a question were estimated. Examples conducted in such an investigation are given below. All questions of December examination are to be found in Appendix 3-3.

Example one:A sprinter runs 100 m in 10 s. He starts from rest, runs with uniform acceleration, reaches full speed after 10 m and then maintains that speed. Calculate the value of his acceleration.

Step 1: $X_1 = 0.5\ t_1v$ (recall)

step 2: $X_2 = vt_2$ (recall)

step 3: $t_1+t_2 =10$

step 4: determine the speed: $v =11\ m\ s^{-1}$

step 5: $v^2 = 2aX$ (recall)

step 6: calculate the acceleration: $a =6.05\ m\ s^{-2}$.

Thus Z-demand of this question is equal to 6 thought steps.

Example two:A long light string passes over a smooth light pulley. To one end of the spring is attached a mass of 1.5 kg. and to the other end two masses of 1.0 kg each. The system is released from rest. After 5.0 s one of the 1.0 kg masses becomes detached from the string. Calculate the further time which elapses before the system comes instantaneously to rest.

step 1: $T - m_1g = m_1a_1$ (recall)

step 2: $T + (m_2+m_3)a_1= (m_1+m_2)g$ (recall)

step 3: calculate the acceleration: $a_1 = 1.4\ m\ s^{-2}$

Step 4: calculate the velocity: $v = a_1t =7\ m\ s^{-1}$

step 5: calculate the new acceleration: $a_2 = -1.96ms^{-2}$

step 6: calculate the time: $t = 3.57\ s$.

Thus Z-demand of this question is equal to 6 thought steps.

Table 3-2

The distribution of the F.V, M.S and Z demand for each question

December examination

	Q-1	Q-2a	Q-2b	Q-3	Q-4	Q-5a	Q-5b	Q-6	Q-7	Q-10	Q-11b	Q-12b
% F.V	24	57	88	8	33	60	51	67	31	23	19	14
Mean score	2.8	3.5	2.8	1.9	4.7	3.1	2.6	4.4	2.2	4.9	2.2	3.6
% M.S	47	70	98	32	59	77	65	88	73	61	45	52
Max mark	6	5	3	6	8	4	4	5	3	8	5	7
Z-demand	6	5	3	7	6	3	5	4	3	6	6	7

3-5-2 **Testing Hypotheses one and two:**

The data obtained were analysed to test hypotheses one and two, in terms of facility value (F.V.) and mean score. The F.V.represents the number of students who answer the question correctly divided by the number of the whole sample who attempted the question.

Analyses I: facility value:

The facility values of each question were calculated. Then the average F.V. were calculated for the questions which have the same complexity of Z-demand. A comparison was made to find out the effect of the complexity of the question on students' performance:

(1) For the whole sample of students

(2) Within each of the three groups of students: X = 7, X = 6 and X=5.

Table 3-3. Relation between students' X-space and their success in solving different questions of Z-demand

Groups	F.V on questions of different Z-demand				
	Z=3	Z=4	Z=5	Z=6	Z=7
X=7	0.55	0.63	0.66	0.30	0.13
X=6	0.70	0.57	0.51	0.20	0.07
X=5	o.55	0.52	0.44	0.19	0.07
TOTAL (7+6+5)	0.66	0.59	0.57	0.25	0.11

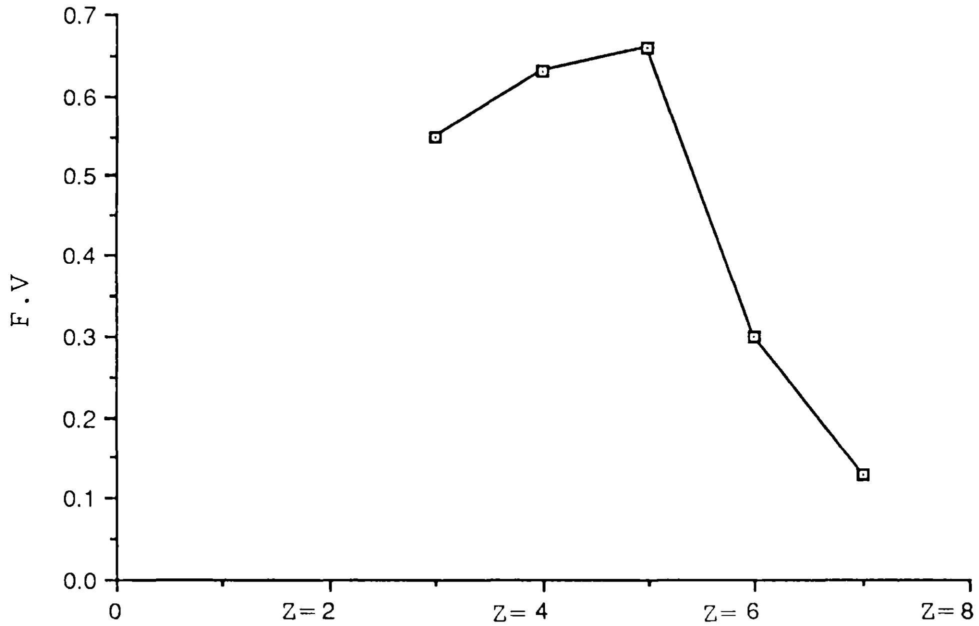


Figure 3-2. The performance (F.V) of **X=7 students** on questions of different Z demand.

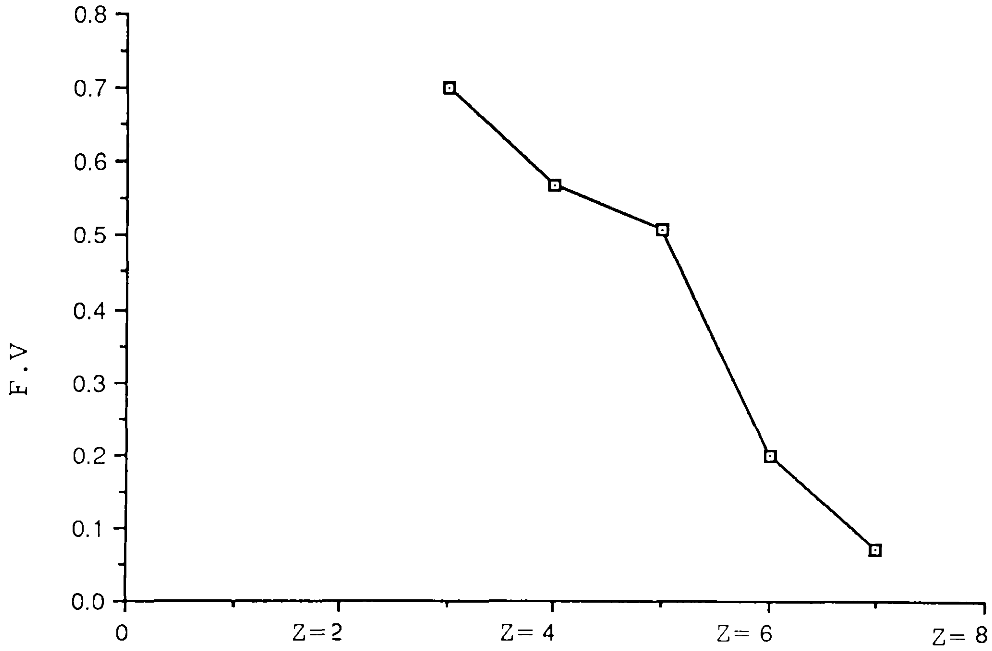


Figure 3-3. The performance (F.V) of **X=6 students** on questions of different Z demand.

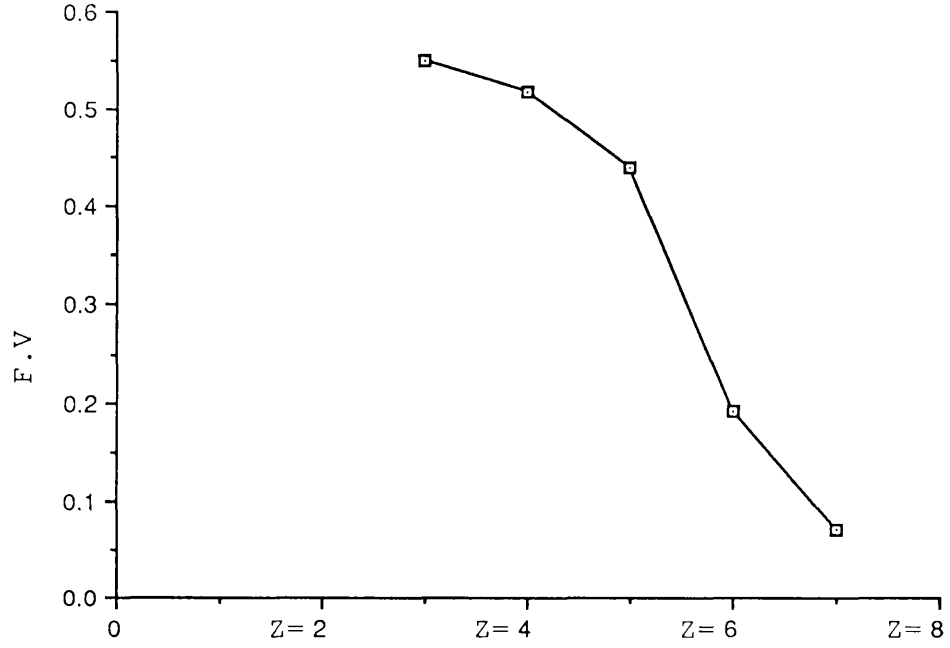


Figure 3-4. The performance (F.V) of **X=5 students** on questions of different Z demand.

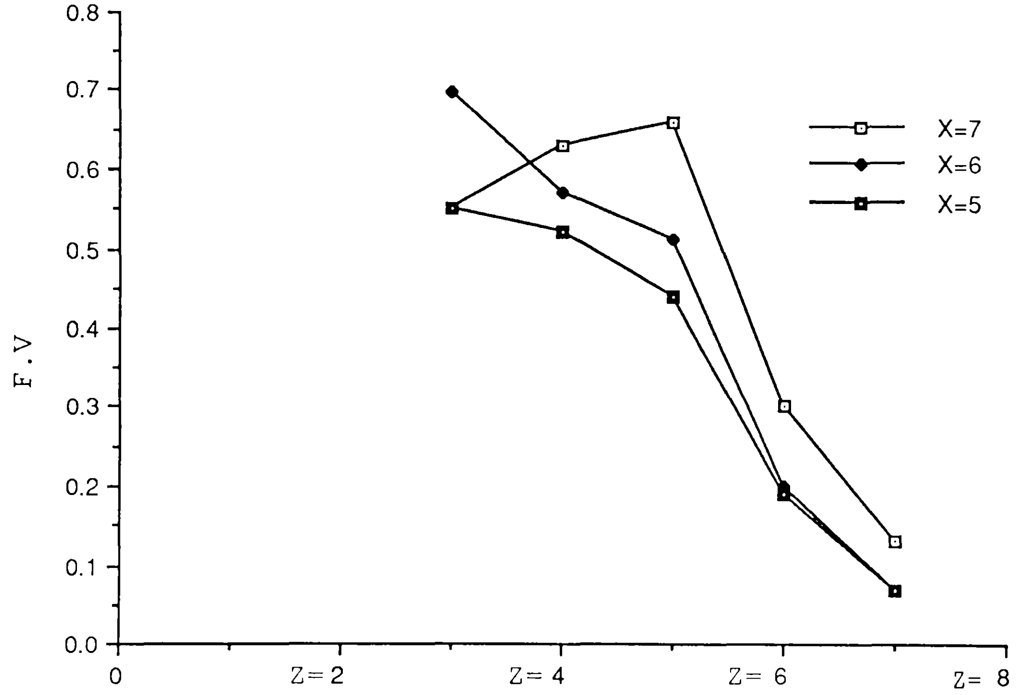


Figure 3-5. Comparison of the performance on questions of different Z demand for different X- space' students.

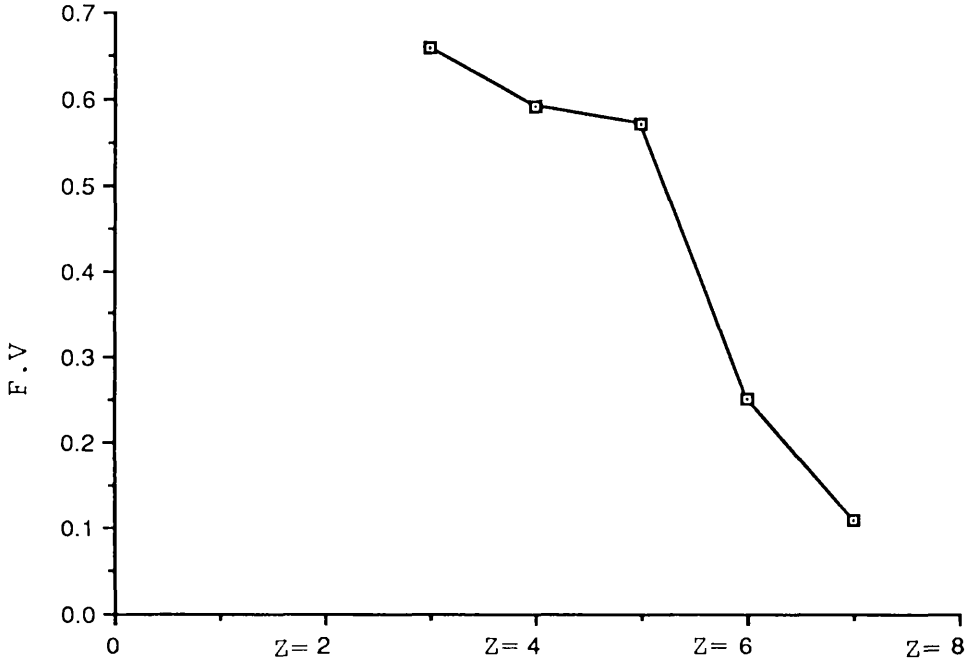


Figure 3-6. The performance of the whole sample of students on questions of different Z-demand in December examination

The results are presented in table 3-2 which gives the facility value, mean score and maximum mark for each question with its Z-demand. The following conclusions can be made:

(1) For all students, the F.V decreased as the Z demand increased.

(2) For questions with Z demand equal to or greater then 4 students who had the highest X-space performed better than those with X=6, who in turn performed better than those with lowest X=5.

Figures 3-2, 3-3 and 3-4 show how the facility value varies with Z demand for each X-space group of students.

The overall pattern, figures 3-5 and 3-6 shows high F.V for Z=3 to Z=5, then a fall off to a much lower F.V as Z=6 and greater is reached.

We conclude that from table 3-3 when Z demand of the question is low (Z=3), the X-space factor does not play an important role in discriminating between students.

Analysis II: Mean score

The second analysis was done by using the mean score. In this case the mean score and standard deviation (S D) were calculated for each question, as well as the average of the mean score for questions of the same complexity for all three students groups, and also for the whole sample of students. The result is shown in table 3-4 which indicates that for all questions, the percentage mean score of students decreased as:

Table 3-4. Relation between student's X-space and their performance on different questions of Z-demand.

Groups	% mean score on questions of different Z-demand				
	Z=3	Z=4	Z=5	Z=6	Z=7
X=7	78.8	80	74	56	46.9
X=6	83.1	74.5	64	49.6	42.2
X=5	75	72.5	62	50.8	33
TOTAL (7+6+5)	81.4	76.5	66.6	52.7	41.8

(1) the X-space of the students decreased with the exception of question with Z demand three for X=7 group.

(2) the Z-demand of questions increased from Z=3 to Z=7 for each group of students having the same X-space.

It should noted that the percentage mean scores of students in question with Z=3 are nearly the same for all groups of students (78.8 %, 83.1 %, 75 %). It can be argued that X=6 and X=5 students were able to spend more time on low demand questions and hence get scores as good as X=7 students. When faced with a difficult question such as question with Z=7, the students' performance was overall worse and the mean score dropped from 47% for X=7 to 33% for X=5.

A t-test (two tailed)[92-93] was used in order to find out whether the differences in students' responses are significant. The results given in table 3-5, show that at 10 % level, there was a significant difference found between X=7 and X=6 in questions 4, 8 and 10, and also between X=7 and X=5 in questions 1, 2, 5 and 12.

At 5 % level, in question 9 with Z=3 there was a significant between X=6 and X=5, and there were significant differences between X=7 and X=5 in questions 4 with Z=7, 8 with Z=4 and 3 with Z=3, although no such significant differences were found in any question between X=7 and X=6.

Table 3-5 . The significance of the difference between X-space' students in each question.

Questions	X=7 & X=6	X=6 & X=5	X=7 & X=5
Q1 Z=6	1.012	0.61	1.55*
Q2 Z=5	1.25	0.2	1.39*
Q3 Z=3	0.93	1.48*	0.95
Q4 Z=7	0.75	1.54*	2.298**
Q5 Z=6	0.917	0.73	1.56*
Q6 Z=3	1.23	0.29	0.55
Q7 Z=4	1.25	0.49	0.55
Q8 Z=4	0.526	1.38*	1.86*
Q9 Z=3	0.78	2.22**	1.69*
Q10 Z=6	1.21	1.47*	0.47
Q11 Z=6	0.56	0.48	0
Q12 Z=7	0.67	0.92	1.56*

* Significant at 10 % level

**significant at 5 % level

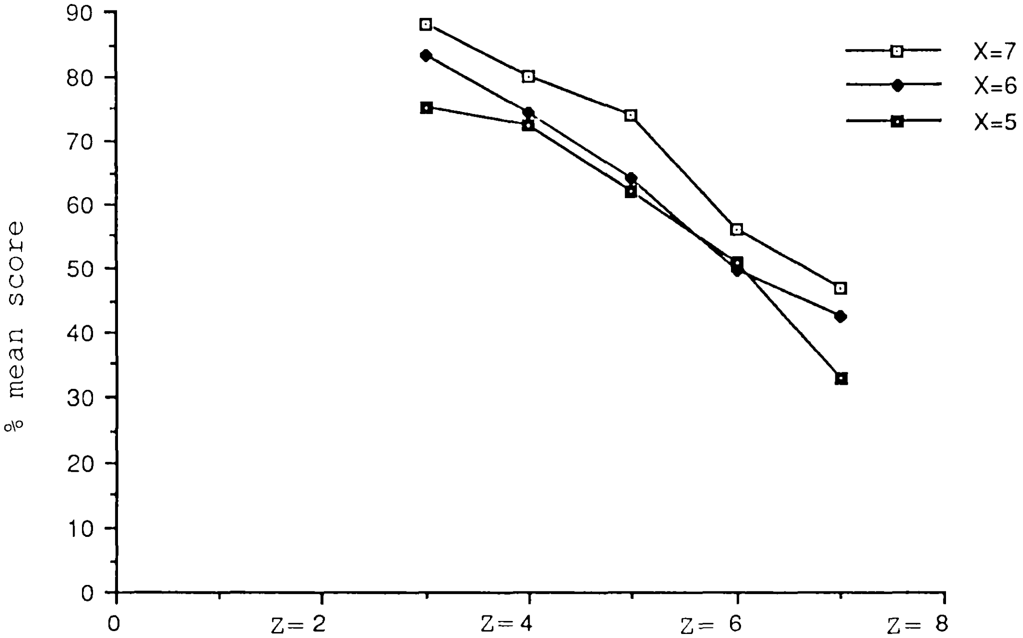


Figure 3-7. Comparison of the performance on questions of different Z demand for different X- space students.

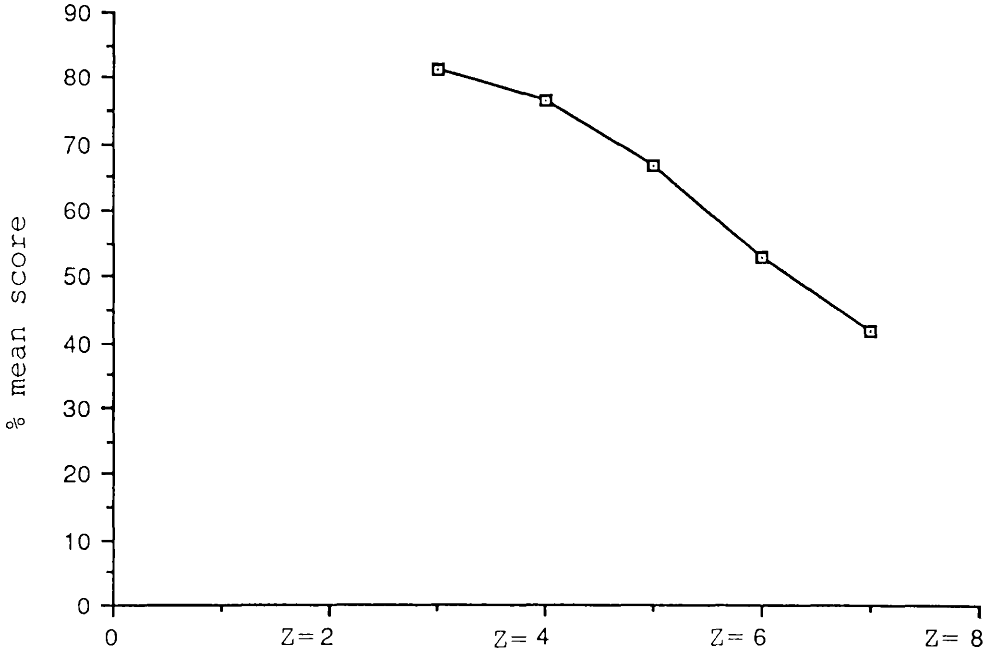


Figure 3-8. The performance of the whole sample of students on questions of different Z demand in December examination.

In addition, it is useful to represent these results graphically, as in figures 3-7 and 3-8, for all of the three students groups together, and also for the whole sample of students.

The performance of X=7 students is about the same level for Z=3 to Z=5 and declines sharply when Z-demand of questions exceeds 5, but both groups of X=6 and X=5 students start dropping down rapidly from Z=3 to Z=7 (figure 3-6).

3-5-3 **Testing hypotheses three and four**

I **Relation between students' performance and their disembedding ability (FD/FI)**

Another comparison was made between students' performance in the December class examination and their degree of disembedding ability, regardless of working memory X-space factor. This was done in order to establish whether the field dependence/field independence factor influenced the students' ability to isolate irrelevant from relevant information in solving physics problems of different complexity.

TAble 3-6. The total mean score of the three different disembedding ability groups.

Groups	Mean score	S.D
F.I	52.5	21.4
F.Int	50.9	18.8
F.D	47.5	16.5

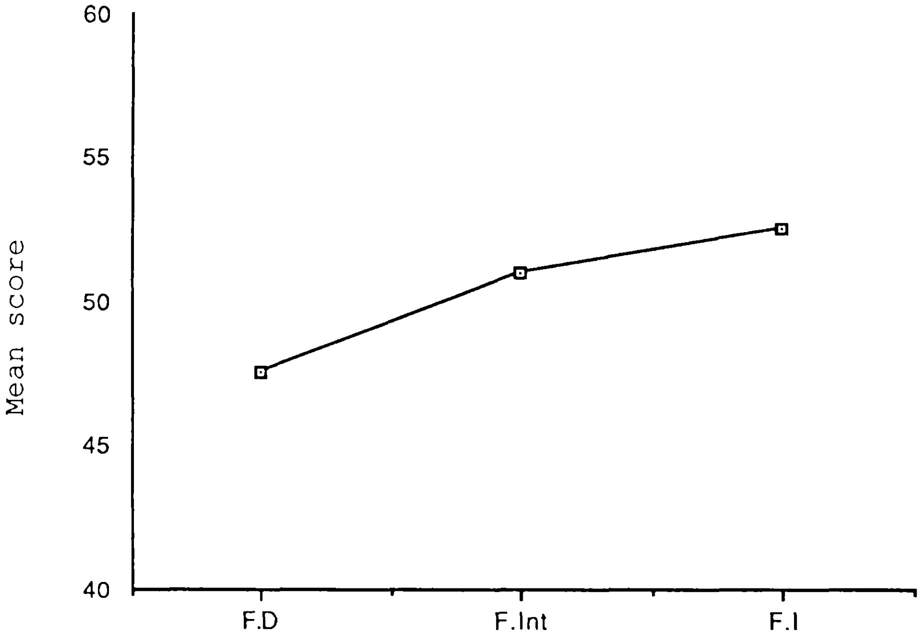


Figure 3-9. Comparison of the results between students of different degree of disembedding ability FD/FI in December examination.

Table 3-6 shows the total mean score, which has a rising trend, but there is no significant difference among the three disembedding ability groups.

II Relation between the disembedding ability, X-space and performance

The sample which was chosen above (students groups) was further divided into sub-groups: field dependent, field intermediate and field independent students. The score for 116 students who took both tests, the working memory X-space and disembedding ability (GEFT) are shown in table 3-7.

Table 3-7. The distribution of FD/DI students for different X-space.

Groups	F.I	F.Int	F.D
X=7	12	28	17
X=6	3	24	10
X=5	0	11	11

The mean score and (S D) were calculated on each question for each group of students having the same X-space and degree of disembedding ability and also the average mean score for all questions having the same Z-demand. The results are presented in tables 3-8 and 3-9, as well as in figures 3-10 and 3-11. The following conclusions can be drawn:

(a) For the students who had the same X-space and degree of disembedding ability (FD/FI), the percentage mean scores on different Z-demand of the questions decreased as the Z-demand increased from Z=3 to Z=7 with one exception, in Z=3 with X=7 and X=5. This result gives support for the fourth hypothesis.

(b) For the students who had the same X-space, the percentage mean scores decreases as the disembedding ability (FD/FI) test decreases (from FI to FD).

In other words, the field independent students performed better than field dependent students in this study, with certain exceptions. For example, X=7, in questions of Z=4 and Z=5, and also for X=6 in question of Z=3. The results obtained in this investigation support the third hypothesis. Here it can be noted that none of field independent students had X-space=5.

Table 3-8. Relation between students success (% mean) on questions of different Z-demand and their disembedding ability with ***X-space=7***

Groups	% mean score on questions of different Z-demand				
	Z=3	Z=4	Z=5	Z=6	Z=7
F.I	86.6	88.3	69.4	55.7	44.8
F.Int	85	77.6	60	51.9	50
F.D	85.6	68.2	66	49.5	35.5

Table 3-9. Relation between students success (% mean) on questions of different Z-demand and their disembedding ability with ***X-space=6***

Groups	% mean score on questions of different Z-demand				
	Z=3	Z=4	Z=5	Z=6	Z=7
F.I	78.7	78.9	91.6	54.5	53.2
F.Int	78.9	79.9	71	58.6	41.3
F.D	83	54.5	69.4	54	41

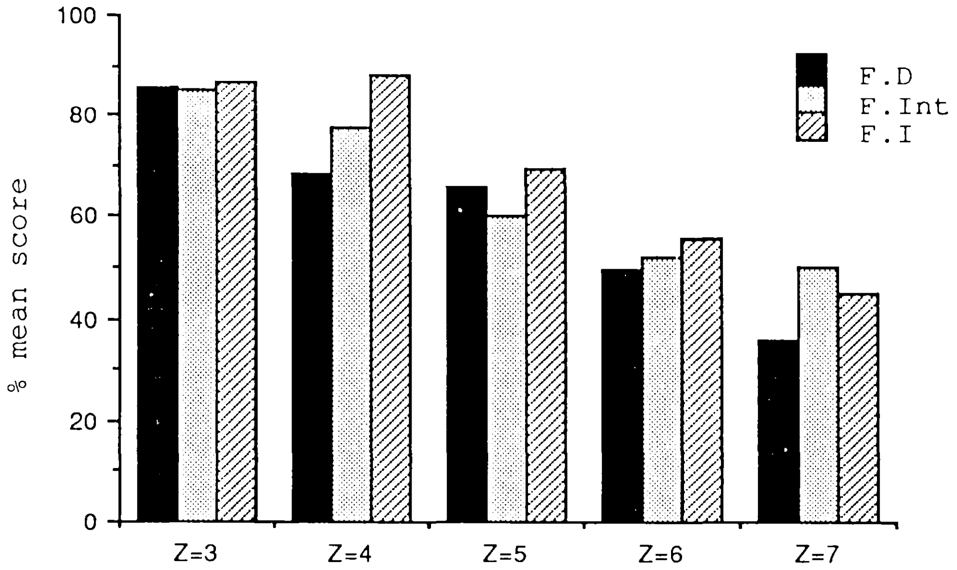


Figure 3-10. Comparison of the performance between students of different degree of disembedding ability for students having the *X-space=7*.

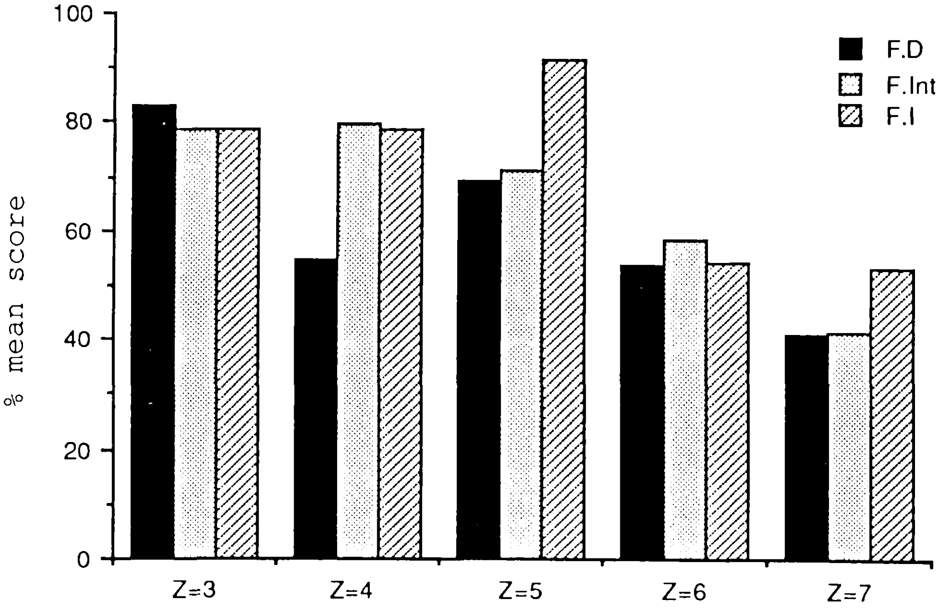


Figure 3-11. Comparison of the performance between students of different degree of disembedding ability for students having the *X-space=6*.

In addition, to the data obtained, the total mean score and (S D) of all questions were calculated regardless of the Z-demand for the students having the same X-space and degree of (FD/FI). It can be seen from table 3-10 as well as in figure 3-12 that field independent students obtained the highest total mean score, where field dependent students provided the lowest performance for both groups of X=7 and X=6.

Table 3-10. Relation between X-space, Disembedding ability (GEFT) and students' overall performance in December examination

Groups	Mean scores on different groups:							
	F.I		F.Int		F.D		TOTAL	
	M.S	S.D	M.S	S.D	M.S	S.D	M.S	S.D
X=7	58.0	18.6	50.6	18.9	53.8	17.5	53.1	18.6
X=6	47.7	24.3	51.3	15.7	44.8	14.2	49.2	16.8
X=5	0	0	42.7	19.1	46.1	13.8	44.7	16.7

Table 3-11. The significance of the differences in overall performance between students of different degree of FD/FI.

Groups	F.I & F.Int	F.Int & F.D	F.I & F.D
X=7	1.68 *	0.54	0.62
X=6	0.26	1.18	0.20

* significant at 5 % level

In order to find out whether these differences are significant, t-test (two tailed) was applied. The results obtained are given in table 3-11, where it can be seen, for X=7 students there is only one significant difference found, and that between the field independent and field intermediate.

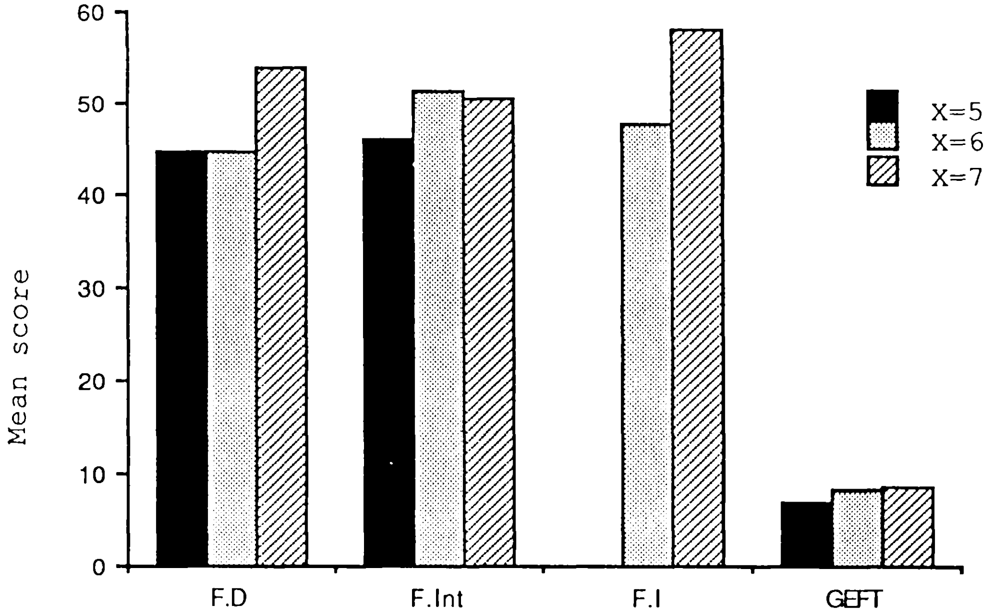


Figure 3-12. Comparison of the the performance between students of different degree of FD/FI and GEFT for different X-space.

3-6 **March examination**

3-6-1 **Question analysis**

The same sample of students was assessed in the March class examination where 11 questions were analyzed. All questions of the March examination are to be found in Appendix 3-4. Each question was evaluated and classified according to its Z-demand as before. Again we note the difficulty of assigning Z value (chapter 3-1, page 48). One question had 3 thought steps, two questions had an Z-demand of 5, three questions had Z-demand of 6, three questions had an Z-demand of 7, one question had 8 thought steps and one question had an Z-demand of 12. The details are given in Appendix 3-5. These values were again obtained by examining students' scripts and giving the Z value to the longest, but ultimately successful route. Many successful students took shorter routes, but they may have been using efficient chunking devices and short cuts. This makes the evaluation of Z a very "soft" piece of data.

3-6-2 **Testing hypotheses one and two:**

Again, identical methods are repeated for testing the validity of both hypotheses 1 and 2 with the same population of students. In this study, the students sample was reduced from 131 to 126 students.

Analysis I: Facility value

The facility value was calculated for each question and then the average of the questions of the same complexity Z-demand for the three groups of different X-space separately as well as the whole sample of students were calculated. Table 3-12 shows the results of the average of facility value for each Z-demand versus the students' X-space. These results indicate that:

(1) for students having the same X-space their performance decreases as the Z-demand increases with one exception,viz in Z=8 with X=7 and X=5 group. These results support the first hypothesis.

(2) for questions having the same complexity Z-demand, the students' performance increases as the X-space increases with certain exceptions, in Z=3, Z=5 and Z=8 with X=5.

The results of these comparisons indicated in general, that X=7 students performed better than X=6, and both are better than X=5.It is interesting to point out that, no students solved correctly the question of Z=12, presumably because it required more recall steps to answer it correctly. In addition, in both questions of Z=3 and Z=5 the students' performance are nearly the same for all the three groups (46.5 %, 43 %,44 %), and even the X=5 students performed better than X=7 students (46 %, 64.5 %,77 %). This also may be explained in term of more time spent on easier questions. The same results are presented graphically in figure 3-13 for each X = space group separately as well as the whole sample of students in figure 3-14.

Table 3-12. Relation between students' X-space and their success on different question of Z-demand.

Groups	F.V on questions of different Z-demand					
	Z=3	Z=5	Z=6	Z=7	Z=8	Z=12
X=7	0.46	0.45	0.28	0.19	0.21	0
X=6	0.64	0.43	0.27	0.14	0.08	0
X=5	0.77	0.44	0.19	0.08	0.11	0
TOTAL (7+6+5)	0.62	0.44	0.25	0.14	0.13	0

The curve of performance of X=7 students began declining after Z exceeded 5 till Z=7, then increased slightly and finally dropped to zero at Z=12. The performance of X=6 students starts dropping sharply from the beginning at Z=3. Similarly for the X=5 students the curve began to decline rapidly till Z=7, then increased slightly at Z=8 and then again dropped to zero at Z=12.

Figure 3-14 shows the performance of the whole sample of students; their performance dropped rapidly from the beginning till Z=7, and then when Z exceeded 8 it dropped to zero at Z=12.

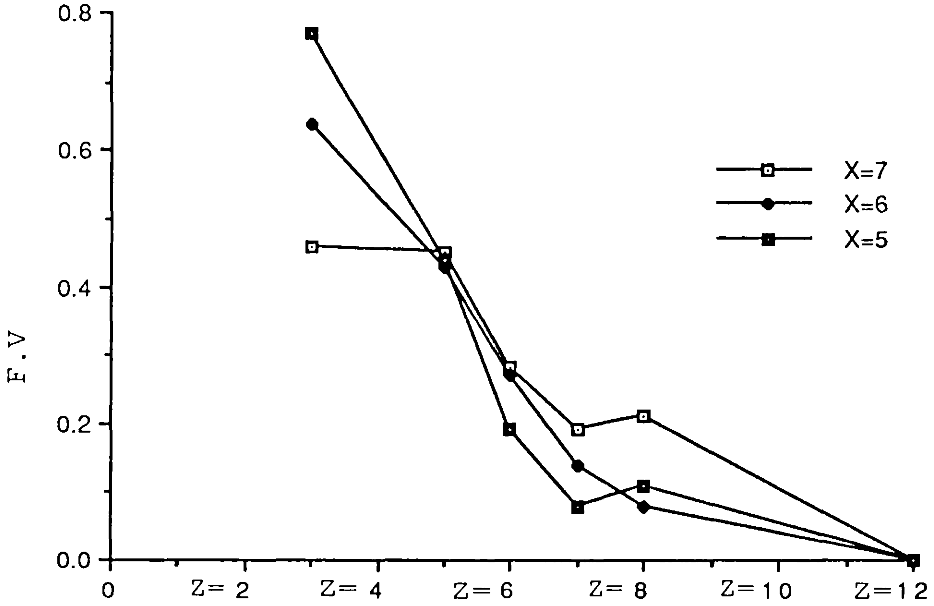


Figure 3-13. Comparison of the performance on questions of different Z-demand for students' different X-space.

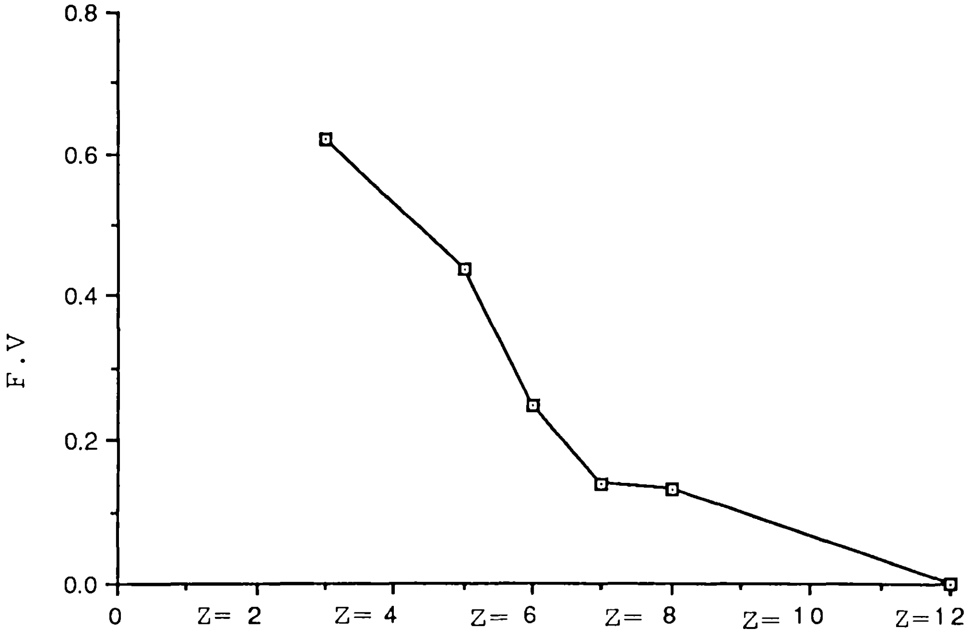


Figure 3-14. The performance of the whole sample of students on questions of different Z-demand for students' different X-space.

Analysis II: mean score

A further comparison was made in order to assess the same data from the March examination by calculating the mean score and S.D for each question, and the average of the mean score for questions having the same Z-demand.

Table 3-13. Relation between students' X-space and their success in solving different Z-demand of question

Groups	% mean score on questions of different Z-demand					
	Z=3	Z=5	Z=6	Z=7	Z=8	Z=12
X=7	73	67	53	46	49	24
X=6	70	64	48	40	33	17
X=5	76	59	47	45	36	21
TOTAL (7+6+5)	73	63.3	49.5	43.7	39.3	20.7

The results are presented in table 3-13. It can be seen from these results that:

(a) the students' performance decreases as the Z-demand increases for each group of students with one exception, in Z=8 with X=7.

(b) the students' performance increases as their X-space increases. With 4 exceptions out 6 results, there is very little pattern to the results. In addition, the same data are shown separately in figures 3-15 separately and in figure 3-16 for the whole sample of students.

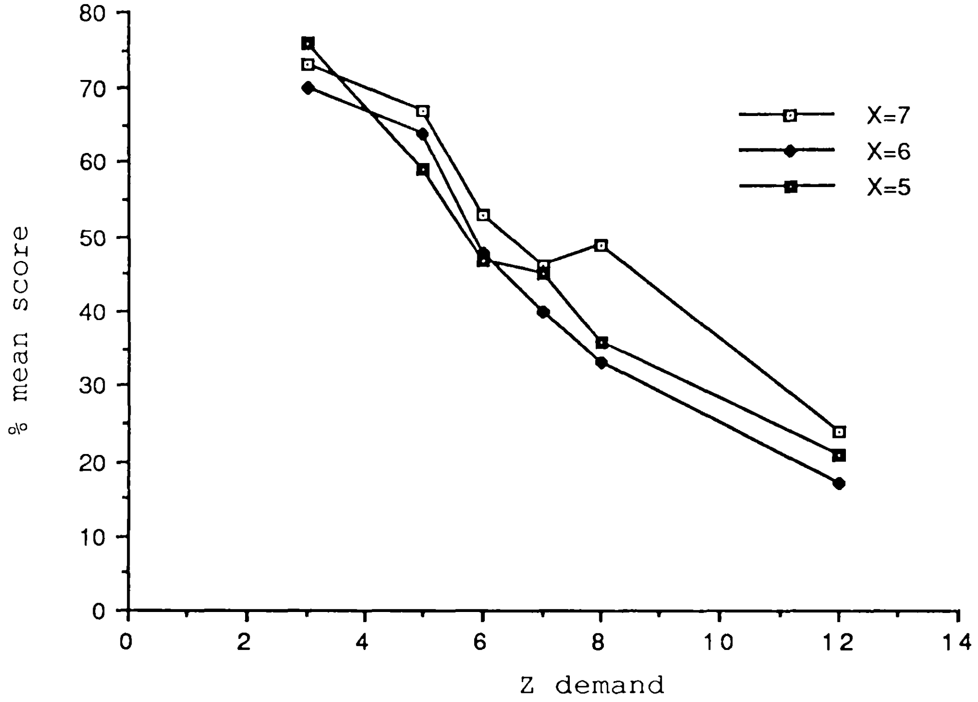


Figure 3-15. Comparison of the performance on questions of different Z demand for students' different X- space.

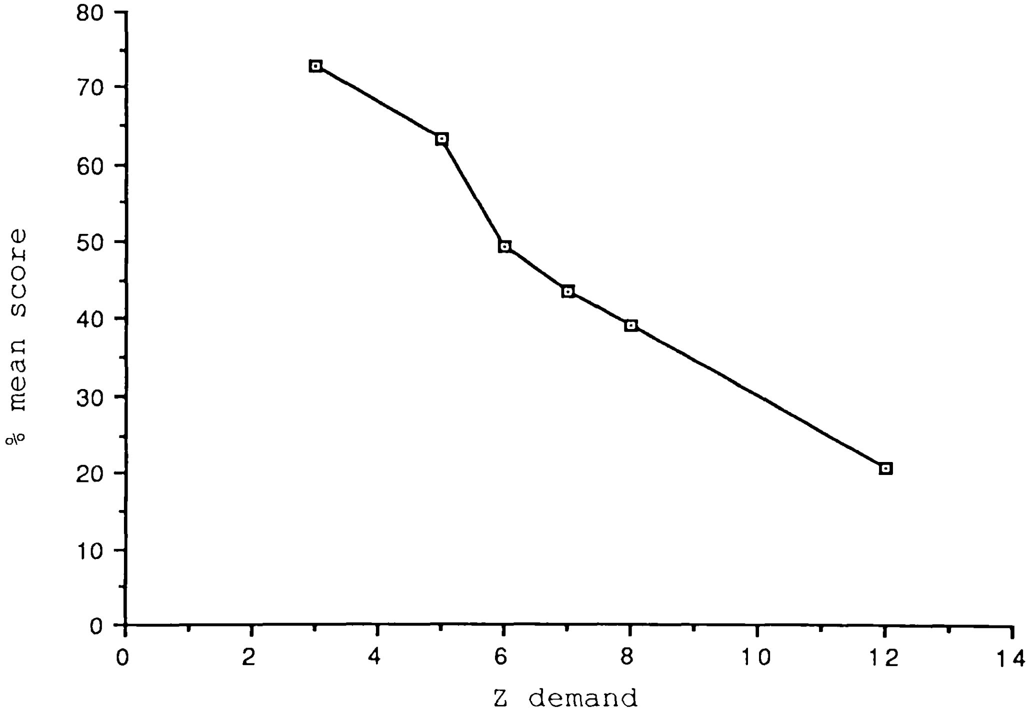


Figure 3-16. The performance of the whole sample of students on questions of different Z demand in March examination.

Table 3-14. The significance of the differences between the three student groups in each question

Questions	X=7 & X=6	X=6 & X=5	X=7 & X=5
Q1 Z=5	0.93	0.31	1.11
Q2 Z=6	0.45	0.4	0.49
Q3 Z=7	2.25**	0.87	1.22
Q4 Z=12	1.75*	0.68	0.55
Q5 Z=8	2.31**	0.44	1.48
Q6 Z=6	0.58	0.47	0
Q7 Z=6	0.81	0.89	1.76*
Q8 Z=5	0.31	1.86*	1.39
Q9 Z=7	0.02	0.46	0.49
Q10 Z=3	0.46	0.8	0.23
Q11 Z=7	0.52	0.02	0.55

* significant at 10 % level

** significant at 5 % level

As can be seen from the whole sample of students in figure 3-16, their performance decreases as Z increases. Here it can be noticed that all the curves cited above did not drop to zero even when Z > X.

Table 3-14 shows the significance of difference of mean scores between the students of different X-space. The results indicate that there is significant difference found between X=7 and X=6 students in both question 3 with Z=7, and question 5 with Z=8, whereas in question 8 with Z=5 there is a significant difference between X=6 and X=5, and also in question 6 with Z=6 between X=7 and X=5.

3-6-3 **Testing hypotheses three and four**

I **Relation between performance and students disembedding ability (FD/FI)**

To test hypotheses three and four, the performance of students in the March examination was investigated as a function of their degree of disembedding ability regardless of the X=space factor. The total mean score of the three groups are shown in table 3-15. It can be concluded that there is little difference in mean score between the three groups.

Table 3-15. The total mean score and S.D for different degree of FD/FI students in March examination.

Groups	Mean score	S.D
F.I	40.4	22.4
F.Int	41.0	18.8
F.D	39.4	17.2

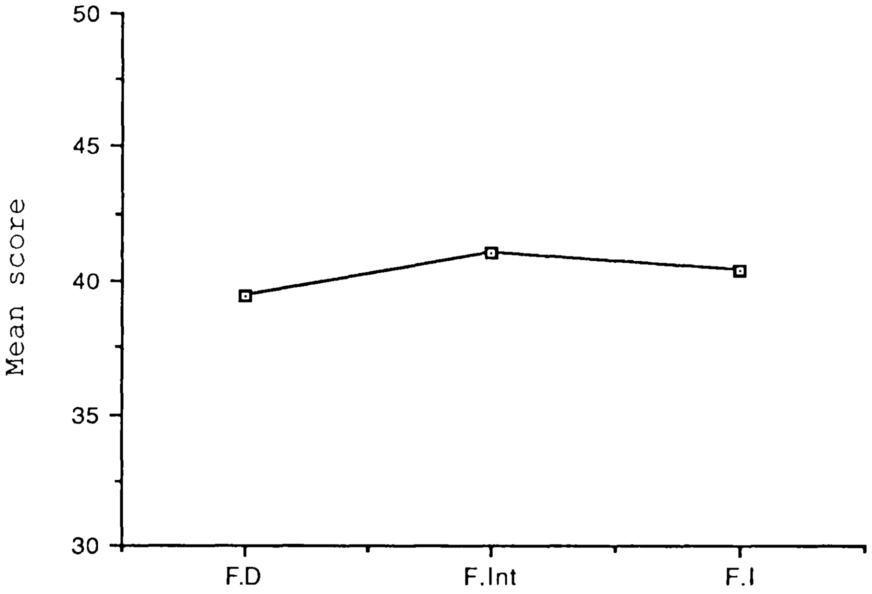


Figure 3-17. Comparison of the performance between students of different degree of FD/FI in March examination.

II **Relation between performance, X-space and Disembedding ability**

A comparison between the three factors; performance, X-space and FD/FI was made for testing the validity of the hypotheses three and four. Tables 3-16 and 3-17 as well as figures 3-18 and 3-19 show the percentage mean scores for each X-space group in different disembedding ability. It can be seen that:

(1) For the students who had the same X-space and degree of FD/FI, for question with $Z \geq 5$ the performance decreases as the Z increases. Question Z=3 does not discriminate between the groups.

(2) For the students who have the same X-space (X=7 and X=6), FI students perform better than FD in questions of a given Z, for $Z \geq 5$ (as above). Because the F.Int contains a mixture of FD/FI their performance is not easily distinguished from FD/FI.

Table 3-16. Relation between students' success in solving questions of different Z-demand and their disembedding ability with *X-space=7*.

Groups	% mean score on questions of different Z-demand					
	Z=3	Z=5	Z=6	Z=7	Z=8	Z=12
F.I	80	72	59.7	51.7	57	25
F.Int	80	65	53.2	42	44	22
F.D	60	63	52	47.3	51	23

Table 3-17. Relation between students' success in solving questions of different Z-demand and their disembedding ability with *X-space=6*.

Groups	% mean score on questions of different Z-demand					
	Z=3	Z=5	Z=6	Z=7	Z=8	Z=12
F.I	55	73	65	43	50	26.6
F.Int	70	64	50.5	28	34	19
F.D	66.6	56	42	41	36	10

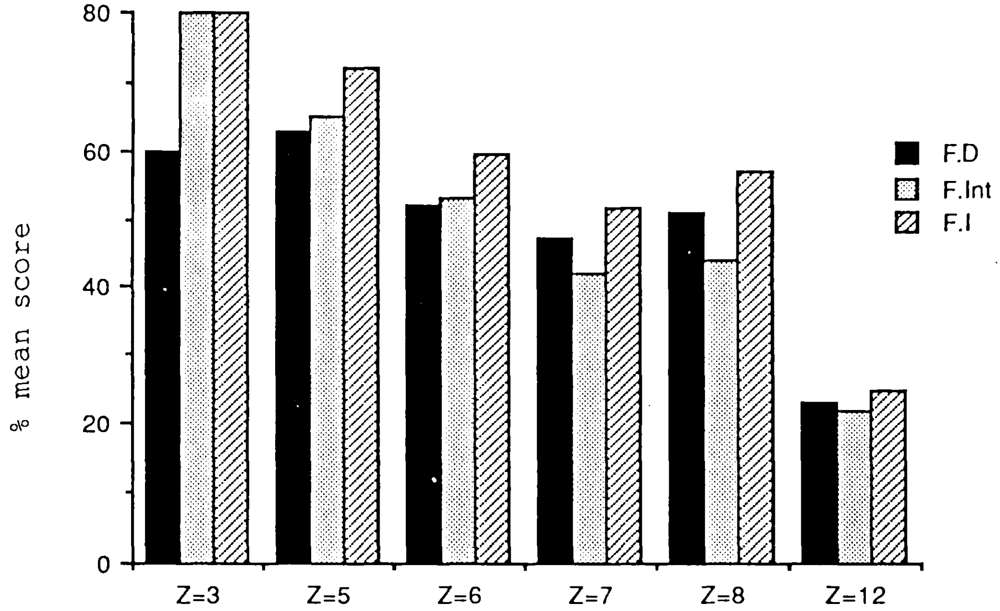


Figure 3-18. Comparison of the performance between students of different degree of FD/FI on questions of different Z-demand With <u>*X=7 students*</u>

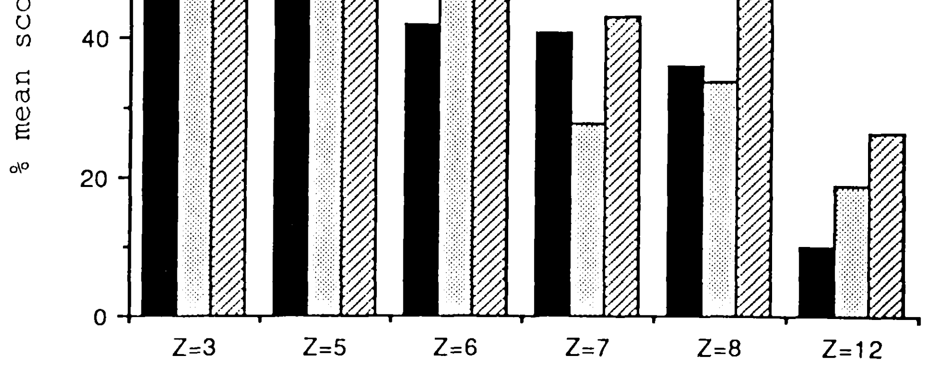


Figure 3-19. Comparison of the performance between students of different degree of FD/FI on different questions of Z-demand With <u>*X=6 students*</u>

Table 3-18 as well as figure 3-20 represents the average of the mean score for each X-space group. The curve shows that the performance fell away when Z exceeded 5 till Z=12, but X=7 students make temporary recovery between Z=7 and 8, and then decreased like others groups. In other words, the field independent students obtained a higher performance than field dependent students in each question for X=7 and X=6.

Table 3-18. Relation between X-space, disembedding ability (GEFT) and students' overall performance in March examination.

Groups	Mean scores on different groups:							
	F.I		F.Int		F.D		TOTAL	
	M.S	S.D	M.S	S.D	M.S	S.D	M.S	S.D
X=7	44.6	21.6	43.0	21.6	43.2	17.1	43.4	18.2
X=6	46.0	14.0	38.7	19.3	36.9	21.4	38.6	19.6
X=5	0	0	32.1	19.1	40.2	14.2	36.1	17.3

The table 3-18 shows the mean score and S.D for each X-space group. As can be seen that the field independent students provided the highest mean score.

Again t-test (two tailed) was applied to find out whether the differences were statistically significant. The results are shown in table 3-19. No such significant differences were found between students of different disembedding ability for each X-space group.

Table 3-19. The significance of the differences between students of different degree of FD/FI for each X-space group.

Groups	F.I &F.Int	F.Int & F.D	F.I & F.D
X=7	0.21	0.034	0.27
X=6	0.82	0.23	1.18

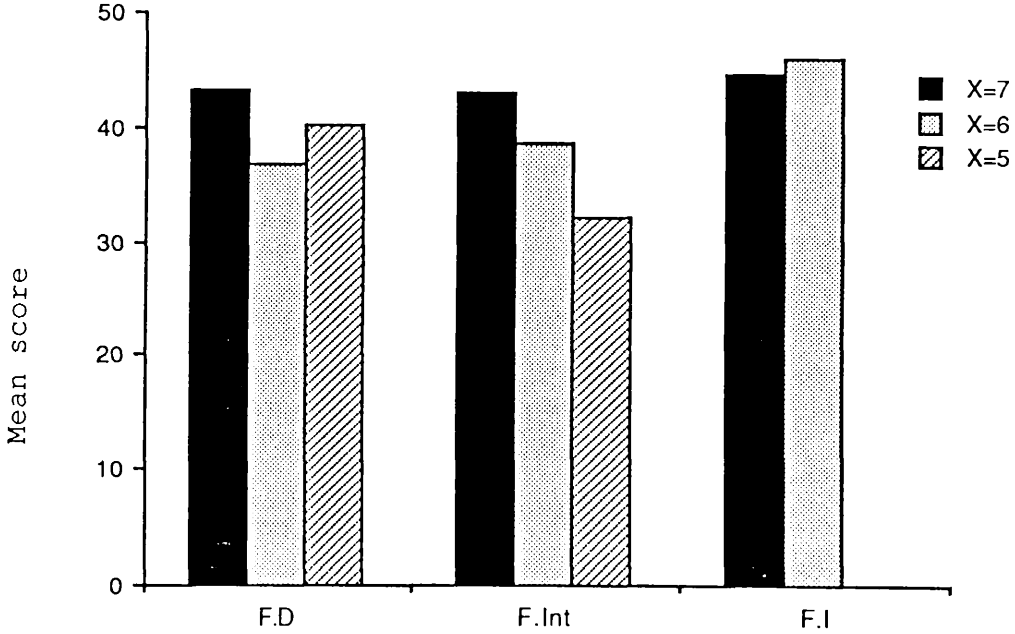


Figure 3-20. Comparison of the performance between students of different degree of FD/FI for different X-space.

3-7 Combined results obtained from the two class examinations.

It is interesting to see how well these students performed in both examinations together. For this analysis comparison was made between students performance and the Z-demand. In this case the average of the facility value and the mean score of questions having

Table 3-20. Relation between students' X-space and their success (F.V) on the different questions of Z-demand in both December and March examination.

Groups	F.V on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=12
X=7	0.51	0.63	0.56	0.29	0.16	0.21	0
X=6	0.67	0.57	0.47	0.24	0.10	0.08	0
X=5	0.50	0.52	0.44	0.19	0.07	0.11	0
TOTAL (7+6+5)	0.56	0.57	0.49	0.24	0.11	0.13	0

Table 3-21. Relation between students' X-space and their success (% mean) on different questions of Z-demand in both December and March examination.

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=12
X=7	75.9	80	70.5	54.6	46.4	49	24
X=6	76.6	74.5	64	48.9	41.1	33	17
X=5	75.5	72.5	60.5	48.9	39	36.3	21
TOTAL (7+6+5)	77.2	76.5	66.6	51.1	42.7	39.3	20.7

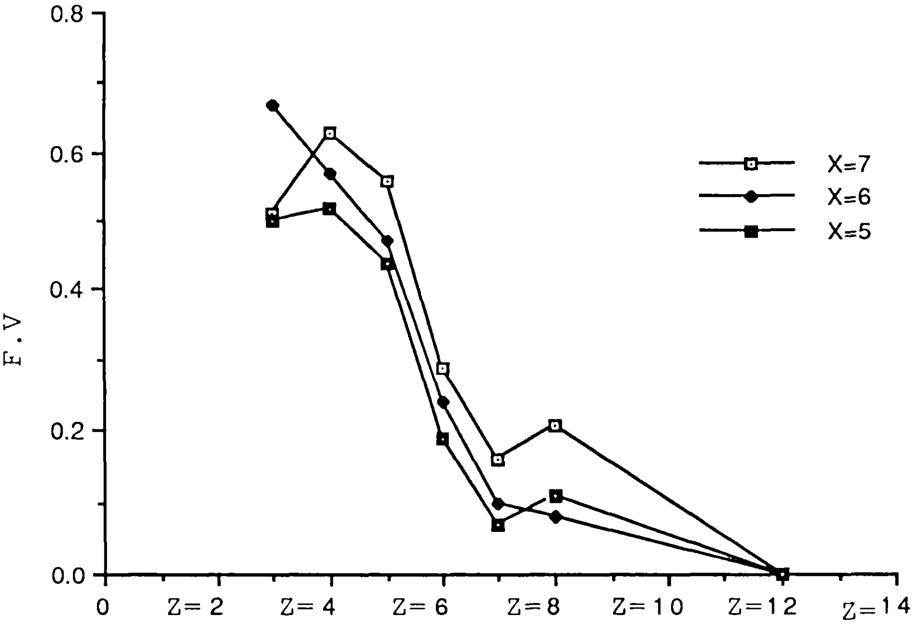


Figure 3-21. Comparison of the average facility value for all groups of different X-space students in the two examinations.

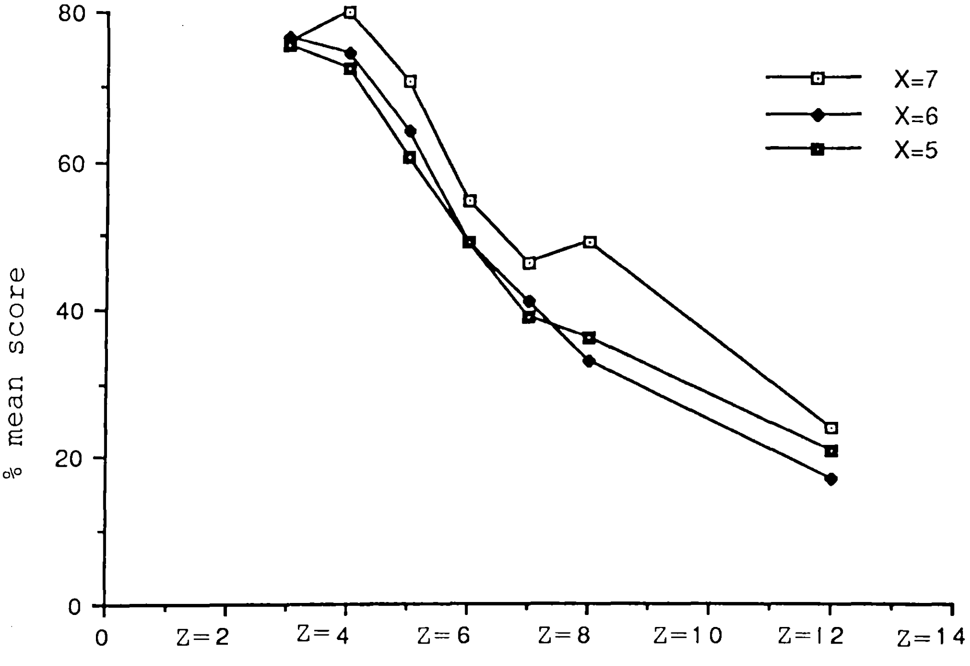


Figure 3-22. Comparison of the average meam score for all groups of different X-space students in the two examinations.

the same Z-demand for each group separately were calculated.

Table 3-20 as well as figure 3-21 shows that the performance of X=6 students, shows a continuous fall, but both X=7 and X=5 students the fall comes after Z=5, and when Z exceeds 7 both groups of students show an increase slightly till Z=8, and then all the three groups coming down to zero.

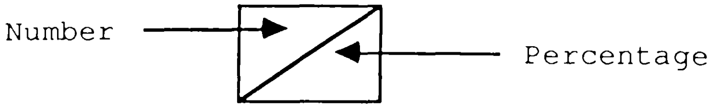
Table 3-21 as well as figure 3-22 represents the average of the mean score for each X-space group. The curve shows that the performance fell away when Z exceed 5 till Z=12, but X=7 students make temporary recovery between Z=7 and 8, and then fall down like others groups.

3-8 **Final results**

It is possible to classify students at the end of one year of study into two categories. First, students who were exempt from the

Table 3-22. Percentage and frequency in the final result for different X-space students

Groups	Exemption	Pass degree exam June	Pass degree exam Sept	Fail	Abs
X=7	28 46	23 36.3	7 11.4	6 9.8	4 6.5
X=6	14 35.9	12 30.8	5 12.8	6 15.4	2 5.1
X=5	8 30.8	7 26.9	4 15.4	3 11.5	4 15.4



June examination; these were students who scored well(> 59 %) in December and March examinations. Secondly students who were not exempted. As can be seen from table 3-22 that 28 (46 %) of X=7 students, 14 (35 %) students of X=6 and 8 (30 %) of X=5 students were exempt from the June examination.

Chapter four

School examination analyses

4-1 Introduction

This chapter describes the follow-up investigation intimated previously in chapter 3. This work is carried out with a different level and sample of students, viz with a "terminal mathematics class" at Lycée EL-Moukrani, Ben Aknoun, in Algeria, over a period of three terms during the academic year 1988/89.

The findings in the previous chapter tended to support the validity of the four hypotheses. These same hypotheses were investigated in this follow-up study.

4-2 Sample

In order to measure the working memory X-space (capacity) of the school pupils in this investigation two kinds of psychological tests were used- Figure Intersection Test (FIT) and Digit span Backwards Test (DBT). The Figure Intersection Test is a group of tests consisting of 42 items; the student must find out the common area of overlap of from two to eight overlapping figures. A sample of this test is given in Appendix 4-1.

The testing of working memory was carried out by applying FIT at the beginning of the first term, and a few days later the DBT was given to the same students. The total sample of students which is considered in this investigation consists of those who took both tests as well as the students who took only one. The students' scores in both tests required was from 4 to 7.

The sample of students under examination consisted of 149, divided into three different X-space groups:

(a) 37 (24.8 %) students with an X-space of 7

(b) 26 (17.4 %) students with an X-space of 6

(c) 86 (57.8 %) students with an X-space of 5.

The sample was also divided into three sub-groups of students according to GEFT. This will be discussed below.

4-3 **December examination**

4-3-1 **Question analysis**

In December 1988, 13 questions of the degree exam paper were analyzed into the number of thought steps required to solve each question correctly. The distribution of Z-demand of different questions is given in table 4-1 which also presents the facility value, mean score and maximum mark in each question. It was found that two questions had a Z-demand of 3; two questions had a Z-demand of 4; one question with a Z-demand of 5; four questions with a Z-demand of 6; one with a Z-demand of 7 and one question with a Z-demand of 16.

4-3-2 **Testing hypotheses 1 and 2**

The same two comparisons were again made to interpret the data collected as in the previous investigation discussed in chapter 3.

Analysis I: Facility value

The facility value was calculated for each question for the three X-space groups of students as well as for the whole sample of students. Then the average facility value was also calculated for the questions which had the same Z-demand. The results of this comparison are presented in table 4-2, where it can be seen that:

Table 4-1

The distribution of F.V , M.S and Z demand for each question

December examination

	Q1-1a	Q1-1c	Q1-2a	Q1-2b	Q2-1a	Q2-1b	Q2-2a	Q2-2b	Q2-2c	Q2-3	Q3	Q4-a	Q4-b
% F.V	7	10	32	20	66	28	54	40	19	11	2	51	39
Mean score	0.77	0.03	0.38	0.22	0.54	0.28	0.28	0.22	0.26	0.16	0.67	0.48	0.53
% M.S	34	11	38	22	72	37	56	44	26	21	19	64	53
Max mark	2.25	0.25	1	1	0.75	0.75	0.5	0.5	1	0.75	3.5	0.75	1
Z-demand	16	8	6	6	4	6	3	5	6	7	8	3	4

(a) the students' performance decreases as the task difficulty increases except in question of Z=16 for both X=7 and X=6, and in Z=4 for X=5. This result supports the validity of the first hypothesis.

Table 4-2. Relation between students' X-space and their success on different questions of Z-demand

Groups	F.V on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=16
X=7	0.56	0.59	0.51	0.29	0.14	0.09	0.11
X=6	0.42	0.54	0.38	0.26	0.12	0.04	0.07
X=5	0.53	0.51	0.30	0.19	0.08	0.04	0.03
TOTAL (7+6+5)	0.5	0.55	0.4	0.25	0.12	0.06	0.07

(b) the students' achievement decreases as the X-space of students decreases with one exception in Z=3 for X=5. This means that, the students with high X-space performed better than the student with the middle X-space, and both did better than those with the low X-space. This results tends to confirm that there is difference in responses of students with different X-space on questions of different Z-demand.

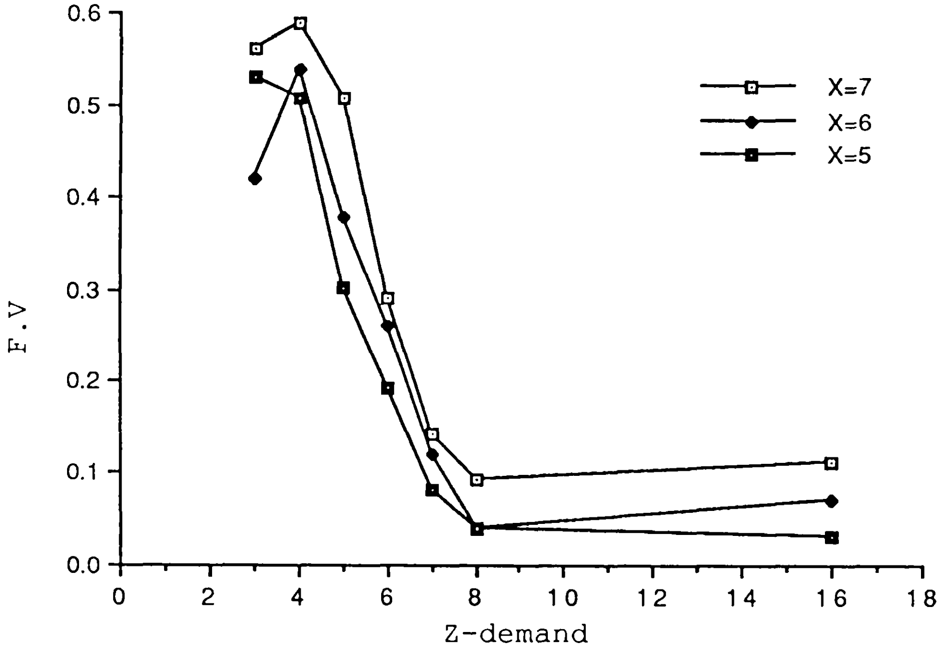


Figure 4-1. Comparison of the performance on questions of different Z-demand for students' different X-space.

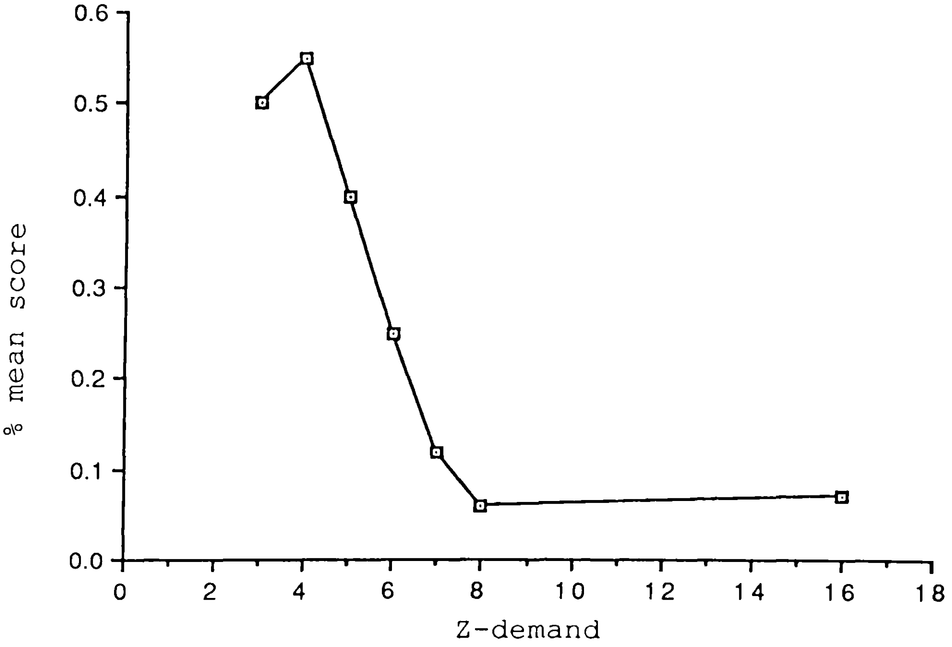


Figure 4-2. The performance of the whole sample of students on questions of different Z-demand in the December examination.

The same data are presented graphically in figures 4-1 and 4-2. The performance of the three groups of students starts to decline gradually. But when Z exceeds 4, their performance declines rapidly till Z=8, and then levels off between Z=8 and Z=16.

Analysis II: Mean score

The analysis of the data obtained was extended by comparing the mean score of each question for groups of students with different X-space, as well as for the whole sample of students. The results are given in table 4-3. The following conclusions can be made:

(1) for each X-space group, the performance decreases as the Z-demand of question increases from Z=3 to Z=16, with certain exceptions in Z=3 and Z=16 for each X-space group. It is noted that in the question with Z=16, students' performance increase when it normally would be expected to decrease. In order to find out why such an increase occurred, we found that the students were given many opportunities to solve similar questions before the examination, so that they have gained strategies which helped them to be successful. These strategies reduced the overload reduced on their working memory space and, thus enabled them to produce an unexpected result (36.5 % 32.4 %, 31.5 %).

(2) For a question of Z demand, the X=7 group performance best. The Z=3 question does not distinguish between the groups. Again it might be that the X=5 students spent more time on the low Z demand question but there is no proof of this.

The curve in figure 4-3 shows that the mean score (%) against the Z-demand of a question. It can be seen that, for each X-space group, the performance starts to increase gradually, but when Z exceeds 4, their performance decline sharply, but then increases at Z=16. Figure 4-4 shows the data for the whole sample of students.

Their performance starts to increase from Z=3 to Z=4, but then drops to Z=8 with the noted increase at Z=16.

Table 4-3. Relation between students' X-space and their success on questions of different Z-demand

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=16
X=7	64	70	56	38	21	23	39
X=6	51	61	42	31	20	12	35
X=5	60	60	36	27	20	12	32
TOTAL (7+6+5)	58	64	45	32	20	16	35

t-test(two tailed) was applied in order to find out whether the differences in mean scores are significant. The results are shown in table 4-4. It can be seen that at 10 % level, there was a significant difference found between X=7 and X=6, in question 5, and also between X=7 and X=5 in question 6. At 5 % level, in questions 8 with X=5, there was a significant differences between X=7 and X=5, and also between X=7 and X=6 in question 11 with Z=8 where at 1 % level, there were significant differences between X=7 and X=5 in question 5 with Z=4 and 11 with Z=8.

Table 4-4. The significance of the performance between students of different X-space.

Questions	X=7 & X=6	X=6 & X=5	X=7 & X=5
Q1 Z=16	0.34	0.45	0.97
Q2 Z=8	0.4	0	0.62
Q3 Z=6	1.02	0.03	1.3
Q4 Z=6	0.96	0.18	1.35
Q5 Z=4	1.715*	0.29	2.68***
Q6 Z=6	0.37	0.98	1.69*
Q7 Z=3	0.87	0.4	0.99
Q8 Z=5	1.16	0.56	2.21**
Q9 Z=6	0.29	0.44	0.93
Q10 Z=7	0.17	0.023	0.18
Q11 Z=8	2.26**	0.22	2.89***
Q12 Z=3	0.74	1.13	0.52
Q13 Z=4	0.18	0.02	0.24

* significant at 10 % level

** significant at 5 % level

***significant at 1 % level

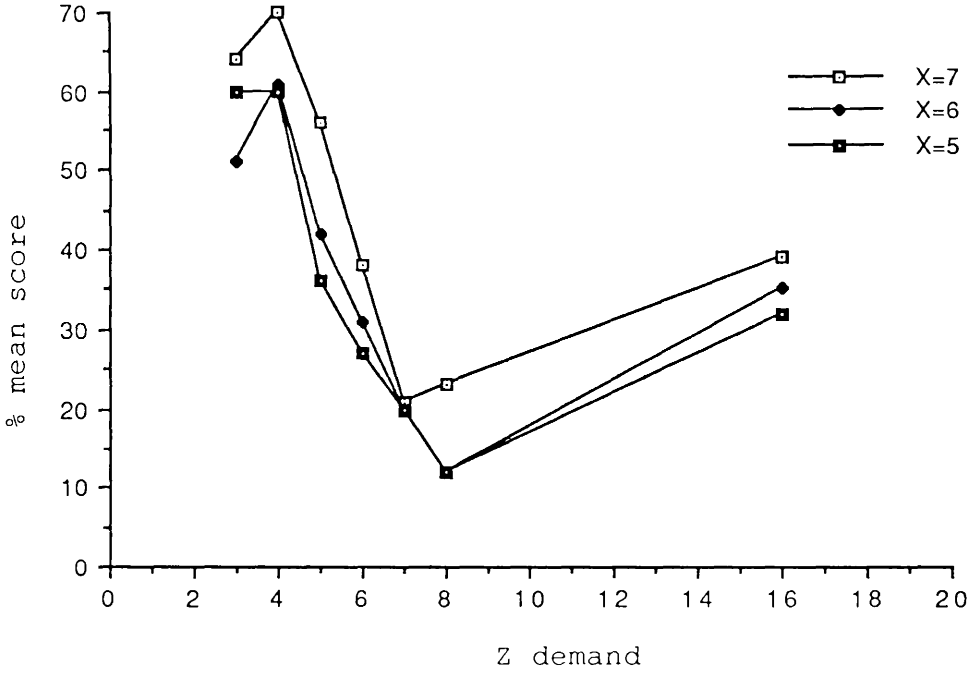


Figure 4-3. Comparison of the performance on questions of different Z demand for students' different X-space.

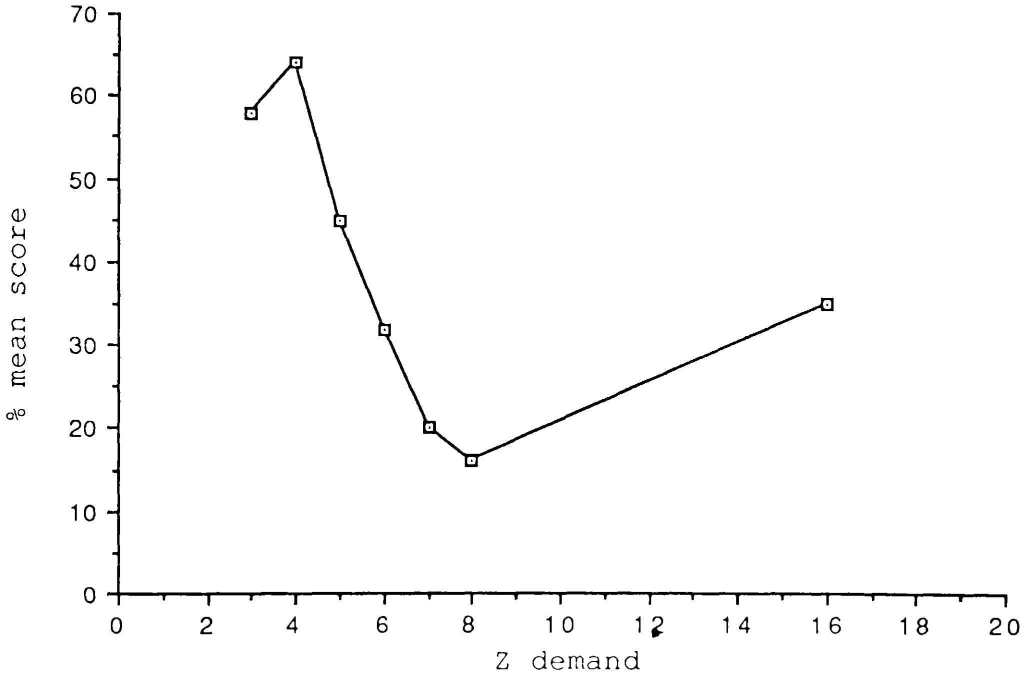


Figure 4-4. The performance of the whole sample of students on questions of different Z demand in December examination.

4-3-3 **Testing hypotheses 3 and 4**

The GEFT was administered to the same sample of students in this part of the research. A total of 149 students took both working memory space tests and GEFT. According to the GEFT score, the students were classified into three different disembedding ability groups; 67 (45 %) students who scored from 2 to 6 were classified as field dependent; 74 (50 %) students who scored from 7 to 12 as field intermediate, and 8 (5 %) students who scored from up 13 as field independent students. Table 4-5 shows the frequency of students on different degree of FD/FI at the different X-space.levels. It should be noticed that in this sample none of the 26 students with X=6 was field independent.

Table 4-5. the distribution of FD/FI students on different X-space.

Groups	F.I	F.Int	F.D
X=7	4	22	11
X=6	—	21	5
X=5	4	44	38
TOTAL (7+6+5)	8	87	54

I **Relation between students' performance and their degree of FD/FI**

A comparison was made between students of different degree of FD/FI and the overall performance in the December examination. The results are presented in table 4-6 as well as in figure 4-5. These results must be treated with caution due to the small size of the F.I sample.

Table 4-6. The overall performance on different groups of FD/FI

Groups	Mean score	S.D
F.I	23.3	8.2
F.Int	18.0	7.3
F.D	17.9	5.5

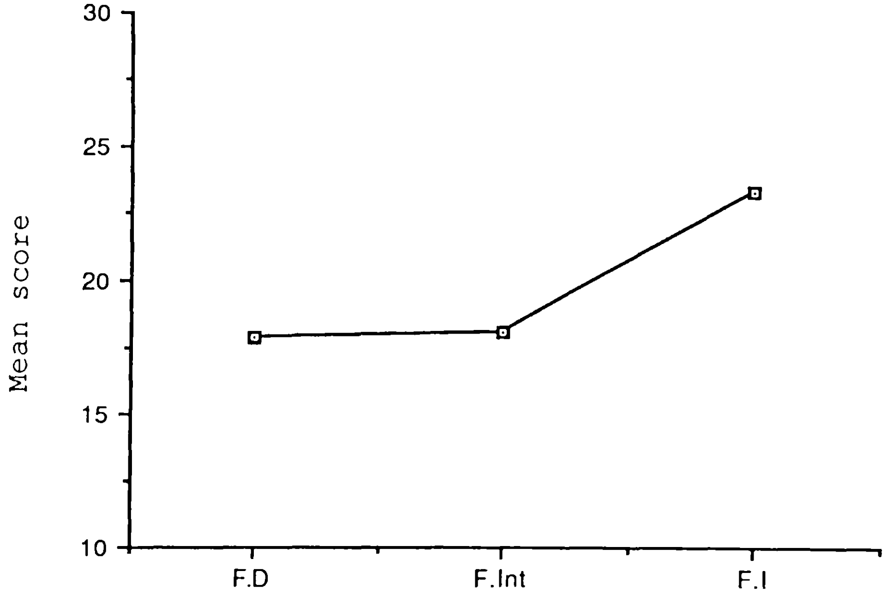


Figure 4-5. Comparison of the overall performance between different degree groups of FD/FI in December examination.

II **Relation between performance, X-space and degree of FD/FI**

A comparison can be made in responses between students of different abilities to disembed information on different questions for both X=7 and X=5 students.

Table 4-7 as well as figure 4-6 shows the mean score (%) of students of X=7. The Z=3 question does not distinguish between the disembedding ability groups. For questions with $Z \geq 4$ the performance generally falls as the Z demand increases for each FD/FI group.

Similar results can be seen from table 4-8 as well as in figure 4-7 for students with X=5.

Once again, tables 4-7 and 4-8 indicate that, for questions with $Z > 4$ the performance decreases as the ability of the students to isolate the irrelevant from relevant information decreases for the two X-space groups X=7 and X=5. It should be noted, however, the field independent students provided the highest results whereas the field dependent students scored the lowest performance in each question, whereas in the low Z-demand questions 3 and 4, field dependent students performed better than field independent or about the same.

In addition, the total mean score was calculated on different FD/FI students for each X-space group in the December examination. The results are shown in table 4-9 as well as in figure 4-8. These indicate that the field independent students obtained higher results than field dependent students.

t-test (two tailed) was applied to find out whether these differences are significant. It can be seen from table 4-10 that at the 5 % level there is significant differences between the field independent and field intermediate students, and a significant difference between field independent and field dependent students for the total group of students.

Table 4-7. Relation between success on questions of different Z-demand and disembedding ability for ***X=7 students***

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=16
F.I	42	69	62	54	25	37	45
F.Int	62	68	56	39	24	24	44
F.D	70	65	54	32	14	15	20

Table 4-8. Relation between success on questions of different Z-demand and disembedding ability for ***X=5 students***

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=16
F.I	62	62	74	37	41	24	52
F.Int	44	55	30	28	18	16	28
F.D	62	66	36	25	20	14	33

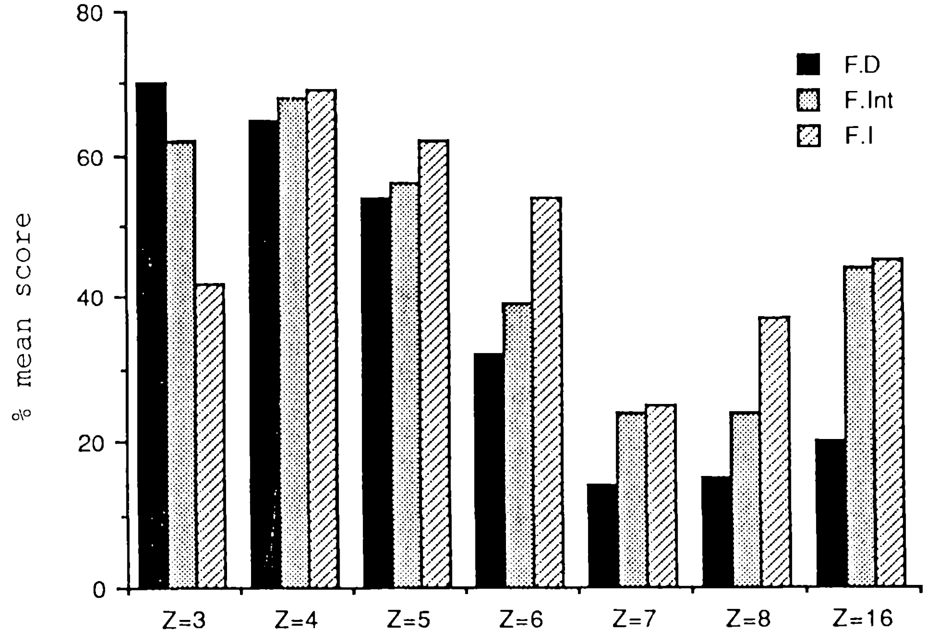


Figure 4-6. Comparison of the performance between students of different degree of FD/FI for <u>*X=7 students*</u>

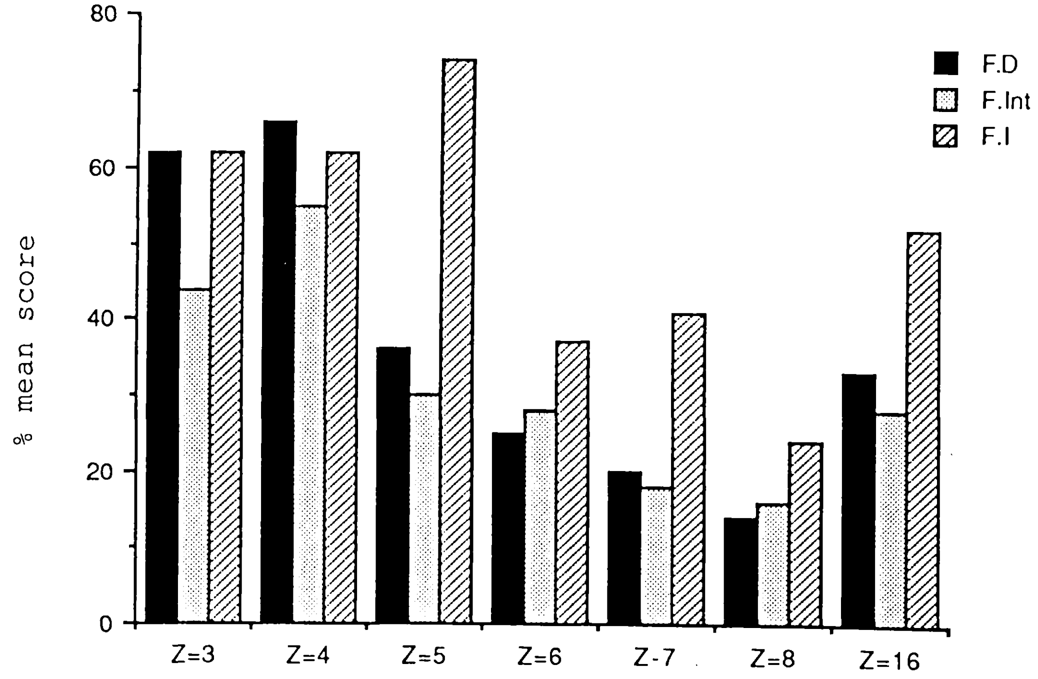


Figure 4-7. Comparison of the performance between students of different degree of FD/FI for <u>*X=5 students*</u>

Table 4-9. Relation between X-space, GEFT and students' overall performance in December examination.

Groups	Mean scores on different groups:					
	F.I		F.Int		F.D	
	M.S	S.D	M.S	S.D	M.S	S.D
X=7	24.0	6.4	20.6	7.1	18.4	5.1
X=6	—	—	19.1	7.9	15.2	4.1
X=5	22.0	6.2	16.4	6.8	18.6	5.6
TOTAL (7+6+5)	23.4	6.3	18.1	7.3	18.1	5.5

Table 4-10. The significance of the differences between different FD/FI students for each X-space group.

Groups	F.I &F.Int	F.Int & F.D	F.I & F.D
X=7	0.96	0.99	1.55
X=6	—	1.54	—
X=5	1.70	1.57	1.05
TOTAL (7+6+5)	2.19*	0.07	2.23*

* significant at 5 % level.

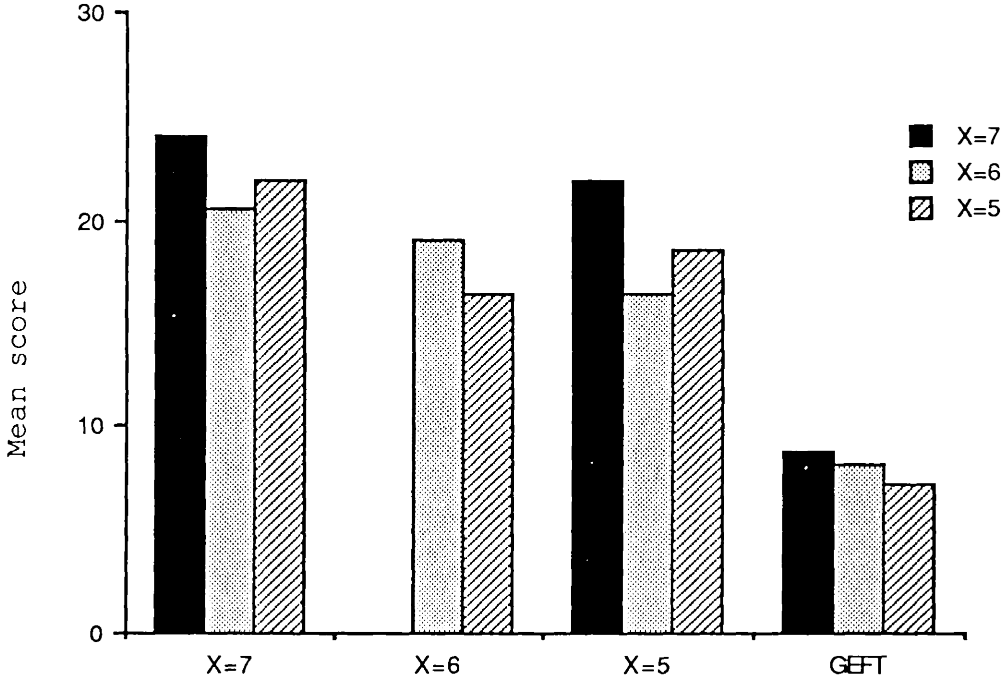
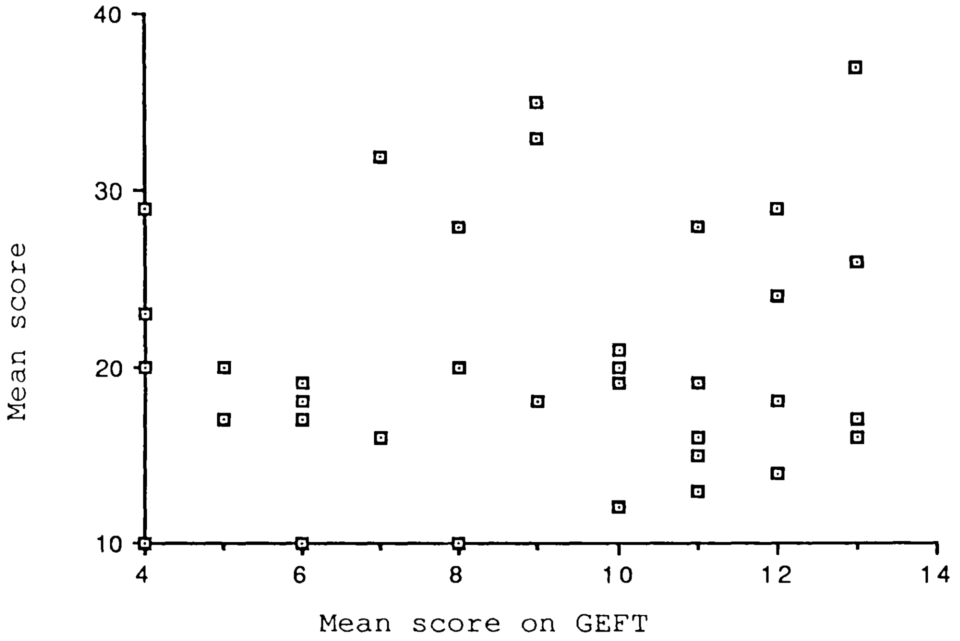


Figure 4-8. Comparison of the overall performance between students of different degree of FD/FI in each X-space group.

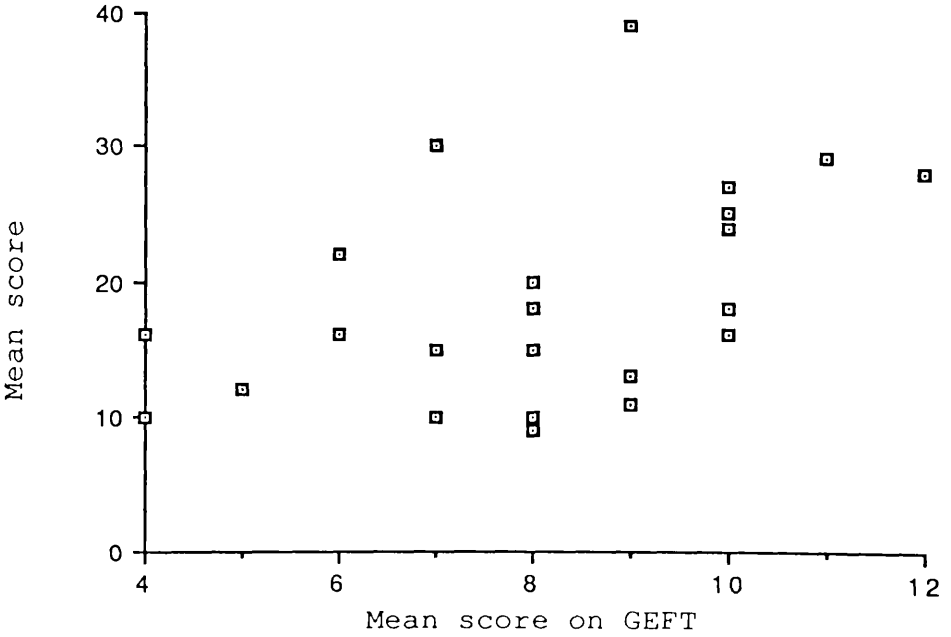
4-3-4 **Pearson correlation coefficient**

The correlation coefficient between the GEFT and students' overall performance in the December examination was low (r= 0.11, p=0.09) and statistically was not significant. On the other hand the X-space was found to correlate significantly with performance (r=0.199 at 5 %). This means that the most successful students in their overall performance were those of the highest X-space whether they were field independent or not. A high significant correlation (r=0.302 at 0.001 level) was found between the predictor variables; X-space and FD/FI.

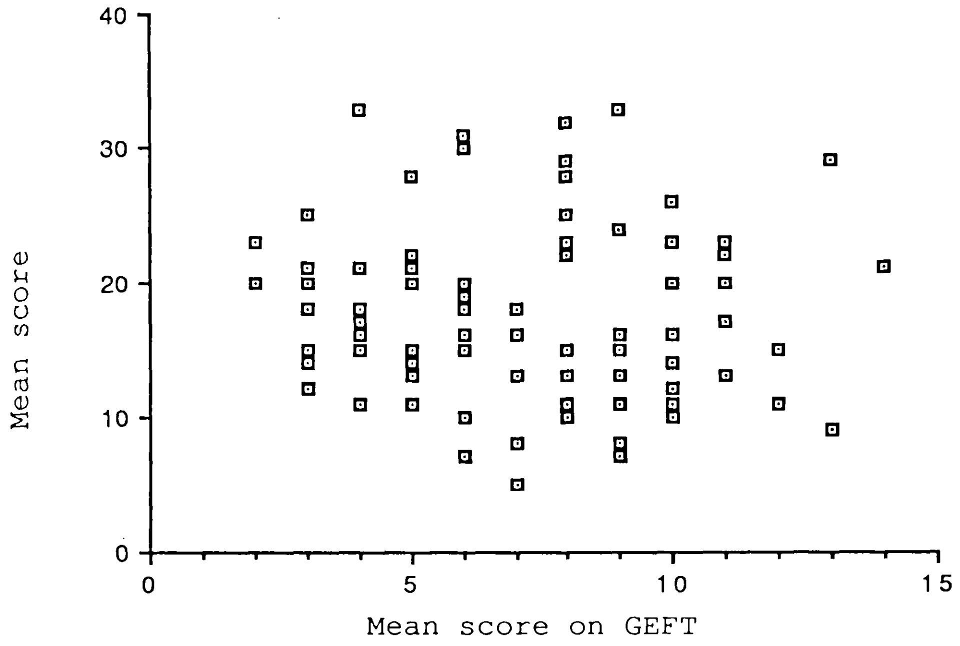
The overall performance of the students on their December examination was plotted against the mean score on GEFT for the three groups of different X-space separately. These are shown in scatter diagrams 4-1, 4-2 and 4-3. There is only one correlation



Scatter diagram 4-1. The relation between students' performance and GEFT for X=7 student



Scatter diagram 4-2. The relation between students' performance and GEFT for X=6 students.



Scatter diagram 4-3. The relation between students' performance and GEFT for X=5 students.

coefficient found between the GEFT and the performance of X=6 students (r=0.445) which is statistically significant at 5 % level.

4-4 March examination

4-4-1 Question analysis

In order to provide more data which might confirm previous results, the same sample of students was assessed in later examination. In the March examination 1989, the answer booklets were collected from which 15 questions were analyzed to determine the number of thought steps involved in each question. The distribution of the Z-demand of different questions, the facility value, mean score and the maximum mark in each question can be found in Appendix 4-2. The sample in the second examination fell to 129 students.

4-4-2 **Testing hypotheses 1 and 2**

Analysis I: Facility value

A comparison was made between the responses of students and their X-space to determine the validity of the two hypotheses above. Table 4-11 shows the facility value of questions of different Z-demand.

Table 4-11. The performance of students on questions of different Z-demand

Groups	F.V on questions of different Z-demand							
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9
X=7	0.70	0.61	0.48	0.48	0.35	0.30	0.24	0.22
X=6	0.61	0.56	0.52	0.43	0.33	0.26	0.21	0.17
X=5	0.42	0.64	0.42	0.45	0.24	0.23	0.19	0.18
TOTAL (7+6+5)	0.57	0.60	0.47	0.46	0.31	0.26	0.21	0.18

It can be seen that:

(a) for students who have the same X-space, their performance generally decreases (with certain exception) as the Z-demand of the questions increases.

(b) for the questions of the same Z-demand, the performance of students generally decreases as the X-space decreases. This means that, in general, the X-space = 7 students performed better than X-space = 6, and both are better than X-space = 5. The same results are shown graphically in figures 4-9 and 4-10. The performance of

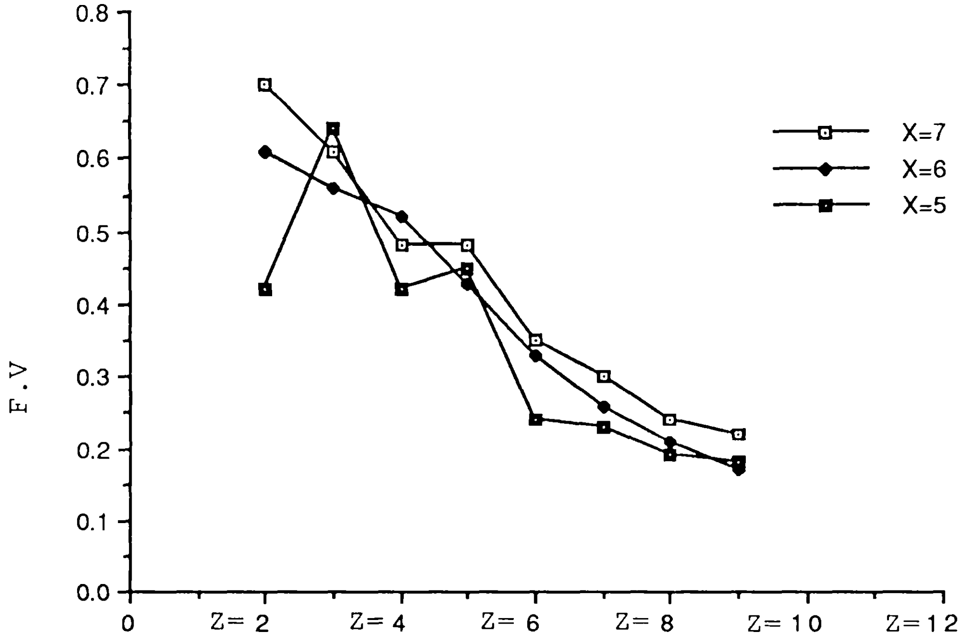


Figure 4-9. Comparison of the performance on questions of different Z demand for students' different X-space.

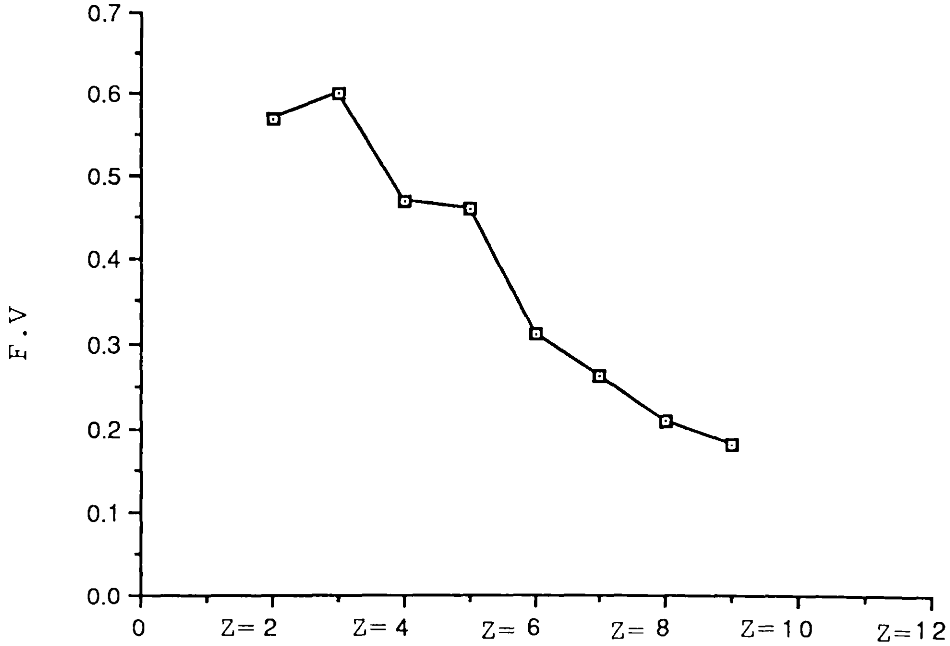


Figure 4-10. The performance of the whole sample of students on questions of different Z demand.

all groups of students (different X space) falls steadily for questions of Z = 2 to Z = 9, with X = 7 students generally above X = 5.

Analysis II: Mean score

The data can be further analysed in terms of mean score and X-space for questions of a given Z-demand. The mean score (%) versus students' X-space are presented in table 4-12. It can be seen that:

Table 4-12. The performance of students on questions of different Z-demand.

Groups	% mean score on questions of different Z-demand							
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9
X=7	76	71	68	56.5	42.2	38	24	16
X=6	66	61	73	53	40.2	34	21	14
X=5	46	56	58	56	31.2	33	19	14
TOTAL (7+6+5)	62.6	62.6	66.3	55.2	37.9	35	21.3	14.6

(1) the students' responses decreases (with certain exception) as the Z-demand of the question increases for each X-space students as well as the whole sample.

(2) the performance of students on each Z-demand decreases as the X-space of students decreases. So far hypotheses 1 and 2 seems to be supported.

Table 4-13. The significance of the difference between different students groups

Questions	X=7 & X=6	X=6 & X=5	X=7 & X=5
Q1 Z=5	0.58	1.01	0.35
Q2 Z=2	0.86	1.80*	3.46***
Q3 Z=6	0.26	2.31**	3.26***
Q4 Z=4	0.56	1.74*	1.153
Q5 Z=6	0.33	0.13	0.58
Q6 Z=7	0.34	0.17	0.65
Q7 Z=8	0.19	0.58	0.91
Q8 Z=5	0.91	1.02	0.02
Q9 Z=3	0.86	0.95	0.02
Q10 Z=5	0.14	0.29	0.21
Q11 Z=5	0.24	0.47	0.21
Q12 Z=8	0.28	0.21	0.58
Q13 Z=6	0.31	0.18	0.58
Q14 Z=6	0.44	0.61	0.15
Q15 Z=9	1.17	1.13	0.28

* significant at 10 % level. ** significant at 5 % level

***significant at 1 % level

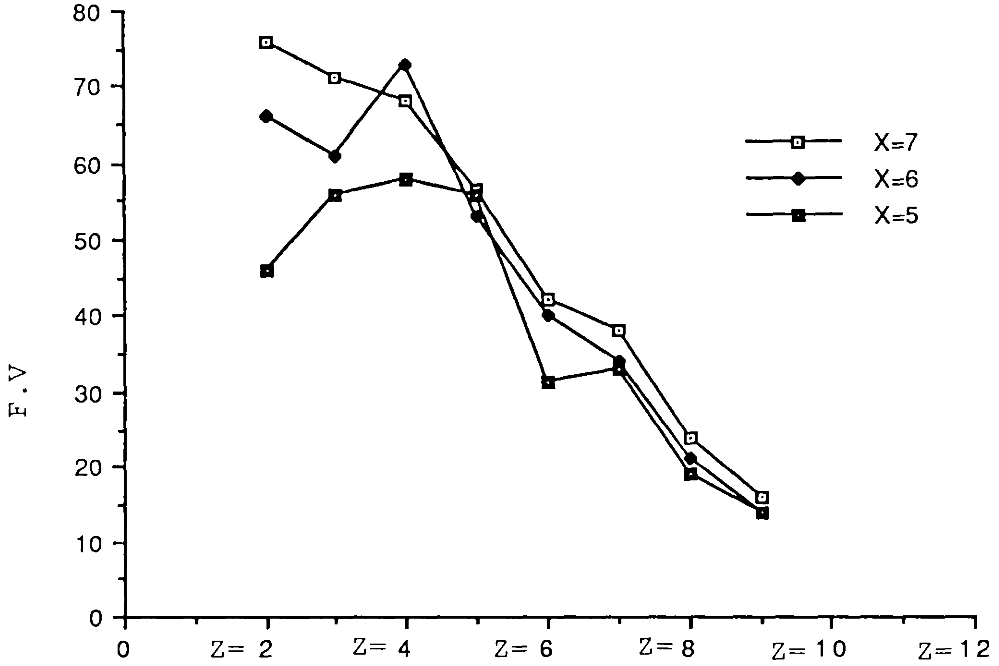


Figure 4-11. Comparison of the performance on questions of different Z demand for students' different X-space.

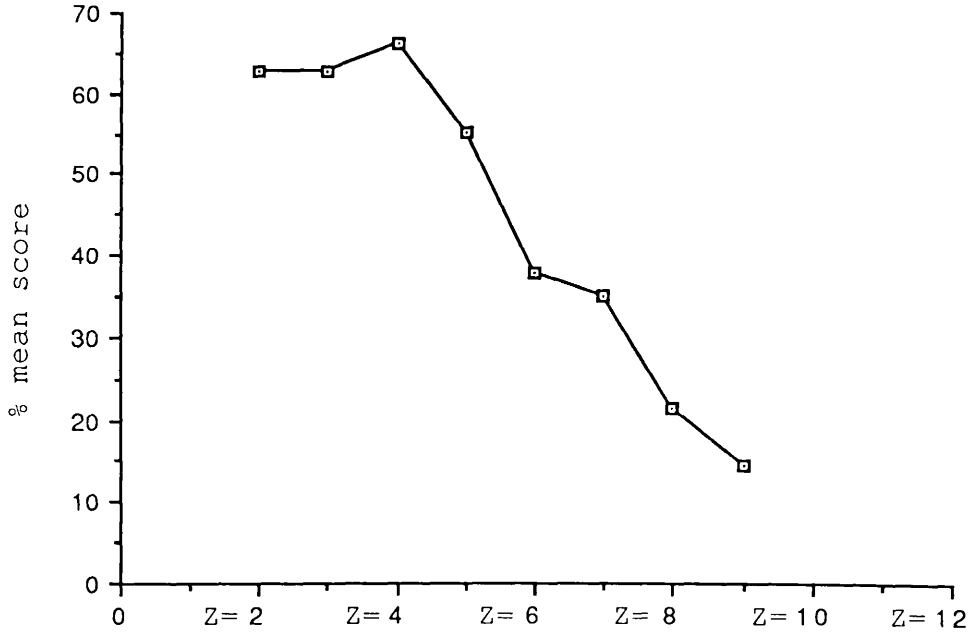


Figure 4-12. The performance of the whole sample of students on questions of different Z demand.

Again t-test(two tailed) was used to find out if the differences in mean score are significant. It can be seen from table 4-13 that in questions 2 and 3 with Z=2 and Z=6, there were significant difference found between X=6 and X=5, and also between X=7 and X=5, whereas in question 4 with Z=4, there was a significant difference found between X=6 and X=5.

The three curves of students are plotted separately in figure 4-11 as well as the whole sample of students in figure 4-12, where it is seen that the mean score is essentially flat for Z=2 to Z=4 and then falls gradually from 60 % to 15 % as Z goes from 5 to 9. This further supports hypothesis 1.

4-4-3 **testing Hypotheses 3 and 4**

I Relation between disembedding ability and students' performance

A comparison of students' performance was then made with their degree of disembedding ability. It can be seen, from table 4-14 as well as figure 4-13 that the field independent students performed only slightly better than field intermediate, and both only slightly are better than field dependent students. Hypothesis three is not supported by this result.

Table 4-14. The performance of different degree of FD/FI students

Groups	Mean score	S.D
F.I	10.60	4.79
F.Int	9.04	4.03
F.D	8.36	0.16

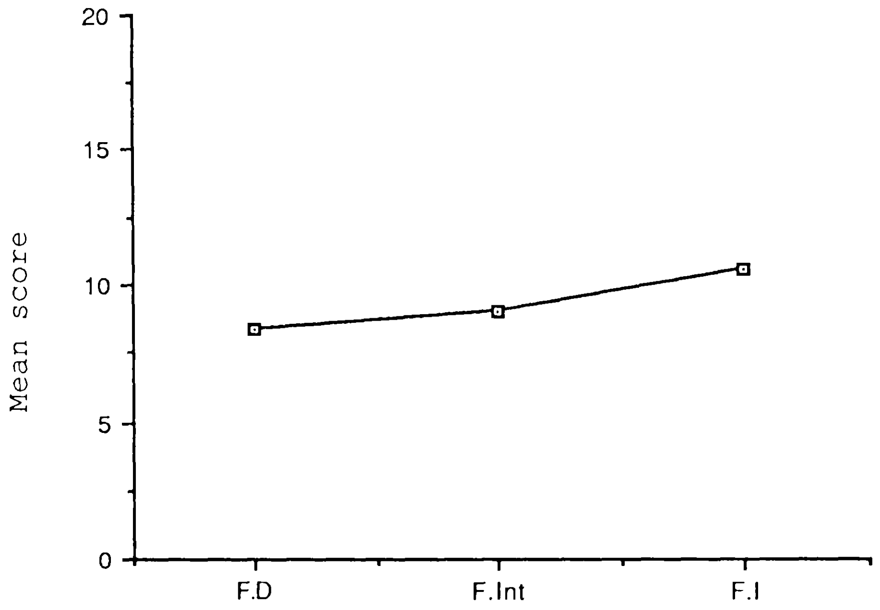


Figure 4-13. Comparison of the performance between students of different degree of FD/FI.

II **Relation between X-space, disembedding ability and students' performance**

Another comparison was made between the three variables; X-space, disembedding ability and performance. The result of this comparison are presented in tables 4-15 and 4-16.

From table 4-15, for students having the same X-space (X=7) and different degree of FD/FI, the performance (expressed as % mean score) on questions of different Z-demand decreases (with certain exceptions) as the difficulty of the question increases. Similar results can be seen from table 4-16 for X=5 students. The performance in each question decreases as the ability to select the relevant information decreases except in Z=4 and Z=6 for X=5. This means that the field independent students achieved higher results than the field intermediate students, and both are higher than field dependent students.

Table 4-15. Relation between students success on different questions and disembedding ability for ***X=7 students***

Groups	% mean score on questions of different Z-demand							
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9
F.I	100	100	93	52.5	70.5	93	37	32
F.Int	70	67	66	56.7	42	41	22	20
F.D	80	55	61	51.5	33.5	16	20	10

Table 4-16. Relation between students success on different questions and disembedding ability for ***X=5 students***

Groups	% mean score on questions of different Z-demand							
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9
F.I	74	75	65	66.2	36	29	31	25
F.Int	50	66	54	59.2	27	36	22	16
F.D	40	69	61	49	30.7	30	15	12

Generally the results obtained indicate that the degree of FD/FI has an affect on students' performance.

In addition, table 4-17 represents the overall results provided from the March examination for different degree of FD/FI in each X-space group. It can be concluded that for students having the same X=space, the field independent ones obtained the highest results, field intermediate students achieved the average, and field dependent students obtained the lowest score. This effect was least for low capacity students. However hypotheses three and four now have some support.

Table 4-17. The overall performance on different degree of FD/FI students in March examination for each X-space group (scores out of 20).

Groups	Mean scores on different groups:					
	F.I		F.Int		F.D	
	M.S	S.D	M.S	S.D	M.S	S.D
X=7	13.1	2.4	9.9	3.1	9.0	2.3
X=6	—	—	9.7	4.1	7.6	2.8
X=5	8.6	5.2	8.3	4.3	8.3	3.7
TOTAL (7+6+5)	10.9	3.2	9.1	3.8	8.3	2.9

t-test (two tailed) was applied to find whether or not these differences are significant, It can be seen from table 4-18 that there is a significant differences between field independent and field dependent for X=7 as well as the whole sample of students.

Table 4-18. The significance of the difference between students different degree of FD/FI

Groups	F.I &F.Int	F.Int & F.D	F.I & F.D
X=7	2.09	0.912	2.877*
X=6	——	1.12	——
X=5	0.11	0	0.11
TOTAL (7+6+5)	1.39	1.31	2.017**

* significant at 10 % level
** significant at 5 % level

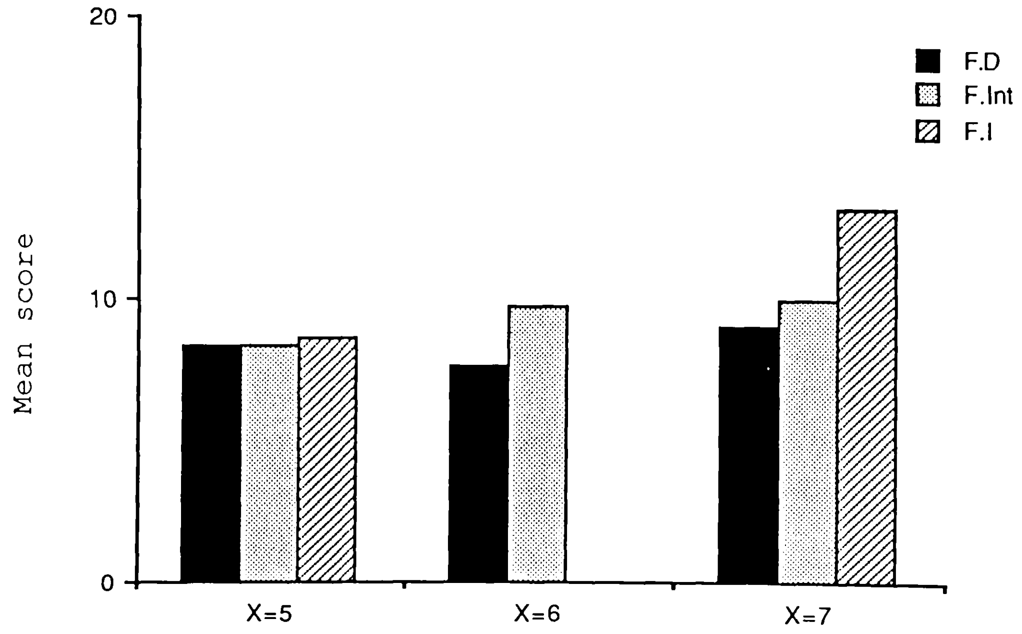
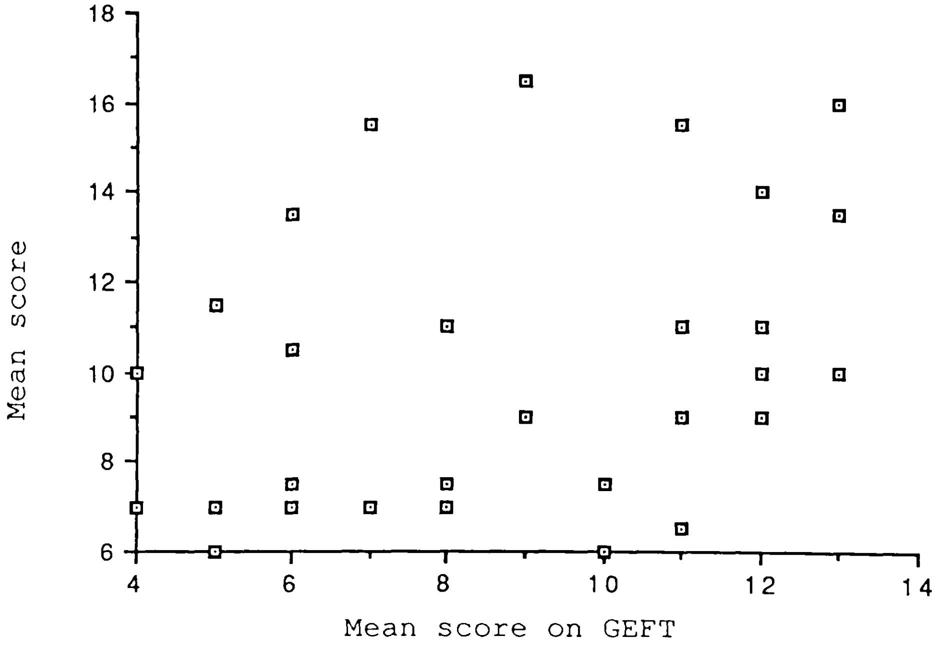


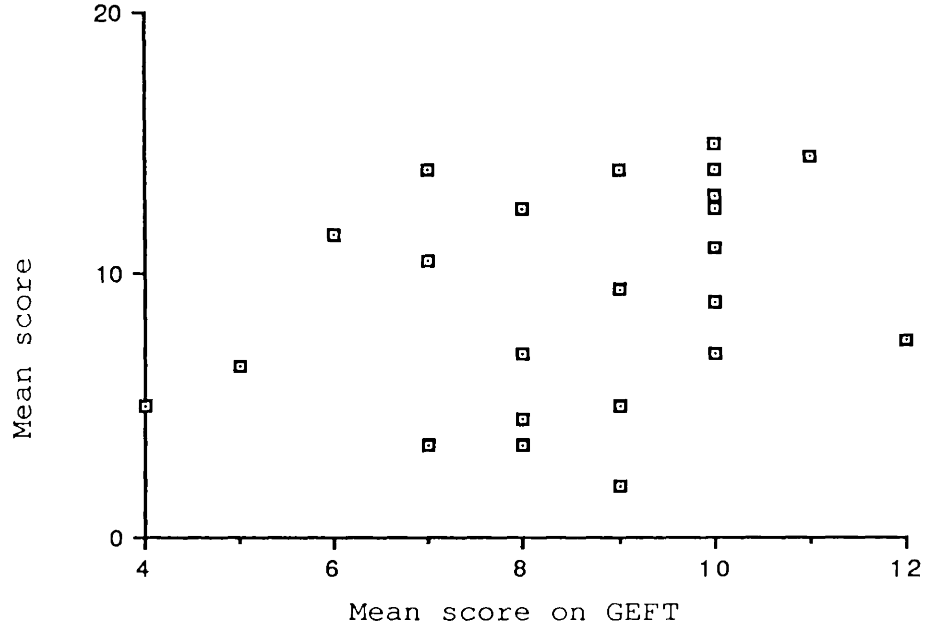
Figure 4-14. Comparison of the overall performance between students of different degree of FD/FI for each X-space group.

4-4-4 **Pearson correlation coefficient**

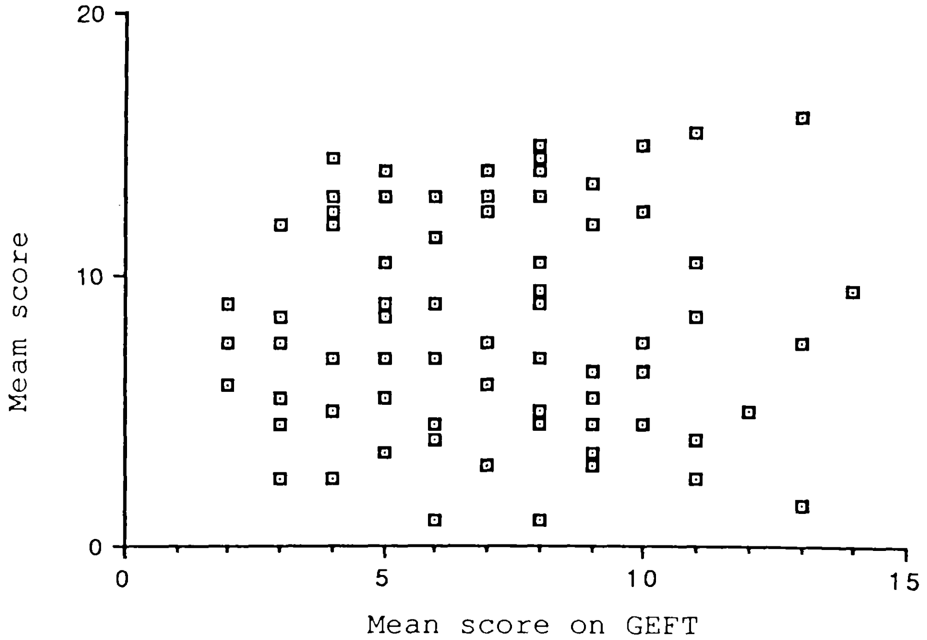
Once again, it was found that the students' performance correlated significantly with their X-space (r=0.176) which is statistically significant at the 5 % level, and also the performance is correlated significantly with GEFT score (r=0.147) at the 10 % level. Furthermore, the overall performance on March examination was plotted against the mean score on GEFT for students of different X space. These are shown in the scatter diagrams 4-4, 4-5 and 4-6. For any group of X space students, no significant correlation coefficient was found between students' responses and the GEFT score.



Scatter diagram 4-4. ***for X=7 student*** in March examination



Scatter diagram 4-5. <u>*for X=6 student*</u> in March examination



Scatter diagram 4-6. <u>*for X=5 student*</u> in March examination

4-5 **June examination**

4-5-1 **Question analysis**

In June 1989, 20 questions were analyzed into number of thought steps. The distribution of the Z-demand on different question, the facility value, mean score and maximum mark in each question are shown in Appendix 4-3. In this part of the investigation, the sample was 117 students.

4-5-2 **Testing hypotheses 1 and 2**

The same method as above is repeated to interpret the data obtained in the June examination.

Analysis I: **Facility value**

A comparison was made in order to find evidence for the two hypotheses above.

Table 4-19. Relation between students' X-space and their performance on questions of different Z-demand.

Groups	F.V on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=10
X=7	0.40	0.43	0.53	0.28	0.21	0.25	0.17
X=6	0.42	0.43	0.50	0.23	0.16	0.24	0.13
X=5	0.40	0.39	0.44	0.21	0.19	0.21	0.10
TOTAL (7+6+5)	0.41	0.42	0.49	0.24	0.19	0.23	0.13

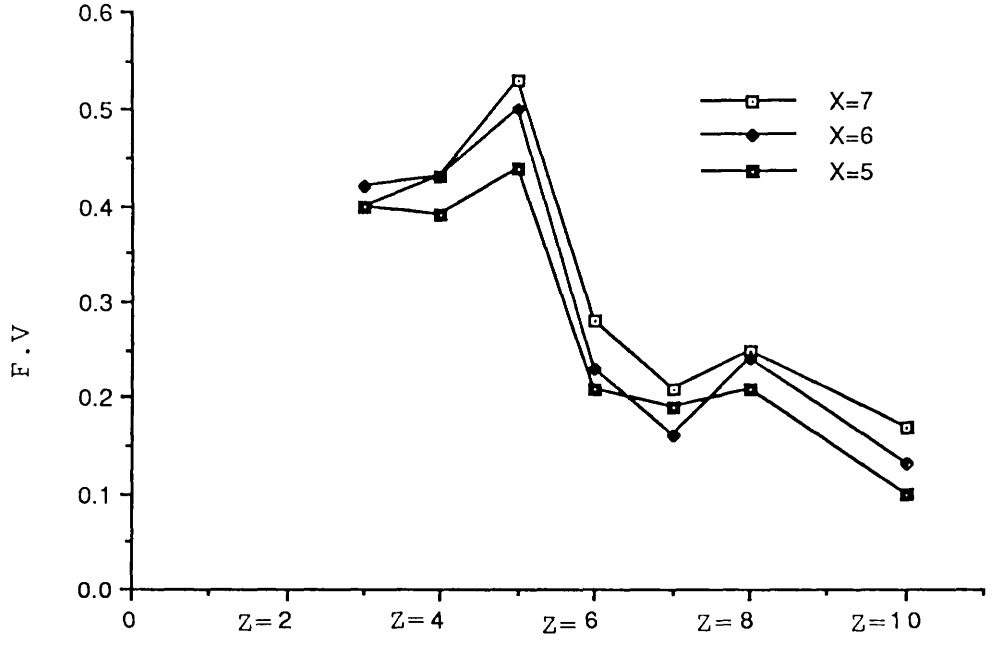


Figure 4-15. Comparison of the performance on questions of different Z-demand for students' different X-space

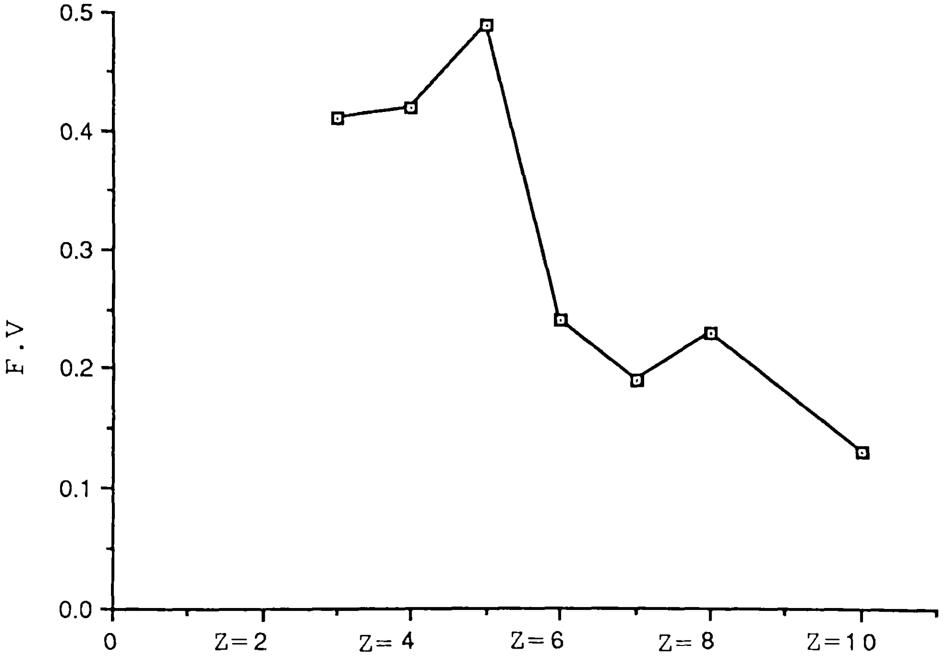


Figure 4-16. The performance of the whole sample of students on questions of different Z-demand in June examination.

The facility value was calculated firstly on different question and then the average of the facility value for questions having the same Z-demand was also calculated. The result is presented in table 4-19 as well as in figures 4-15 and 4-16.

It can been seen that, for students having the same X-space, the performance decreased (with certain exceptions) as the Z-demand of questions increased from Z=3 to Z=10. Also the students' performance decreased as the X-space of students decreased in each question.

F.V increased from 0.4 to 0.5 as Z went from 3 to 5, then decreased to Z=6, essentially levelled off between Z=6 to Z=8 and then fell to 0.1 at Z=10.

Analysis II: Mean score

Another comparison was made of the responses of groups of students of different X-space and also for the whole sample of students in terms of the Z-demand of the questions.

Table 4-20. Relation between students X-space and their success on questions of different Z-demand.

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=10
X=7	46.8	49	60	38.5	33	27.3	16
X=6	48.5	51	56	37.6	25.5	26.5	14
X=5	48.1	51	50	33.4	28.6	24.2	11.4
TOTAL (7+6+5)	47.8	50.3	55.3	36.5	29	25.8	13.8

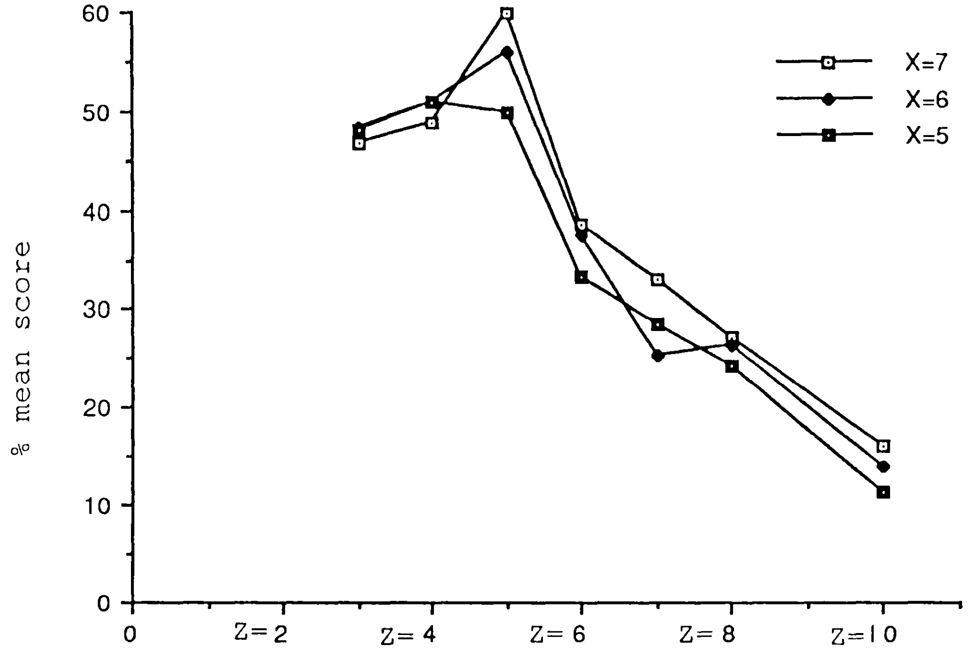


Figure 4-17. Comparison of the performance on questions of different Z-demand for students' different X-space in June examination.

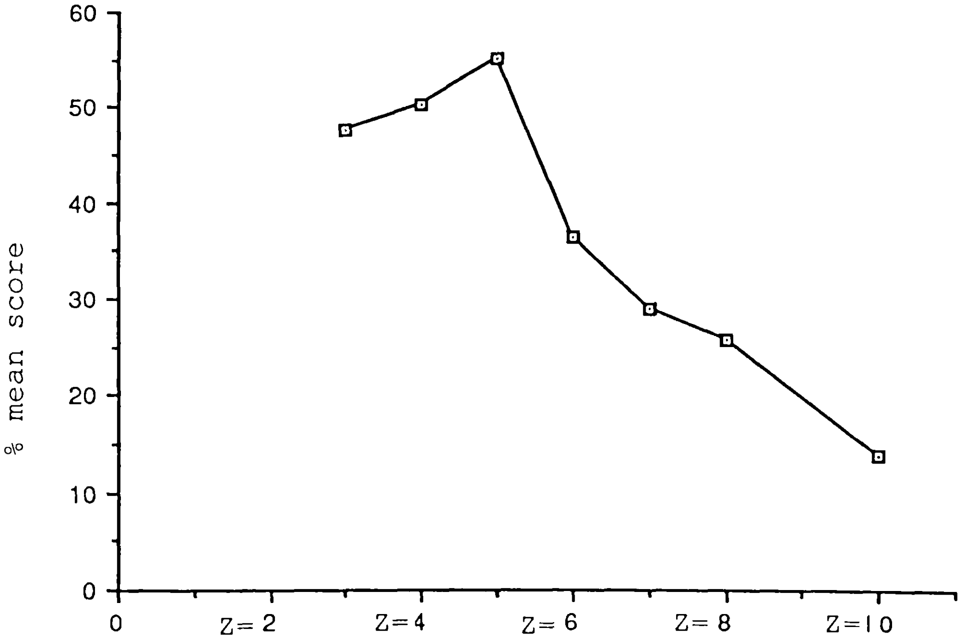


Figure 4-18. The performance of the whole sample of students on questions of different Z-demand in June examination.

The mean scores provided are given in table 4-20. as well as in figures 4-17 and 4-18.

From the results it is concluded that the performance of students who have the same X-space decreased as the difficulty of questions increases, with certain exceptions. For a questions which have complexity greater than four the achievement decreases as their X-space. From this study the two sets of analyses above tend to support the validity of hypothesis 1 and 2

Initial rise in mean score from 48 % to 54 % was as Z goes from Z=3 to Z=5 then a gradual fall to 12 % at Z=10.

4-5-3 **Testing hypotheses 3 and 4**

Relation between X-space, FD/FI and performance

In order to compare the three variables cited above, the mean examination score for students of different groups of X-space within each group of FD/FI students was calculated. It must be recalled that the following was based on small numbers of F.I students. In table 4-21, the results for Z =4 and Z=5 show the FD students do better than the FI group, and the F.Int group do best of all. In table 4-22, for Z=3 and Z=4, the FI group perform least well, and the F.Int group perform best.

Table 4-21. Relation between students success on different questions of Z-demand and their ability FD/FI for ***X=7 students***

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=10
F.I	55.7	24	50	38	49	33.2	100
F.Int	46.4	56.5	62	37	31.5	31.2	16
F.D	38.7	41	54	29.5	22.5	17.2	0

For questions with Z > 5, field independent students obtained higher results than field intermediate students, and both are higher than field dependent students. Hypotheses 3 and 4 have some support when Z > 5.

Table 4-22. Relation between students success on different questions of Z-demand and their ability FD/FI for ***<u>X=5 students</u>***

Groups	% mean score on questions of different Z-demand						
	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=10
F.I	39.5	24.5	50	42.5	44	31.5	16
F.Int	48.7	56	40	40.5	27.5	25	12
F.D	48	48	50	28	28.5	20.8	10

Table 4-23. The overall performance of students with different degree of FD/FI in each X-space groups (scores out of 20).

Groups	Mean scores on different groups					
	F.I		F.Int		F.D	
	M.S	S.D	M.S	S.D	M.S	S.D
X=7	11.2	0.7	10.0	3.9	7.7	3.5
X=6	—	—	9.6	3.1	7.0	2.5
X=5	10.3	4.4	8.6	3.07	8.3	3.0
TOTAL (7+6+5)	10.7	3.3	9.2	3.4	8.0	3.2

In addition, table 4-23 shows the overall achievement for student of different degree of FD/FI within each X-space group. For these results, it can be concluded that the field independent students performed better than the field dependent students in both X=7 and X=5 students

Table 4-24. The significance of the difference between students of different disembedding ability for each X-space group.

Groups	F.I &F.Int	F.Int & F.D	F.I & F.D
X=7	1.16	1.58	2.76
X=6	——	1.62	——
X=5	0.67	0.37	0.78
TOTAL (7+6+5)	0.97	1.92*	1.73*

* significant at 10 % level.

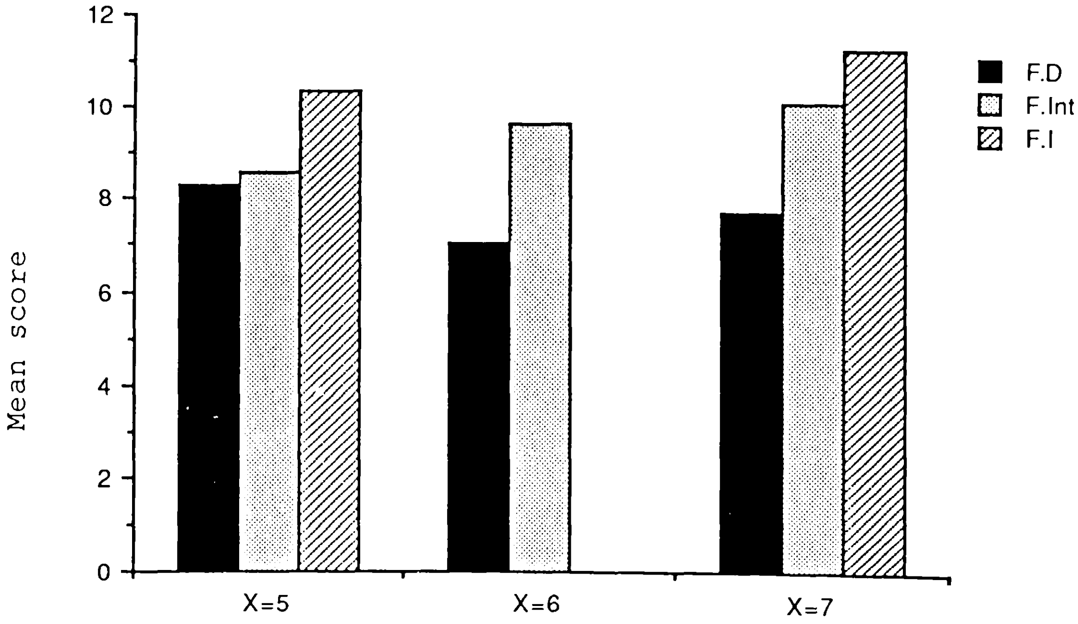
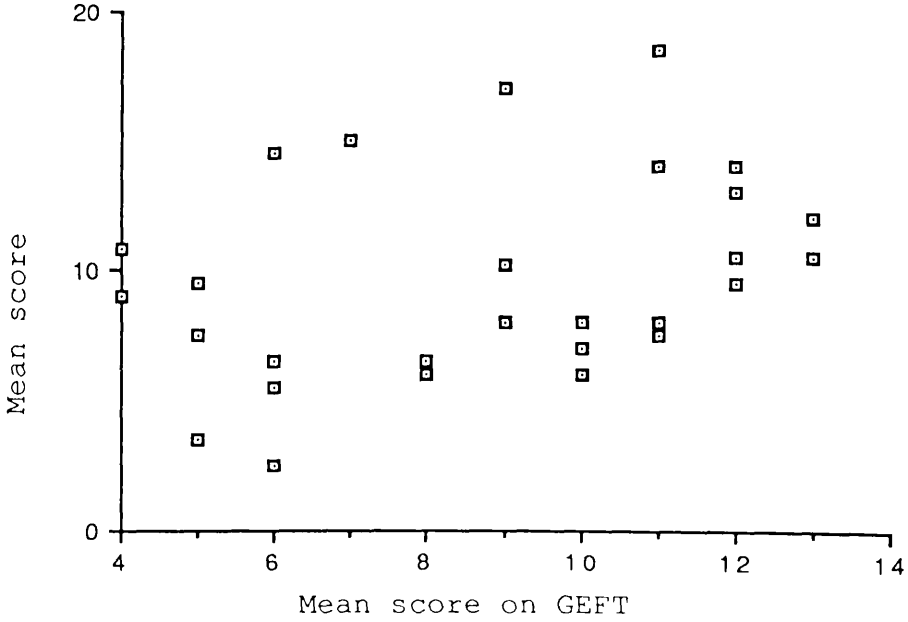


Figure 4-19. Comparison of the overall results between students of different degree FD/FI within each X-space.

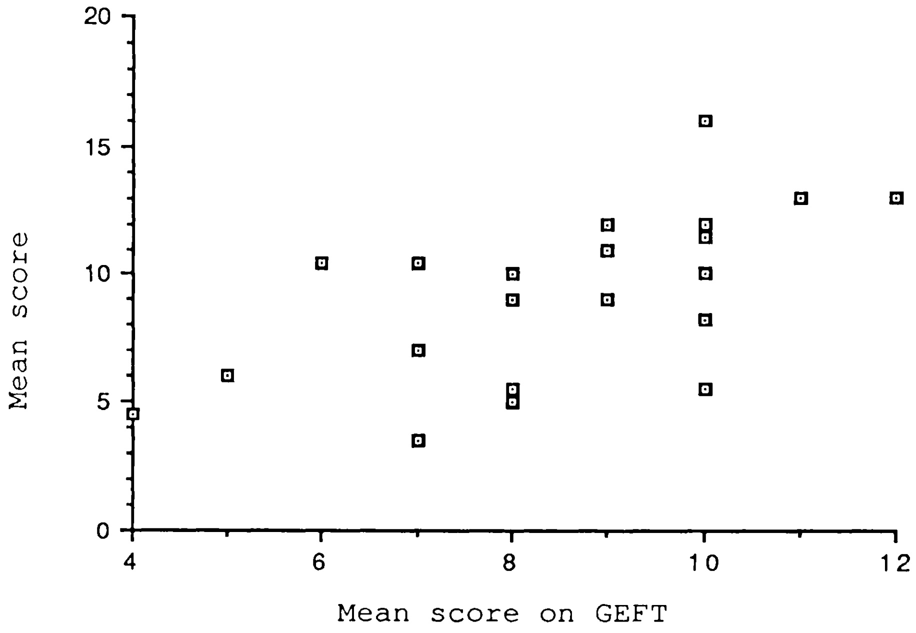
It can be seen from table 4-24 that, for the whole sample of students, there are significant differences between field intermediate and field dependent students as well as between field independent and field dependent students. In the X=7 row the apparently large differences are not significant because of the small size.

4-5-4 **Pearson correlation coefficient**

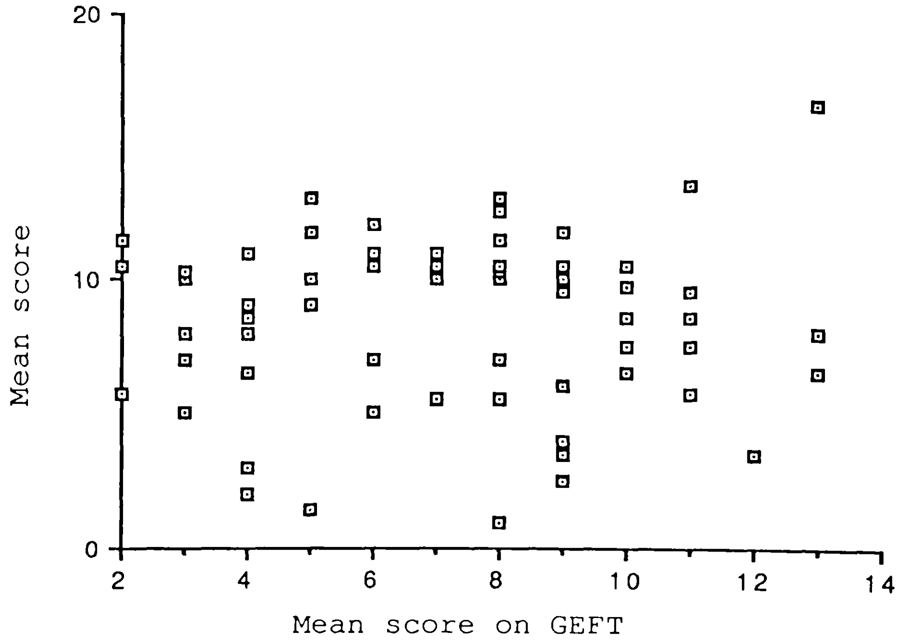
The Pearson correlation coefficient was calculated between the three variables; X=space, GEFT score and the results obtained in June examination. It was found that, the X-space correlated significantly (r= 0.146, at 10 % level) with the performance, and the disembedding ability factor was found to correlate with students' performance (r= 0.229) which is statistically significant at 5 % level. A high correlation was found between increasing students' X-space and their increasing disembedding ability (r= 0.296, at 1 % level). Furthermore, for X=6 students, a significant correlation was found between the students' performance and their degree of GEFT score (r=0.614, at 1 % level), and also for X=7 students (r= 0.349, at 10 % level). This is shown in scatter diagrams 4-7, 4-8 and 4-9.



Scatter diagram 4-7. Scatter diagram for ***X=7 students*** in June examination.



Scatter diagram 4-8. Scatter diagram for ***X=6 students*** in June examination.



Scatter diagram 4-9. Scatter diagram for ***X=5 students*** in June examination.

4-6 **Final results**

It is worthwhile to see how well these students performed in three examinations together. A comparison can be made between students' responses and the Z-demand.

Table 4-25. The overall performance for different X=space groups of students.

Groups	F.V on questions of different Z-demand									
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9	Z=10	Z=16
X=7	0.70	0.52	0.50	0.51	0.34	0.22	0.19	0.22	0.17	0.11
X=6	0.61	0.47	0.50	0.44	0.27	0.18	0.16	0.17	0.13	0.07
X=5	0.42	0.52	0.44	0.40	0.22	0.17	0.15	0.15	0.10	0.03
TOTAL (7+6+5)	0.57	0.52	0.48	0.45	0.27	0.18	0.17	0.17	0.13	0.07

Table 4-26. The overall performance for different X=space groups of students.

Groups	% mean score on questions of different Z-demand									
	Z=2	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8	Z=9	Z=10	Z=16
X=7	76.0	60.7	62.3	57.5	39.7	30.7	24.8	16.0	16.0	39.0
X=6	66.0	53.5	61.7	50.3	36.3	26.5	19.8	14.0	14.0	35.0
X=5	46.0	54.7	56.3	47.3	30.6	27.2	18.4	14.0	11.4	32.0
TOTAL (7+6+5)	62.0	56.0	60.0	51.7	35.5	28.0	20.9	14.6	13.8	35.0

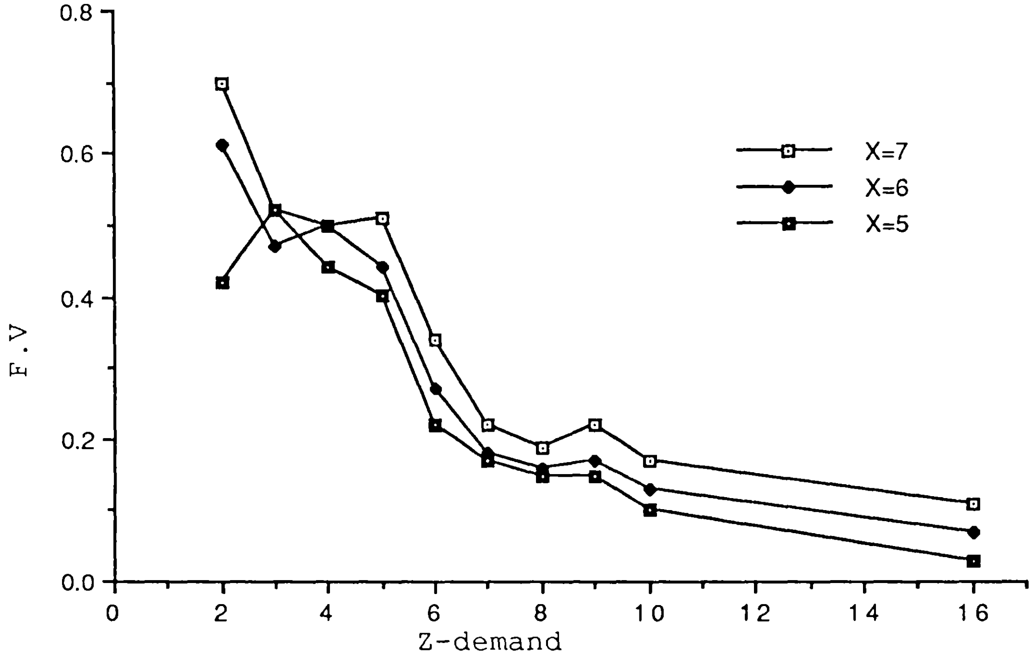


Figure 4-20. The overall performance (F.V) on questions of different Z-demand for students' different X-space in the three examinations.

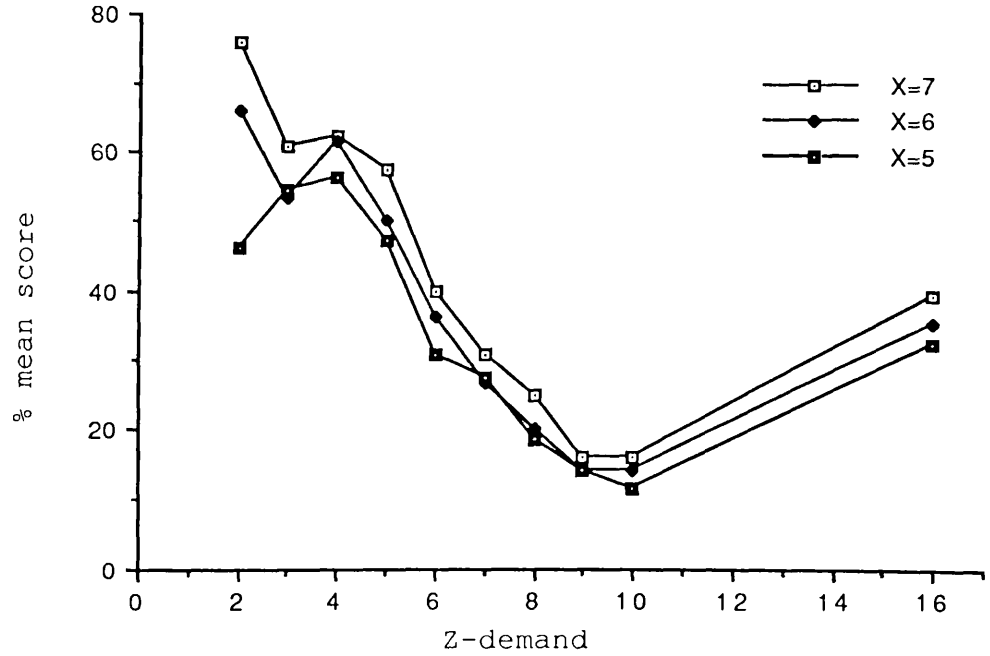


Figure 4-21. The overall performance (% mean) on questions of different Z-demand for students' different X-space in the three examinations.

The average of the facility value and mean score for questions having the same difficulties (Z-demand) for each group separately were calculated. These results can be shown in tables 4-25 and 4-26. as well well in figures 4-20 and 4-21.

It can be seen from figure 4-20 that the performance of X=5 students increases from Z=2 to Z=3 and then falls from 0.52 to 0.03 as Z goes from 3 to 16. Whereas both groups of X=7 and X=6 start to decline from the beginning, essentially levelling off between Z=4 and Z=5 and then falls down like X=5 group.

4-7 **Conclusion**

The findings presented in chapters 3 and 4 tend to support the four hypotheses. This leads to the following conclusions:

1. The correlation between students' X-space and their performance in physics examinations was found to be significant. Likewise between the two predictor variables, X-space and GEFT score.

2. There is clear evidence that the complexity of a question can affect the students' achievement.

(a) The students' performance was found to decrease as the complexity (Z-demand) increased for each X-space group beyond Z = 5.

(b). Generally the students who have a large X-space achieved higher results than those with the average X-space, and both of these obtained higher scores than students with small X-space particularly beyond Z = 5.

3. The field dependence/field independence factor was found to be an important one in the students' performance;

(a). Within each group of students who have the same degree of FD/FI, and the same value of X space, the performance decreased as the Z-demand increased beyond Z = 5.

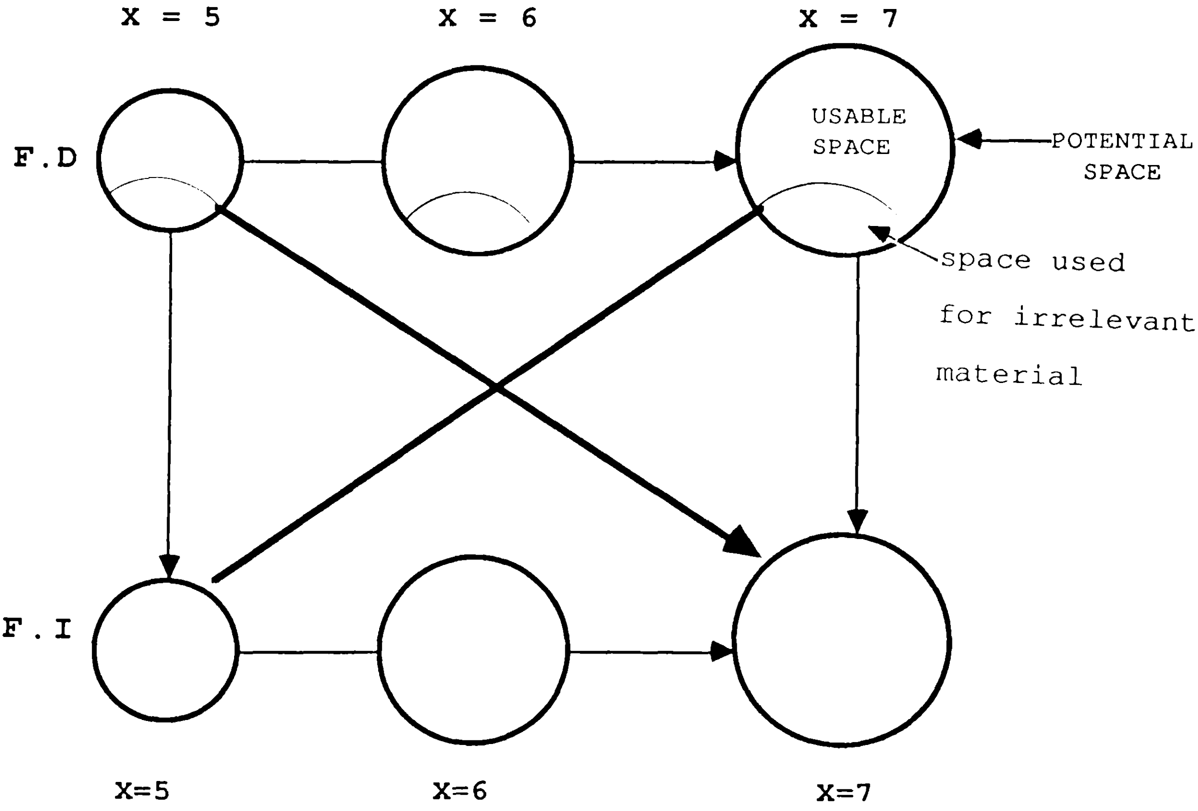
(b). For a given X-space, FI students perform better than FD for questions of Z > 5.

(c). For a given group of FD or FI students, X=7 students perform better than X=5, in most cases.

(d). It is seen that the greatest increase in performance occurs in going from FD, X=5 to FI, X=7 groups of students in all activities (problem solving) investigated.

(e). It can be seen that FD, X=7 students perform nearly the same as FI, X=5 students. This would suggest that, to reach the same level of achievement, FD students need more working memory space to compensate for their field dependent characteristic, to overcome the working space occupied by irrelevant information

It is possible to use a simple diagram to present visually the logical connection between the two factors i.e working memory space and FD/FI, as shown in figure 3-21.



→, indicates increase in the performance

Figure 3-21. Diagram of the different measurements.

There is evidence for the same type of behaviour in chemistry [47,48] and this matter is raised by Johnstone.[33]

4. It is worth noting that, when the Z-demand of the questions is small (2 - 5) the size of the X-space does not discriminate much between students performance in solving physics problems, but when the Z-demand is greater, students need sufficient X-space in order to succeed.

5. When students were given many opportunities to solve several small problems they gained experience which helped them to develop and employ different strategies. Hence it is possible to reduce the Z-demand of the question without changing its logical structure (page 91). This will be discussed later in chapters 7 and 8.

In the work of Johnstone and El-Banna they reported S-shaped curves when F.V was plotted against Z. There was a rapid fall in performance when $Z > X$ (page 40).

In this present work in physics similar trends were observed in that a shap fall tended to occur when Z exceeded 5. Below 5 there was little discrimination in general between those of different X space presumably because all the questions were within the students capacity. Any variation could have been caused by differences in FD/FI. A greater proportion of $X = 5$ students are FD than in the case for $X= 7$ students (tables 3-7 and 4-5) and refrence 48.

From the evidence so far it seems that the working memory and FD/FI theories are applicable in physics examinations. In the next parts of this work we intend to use these theories to guide our investigation of how teaching and problem solving in physics can be improved. They will be used to help in the formulation of hypotheses for this work.

Practical Work

Chapter five

Results of the first experimental year

5-1 Introduction

An investigation was made of the performance of students in practical work in the first level University physics course. It was decided to use a questionnaire method for collecting the data, from both students and demonstrators.

Seventy five students were chosen from a class of 170, selecting those who met on three practical groups from a maximum of seven in a given week. The sample was classified into

(a) those students with a Certificate of Sixth Year Studies in physics. The Certificate of Sixth Year Studies (CSYS) is a post SCE H-grade course. It is designed as a bridging course between secondary and tertiary education, and it encourages pupils in independent learning .

(b) those students whose most advanced qualification for University physics is SCE Higher grade physics.

There were a few students (about 10 %) who did not fit either category.

Previous experience

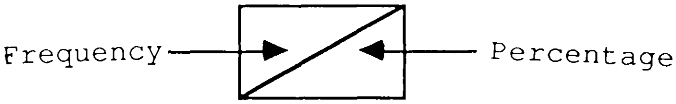
In order to gain information about their experience of experimental physics, based on work done before starting University, students were asked this question:

"Have you personally carried out experiments in physics for at least one year?"

The answer to this question was given in table 5-1. This table shows that, as expected, most of the CSYS candidates had personal experience of practical work in physics. There are many, however, of the Higher grade candidates who did not have this experience.

Table 5-1. Percentage and frequency of Students' responses for personal experience of practical physics

Groups	Students'responses	
	Yes	No
S.Y.S students	21 / 28	6 / 8
S.C.E students	17 / 23	23 / 31
Whole sample	42 / 56	33 / 44



A questionnaire was devised, consisting of a series of ten categories of word pairs, such as interesting / boring (see Appendix 5-1-A and 5-1-B) using Osgood[94] scales, ranging from A to E for each item (word pair) to indicate students'opinions about previous experience in practical work. Students were asked to indicate a point on a scale A to E for each of ten possible categories.

The same group of students were asked to complete the same questionnaire after they had been through a University course of practical physics lasting one term. This allowed a comparison to be made between opinions about and attitudes to practical physics before coming to University and after the experience of one term.

5-2 **Comparison between pre-University and University test**

The percentage frequencies of responses of students to the ten categories on both pre-University and University tests are given in table 5-2.

Responses A and B were grouped together and called positive responses, while D and E were grouped as negative responses, as shown in table 5-2 and figure 5-1.

The following general conclusions can be made for the whole sample:

(a) the students expressed a clear indication that the organization of the University laboratories was superior to their earlier experience.

(b) they received sufficient help from demonstrators in the University laboratories.

(c) the University work was reckoned to be more difficult

(d) they found the University work less enjoyable and less exciting.

It is interesting to apply statistical analysis to test the level of significance of corresponding results obtained in the two questionnaires. A X^2 test was applied to the raw data. A significant difference in opinions of students was found between pre-university and university test for these items: (enjoyable/ unenjoyable), (well organized/ not well organized), and (exciting / dull). Overall the university experience was of well organized, well staff supported laboratories but less exciting work which was less enjoyable perhaps because it was more difficult.

Table 5-2. Comparison between pre-university and University test

Categ-ories	Word pair	% Frequency of students' responses on				
		Positive	Neutral	Negative	X^2	Signi
1	Interesting/ boring	75.8 69.7	21.2 21.3	3.0 9.0	—	NS
2	Enjoyable / unenjoyable	72.7 59	24.3 25.7	3.0 15.2	6.29	5 %
3	Difficult / easy	21.2 37.9	44 30.3	34.8 31.8	4.84	NS
4	Worthwhile / waste of time	72.7 65.2	22.7 25.8	4.6 9.0	1.39	NS
5	Satisfying / frustrating	57.6 45.5	33.4 42.5	9.0 12.1	1.97	NS
6	Confusing / understandable	13.6 9.0	28.8 33.3	57.6 57.6	0.81	NS
7	Well organized/ disorganized	40.9 87.9	36.4 10.6	22.7 1.5	32.9	1 %
8	Adequate / inadequate instructions	53 50	22.7 34.8	24.3 15.2	3.12	NS
9	Enough help / not enough help from staff	59 72.7	15.2 16.7	25.8 10.6	5.14	NS
10	Exciting/ dull	36.4 15.2	51.5 47	12.1 37.8	14.7	1 %

Pre-University test → ◩ ← University test

NS, not significant

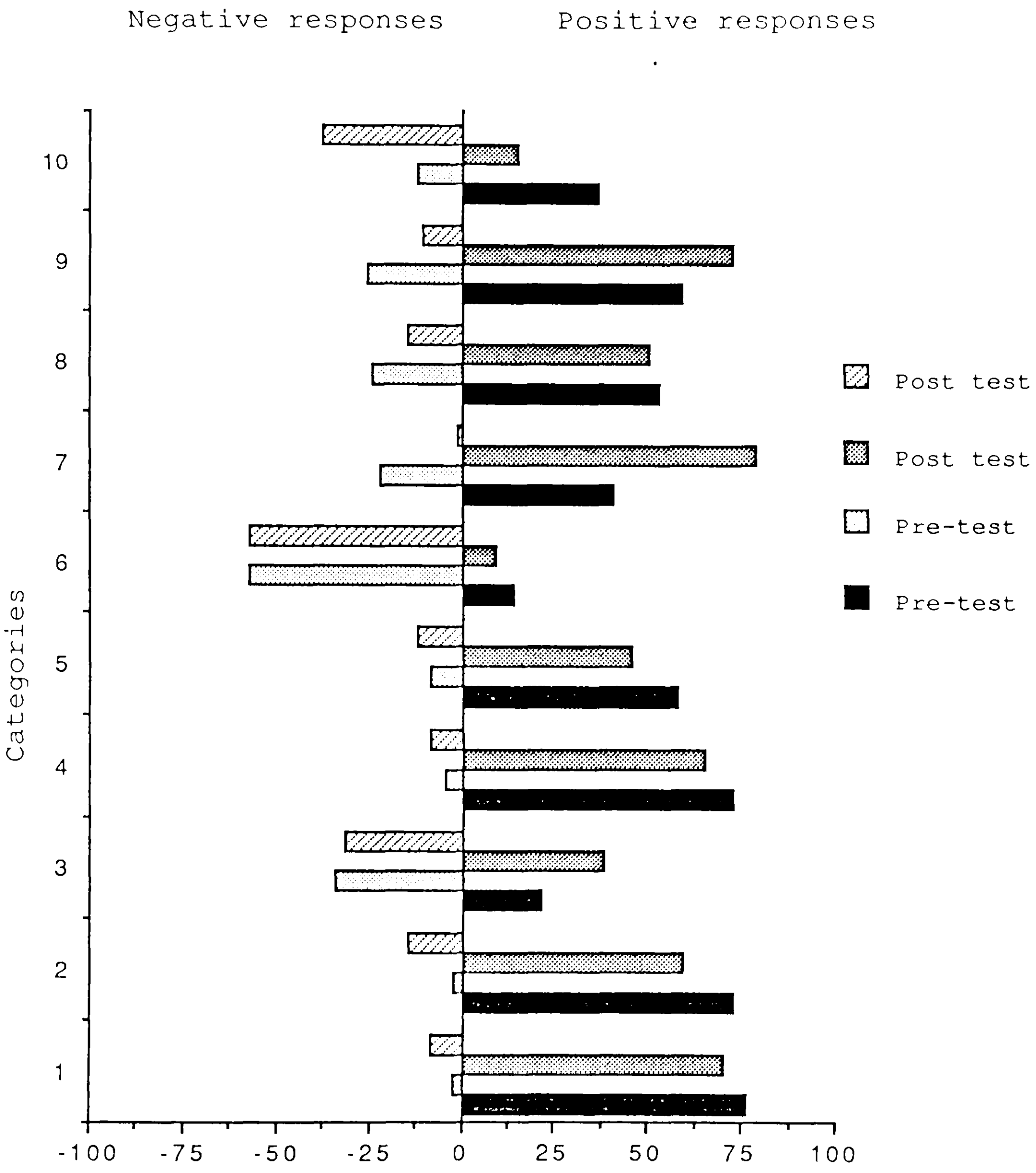


Figure 5-1.

Comparison between pre-University test (Pre-test) and the test taken after one term of University (Post-test)

5-2-1 **Change in attitudes to practical work**

An objective of the present work was to establish whether the attitudes to practical work became more favourable as they progressed through their first term of University. A comparison of the items was made between data from pre-university test and data obtained one term later. The existence of possible trends was examined using the data in tables 5-3 and 5-4. Table 5-5 shows the variation in responses of students to each category for the ten items. For example, in table 5-2 a responses of 75.8 % was made to category one of the interesting / boring word pair for pre-university test. Whereas a responses of 69.7 % was made in the same category one term later, as shown in same table 5-2. This change in now expressed in table 5-5, as -6.1 %. The (+,-) shows the direction of change of the students' opinions from previous experience to University level; a change is taken as a negative quantity for any category which favours previous experience, while a positive quantity indicate an increase in response after practical work at University. These comparisons were made for the whole sample and as well as the separate CSYS and SCE Higher students. These results are presented in tables 5-5 and 5-6.

5-2-2 **CSYS/SCE comparison**

The responses to the questionnaires were then looked at from the two main groups- CSYS and SCE Higher students, [a] and [b] above.

As can be seen from tables 5-3 and 5-4, there was no significant distinction in the responses of these two groups; both found the university work better organized, but less enjoyable and less exciting.

It should also be noted that the university practical classes are not streamed until after the first term, which was after the survey. The streaming puts the more able students in a more challenging

Table 5-3. CSYS/SCE comparison

pre-University test

Word pair	% Frequency of students' responses on					
	Positive		Neutral		Negative	
	SYS	SCE	SYS	SCE	SYS	SCE
Interesting / boring	84.0	69.5	16.0	27.5	0	2.7
Enjoyable / unenjoyable	80.0	59.9	16.0	27.7	4.0.	2.7
Difficult / easy	24.0	13.9	48.0	41.7	28.0	44.4
Worthwhile / waste of time	76.0	72.2	24.0	19.4	0	8.4
Satisfying / frustrating	64.0	50.0	32.0	38.9	4.0	11.1
Confusing / understandable	12.0	13.9	20.0	33.3	68.0	52.8
Well organized/ disorganized	28.0	52.8	44.0	27.7	28.0	19.5
Adequate / inadequate instructions	48.0	58.3	20.0	22.2	32.0	19.5
Enough help / not enough help from staff	56.0	66.7	16.0	13.8	32.0	19.5
Exciting/ dull	36.0	33.3	48.0	55.6	16.0	11.1

Table 5-4. CSYS/SCE comparison

University test

Word pair	% Frequency of students' responses on					
	Positive		Neutral		Negative	
	SYS	SCE	SYS	SCE	SYS	SCE
Interesting / boring	72.0	69.5	24.0	16.7	4.0	13.8
Enjoyable / unenjoyable	60.0	58.3	32.0	25.0	8.0	16.7
Difficult / easy	24.0	47.2	36.0	22.2	40.0	30.5
Worthwhile / waste of time	68.0	63.9	28,0	25.0	4.0	11.1
Satisfying / frustrating	56.0	36.1	36.0	50.0	8.0	13.9
Confusing / understandable	4.0	13.9	44.0	22.2	48.0	63.9
Well organized/ disorganized	88.0	88.9	12.0	8.3	0	2.8
Adequate / inadequate instructions	48.0	47.3	32.0	41.7	16.0	11.0
Enough help / not enough help from staff	84.0	61.1	8.0	25.0	8.0	13.9
Exciting/ dull	12.0	11.1	48.0	50.0	9.0	38.9

Table 5-5. Comparison between Pre-University and University test for ***Whole sample of students***

Word pair	% Frequency of students' responses on		
	Positive	Neutral	Negative
Interesting / boring	-6.1	+0.1	+6
Enjoyable / unenjoyable	-13.7	+1.5	+12.2
Difficult / easy	+16.7	-13.7	-3
Worthwhile / waste of time	-7.5	+3.1	+4.4
Satisfying / frustrating	-2.1	+9	+3.1
Confusing / understandable	-4.6	+4.5	0
Well organized/ disorganized	+47	-25.8	-21.3
Adequate / inadequate instructions	-3	+12.1	-9.1
Enough help not enough help from staff	+13.7	+1.5	-15.2
Exciting/ dull	-21.2	-4.5	+25.7

Note: (+,-) show direction of change of students' opinion from pre-University to University test.

Table 5-6. Comparison between Pre-University and University test for CSYS and SCE students

Word pair	% Frequency of students' responses on					
	Positive		Neutral		Negative	
	SYS	SCE	SYS	SCE	SYS	SCE
Interesting / boring	-12	0	+8	-11	+4	+11.1
Enjoyable / unenjoyable	-20	-1.6	+16	-3.7	+4	+14
Difficult / easy	0	+33.3	-12	-19.5	+12	-13.9
Worthwhile / waste of time	-8	-8.3	+4	+5.6	+4	+2.7
Satisfying / frustrating	-12	-13.9	+4	+11.1	+4	+2.8
Confusing / understandable	-8	0	+24	-11.1	-20	+11.1
Well organized/ disorganized	+60	+36.1	-32	-19.4	-28	-16.7
Adequate / inadequate instructions	0	-11	+12	+19.5	-16	-8.5
Enougp help from staff	+28	-5.6	-8	+11.2	-24	-5.6
Exciting/ dull	-24	-22.2	0	-5.6	-7	+27.8

practical class. It should be pointed out that it is not possible to apply chi-squared (X^2) test for the significant differences between those groups of students because the sample was too small.

5-3 Students'responses to University practical work using diaries

5-3-1 Introduction

It was decided to follow up the above work during the first and second terms at university by asking students to keep diaries for each of their experiments. The students were expected to carry out a total of seventeen experiments, in weekly sessions each of three hours. The titles of these experiments are given in Appendix 5-2 which is to be found in the pocket attached to the back cover. During the first term all students were in a common practical class where they were treated in the same way and were expected to carry out the same work. In the second term, however, the students were streamed into an advanced laboratory and a normal laboratory. In the advanced lab more initiative was expected of the students, selected by previous University performance in both practical and theory work. In the normal laboratory more help from demonstrators was expected to be needed, as was in fact given.

5-3-2 Questionnaire diaries

The general aim of the survey was to find a method of evaluating and assessing the behaviour and the attitude of the students in the experimental work. The diaries took the form of questionnaire sheets for each experiment; the questions were divided into two parts:

(a) to gain information about the students' attitude to each experiment

(b) to assess the achievement in the practical work as perceived by the students.

Typical diary sheets are given in Appendix 5-3. The students were given the questionnaire towards the end of the three hour laboratory periods. The questions were chosen which would each relate to the two parts above [a] and [b] and give us information about the different aspects of the practical course.

It was decided to divide the responses of the students into two categories- positive responses and negative responses. There are three ways of making this division:

I responses per student

II responses per experiment

III the comparison in responses between CSYS and SCE Higher students.

The analysis was carried out in terms of negative responses. We define a negative responses as **NO** to the question:

" *Did you find the experiment interesting ?* "

and **YES** to

" *Did you find the experiment difficult ?*"

The following questionnaire asked about the experiment: uninteresting, difficult, disorganized, unenjoyable, waste of time, not enough time, not enough help from demonstrator, not enough help from books, not enough help from notes, not understood the background theory, not improved the theory by this experiment, the objective not clear at all, not enough time for recording all data, not given sufficient instructions, equipment not available, not learned any new practical technique.

I Negative responses per students

In this study we wished to investigate the attitude of students to a given experiment and his/her achievement in that experiment. It is also interesting to relate the negative responses produced from diaries sheets to the following marks averaged over two consecutive terms:

(a) examination mark (theory)

(b) laboratory report mark

(c) laboratory record book

The record book is the daily log note book which the student is expected to use on every experiment. It is marked by the demonstrator (α β γ) and these were scaled to a mark out of ten. The report book is used twice per term to present a full account of experiment work previously done, and written in private study time. These are marked directly out of ten.

The average of the two examinations marks, the laboratory report marks and laboratory record marks were calculated for each student.

The average negative responses were calculated for every student. Because not all students returned a diary sheet for every experiment the ratio of number of negative responses to the numbers of experiments for which diary sheets were returned was calculated.

These results are shown in Appendix 5-4. It is seen from the table that there is a wide variation in the above ratio from 2.3 to 7.4 points

A relationship was sought among the average ratio of negative responses, examination mark (theory), laboratory report mark and record book mark. The results obtained over two terms are presented in table 5-7.

From this table, the following points emerge:

1. There is a significant correlation coefficient between the average ratio of negative responses and examination results. In other words students who had high marks in two class examinations made fewer negative responses an average.

2. Similarly, for the laboratory report mark and the laboratory record book mark, students gaining high marks for their reports and

record books made, an average, fewer negative responses.

3. Significant positive correlations were found between the average examination mark and both the laboratory report mark and the laboratory record book mark. Students who had high marks in the two class examinations also had high marks for their laboratory reports and laboratory record books.

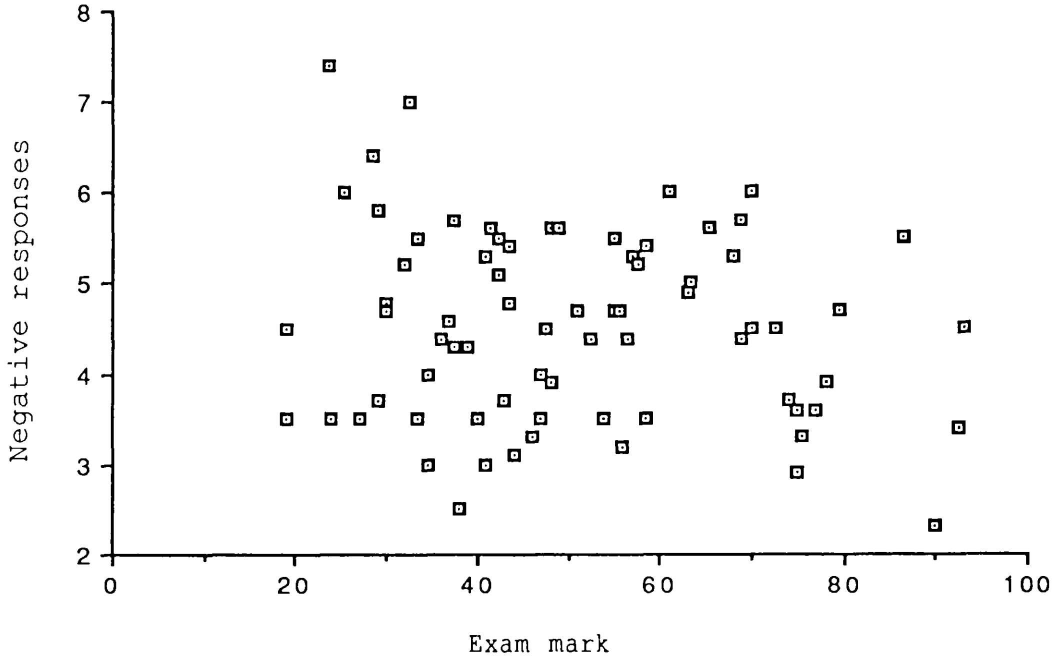
4. The most significant positive correlation was found between the laboratory report mark and the laboratory record book mark.

In general these results confirm the expectation that students who had a positive attitude to practical work also have a higher overall performance.

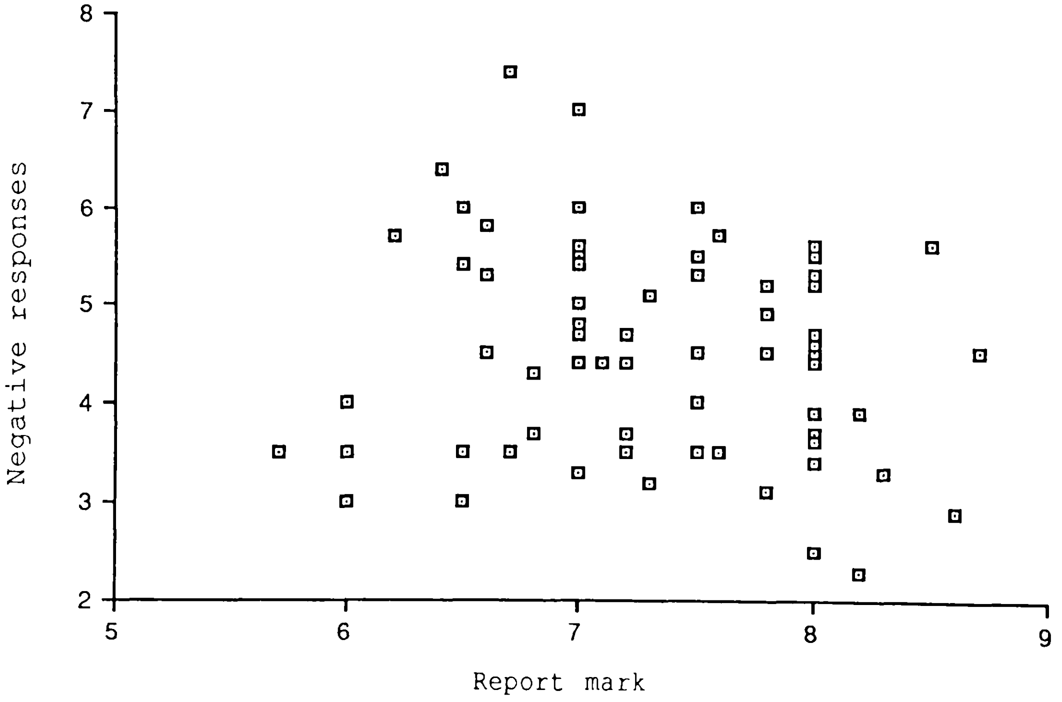
Six scatter diagrams are drawn to illustrate those findings above as follows:

Table 5-7. Correlation coefficient between the different marks

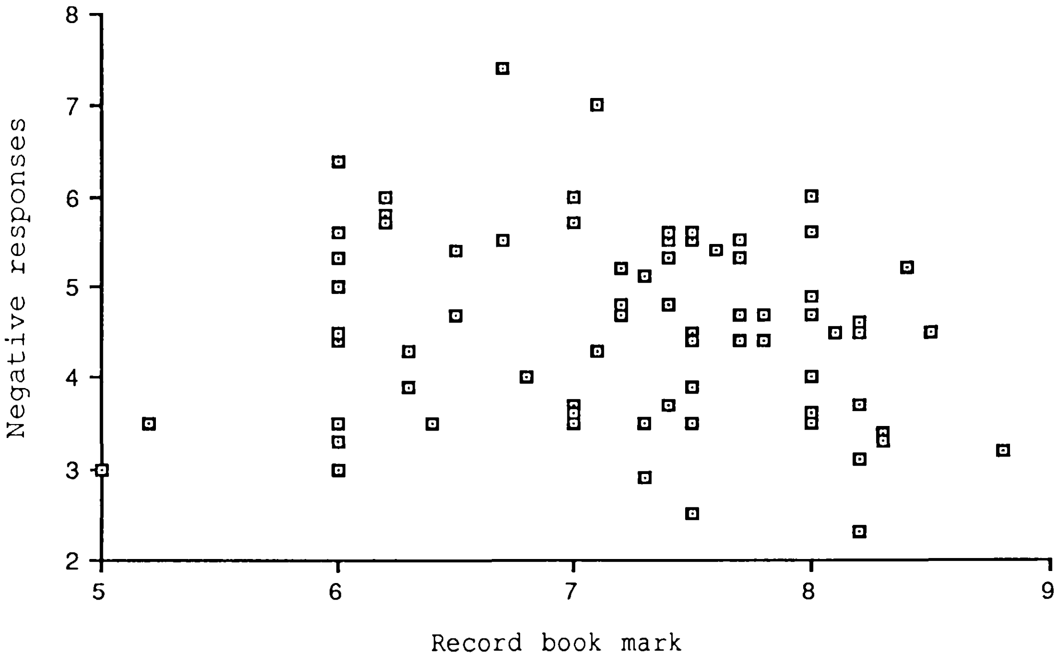
	Negative responses	Examination mark	Report mark	Record book mark
Negative responses	—	-0.38	-0.27	-0.24
Examination mark		—	0.57	0.58
Report mark			—	0.69
Record book mark				—



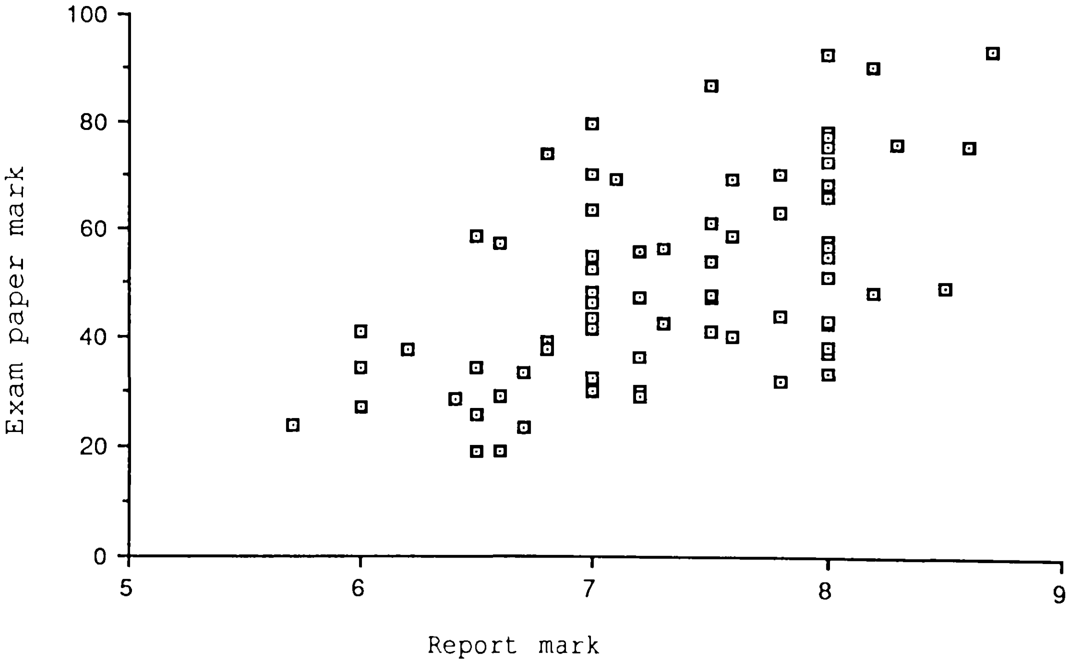
Scatter diagram 5-1. Relationship between negative responses and examination results



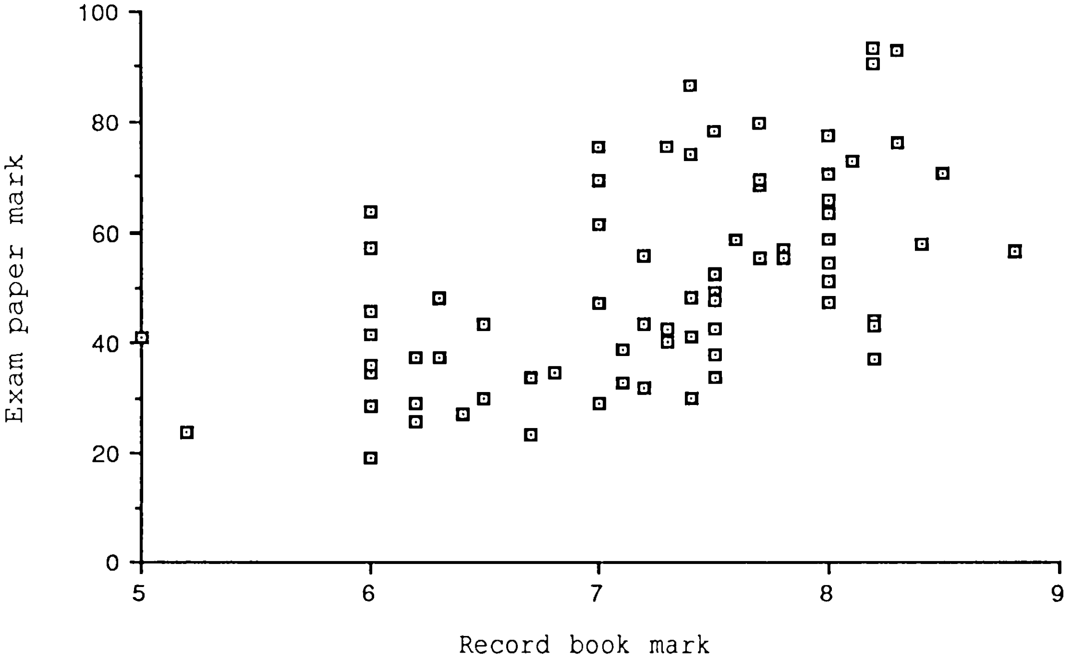
Scatter diagram 5-2. Relation between negative responses and report mark.



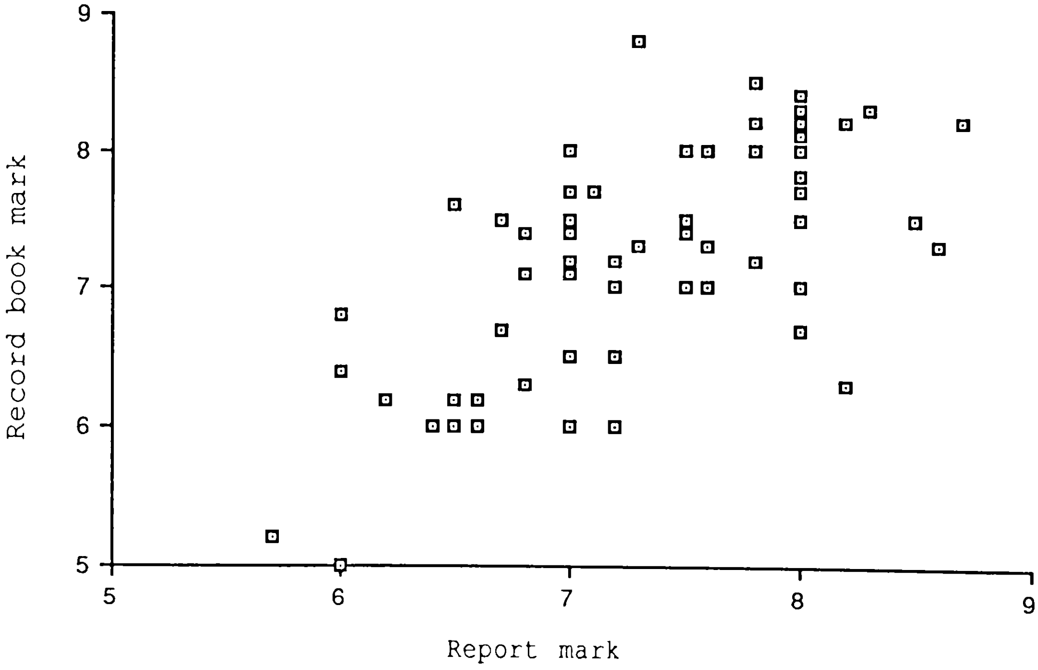
Scatter diagram 5-3. Relationship between exam paper and record book mark



Scatter diagram 5-4. Relationship between exam paper and report mark



Scatter diagram 5-5. Relationship between exam paper and report mark.



Scatter diagram 5-6. Relationship between report and record book.

Table 5-8. Negative responses of students per experiment

Category Expt	Uninteresting	Difficult	Disorganized	Unenjoyable	Waste of time	Not enough time	No help from demonstrator	No help from books	No help from notes	Not understood theory	Not improved theory	Not clear object at all	Not enough time for recording	Insufficient instructions	Not any new equipment	Equipment not available	Not learned any new techniques
Air track	8 14	24 41	4 7	17 29	8 14	18 31	7 12	7 12	12 20	6 10	23 40	0 0	32 55	17 29	32 55	3 5	40 69
S H M	13 22	16 27	4 7	17 28	5 8	29 48	5 8	20 33	22 36	15 25	14 23	0 0	29 48	8 13	37 62	5 8	43 72
Refraction	6 11	20 36	4 7	14 25	7 13	18 33	5 9	13 24	19 34	4 7	10 18	0 0	25 45	13 24	28 51	2 4	37 67
Lenses	6 10	18 31	6 10	15 26	1 2	36 62	1 2	12 21	15 26	5 9	6 10	0 0	31 53	7 12	46 79	1 2	42 72
Spectrometer	9 13	32 48	6 9	18 27	4 6	11 16	2 3	19 28	21 31	20 30	9 13	0 0	38 57	8 12	35 52	1 1	43 64
Newton's rings	14 20	32 46	3 4	18 26	5 7	13 19	1 1	23 33	25 36	27 39	13 19	3 4	40 57	6 9	46 66	3 4	60 86
Melde's expt	17 24	28 46	1 2	24 39	4 6	7 11	6 10	26 42	28 45	40 65	11 18	1 2	32 52	8 10	57 92	0 0	57 92
vibrating blade	21 32	15 23	6 9	25 38	10 15	13 20	1 2	19 29	22 33	29 44	14 21	2 3	39 59	5 8	50 76	1 2	47 71

Table 5-8 Continued

Thermal cond	19 40	19 40	3 6	19 40	8 17	12 25	3 6	20 42	20 42	19 40	14 30	2 4	29 62	12 25	23 50	1 2	38 81
Compound pendulum	15 33	6 13	4 9	22 51	6 13	4 9	3 7	14 31	19 42	23 51	7 15	1 2	24 53	4 9	37 82	2 4	43 95
Force & potential	7 19	7 19	3 8	14 38	5 13	12 32	1 3	11 30	13 35	11 30	11 30	0 0	22 59	1 3	34 92	1 3	34 92
Sound	1 4	6 27	0 0	7 32	3 14	7 32	0 0	7 32	7 32	7 32	6 27	1 4	11 50	0 0	17 77	0 0	19 86
Growth & Decay	14 37	10 26	3 8	15 39	8 21	13 34	1 3	13 34	13 34	12 31	12 31	2 5	27 71	5 13	29 76	0 0	32 84
Radio-activity	9 18	11 21	2 4	12 23	3 6	8 16	1 2	7 14	11 21	13 25	4 8	2 4	24 47	4 8	15 29	1 2	40 78
e/m	22 34	23 36	3 5	29 45	12 19	10 16	3 5	17 26	17 26	26 40	19 30	2 3	38 59	9 14	40 62	1 2	59 92
Solenoid	23 46	14 28	5 10	27 54	10 20	5 10	1 2	15 30	17 34	23 46	15 30	0 0	26 52	3 6	38 76	0 0	47 94
Current electricity	13 24	1 20	5 9	15 28	8 15	3 5	1 2	11 20	15 28	11 20	15 28	2 4	20 37	4 7	44 81	3 5	49 90

Number

Percentage

II Negative responses per experiment

The negative responses to each category from the diary sheets are presented in table 5-8 as a number and percentage for every experiment.

One way to present this data is to use a decimal fraction for each category in all experiments, i e the decimal fraction is the ratio of the students who had obtained responses out to the whole sample of students. For example, in the air track experiment 24 students out of 58 expressed difficulty (therefore expressed as 24/58 =0.41).

The data are given in table 5-9. At this stage, it is noted that three questions, given below, were not included in this analysis- these are looked at later in this section (see table 5-12, page 155, and pages 156-157).

1. When did the objective of today's experiment become clear to you?
   (a) at the beginning (b) part way through
   (c) at the end (d) or not all.
2. Did you learn any practical techniques that were completely If so, state what technique.
3. Did you have enough time to write up your record?

These data from table 5-9 were then divided into different tables in terms of frequency level. For example, tables 5-10 and 5-11 shown the frequencies with values >0.50 and >0.42 for all experiments. Further tables are shown in Appendix 5-5-A, 5-5-B, 5-5-C and 5-5-D.

This method shows the frequency for all classes of responses to the experimental work. A diagrammatic way of showing these data was also made; a "pyramid" presentation was chosen to show the frequency for all level of responses to the experimental work, and it emphasizes which responses had high frequencies.

Table 5-9 . Negative responses (Decimal fraction) per experiment

Categ / Expt	Uninteresting	Difficult	Disorganized	Unenjoyable	Waste of time	Not enough time	No help from demonstrator	No help from books	No help from notes	Not understood theory	Not improved theory	Insufficient instructions	Equipment not available
Air track	0.14	0.41	0.07	0.29	0.14	0.31	0.12	0.12	0.2	0.1	0.4	0.29	0.05
S H M	0.22	0.27	0.07	0.28	0.08	0.48	0.08	0.33	0.36	0.25	0.23	0.13	0.08
Refraction	0.11	0.36	0.07	0.25	0.13	0.33	0.09	0.24	0.34	0.07	0.18	0.24	0.04
Lenses	0.1	0.31	0.1	0.26	0.02	0.62	0.02	0.21	0.26	0.09	0.1	0.12	0.02
Spectro-meter	0.13	0.48	0.09	0.27	0.06	0.16	0.03	0.28	0.31	0.3	0.13	0.12	0.01
Newton's Rings	0.2	0.46	0.04	0.26	0.07	0.19	0.01	0.33	0.35	0.39	0.19	0.09	0.04
Melde's expt	0.24	0.46	0.02	0.39	0.06	0.11	0.1	.042	0.45	0.65	0.18	0.1	0.0
Vibrating blade	0.32	0.23	0.09	0.38	0.15	0.2	0.02	0.29	0.33	0.42	0.21	0.08	0.02

Table 5-9 . Continued

Thermal cond	0.4	0.4	0.06	0.4	0.17	0.25	0.06	0.42	0.42	0.4	0.3	0.25	0.02
Compound pendulum	0.33	0.13	0.09	0.51	0.13	0.09	0.07	0.31	0.42	0.51	0.15	0.09	0.04
Force & potential	0.19	0.19	0.08	0.38	0.13	0.32	0.03	0.3	0.35	0.3	0.3	0.03	0.03
Sound	0.04	0.27	0.0	0.32	0.14	0.32	0.0	0.32	0.32	0.32	0.27	0.0	0.0
Growth & decay	0.37	0.26	0.08	0.39	0.21	0.34	0.3	0.34	0.34	0.31	0.31	0.13	0.0
Radio-activity	0.18	0.21	0.04	0.23	0.06	0.16	0.02	0.14	0.21	0.25	0.08	0.08	0.02
e/m	0.34	0.36	0.05	0.45	0.19	0.16	0.05	0.26	0.26	0.4	0.3	0.14	0.02
Solenoid	0.46	0.28	0.1	0.54	0.2	0.1	0.02	0.3	0.34	0.46	0.3	0.06	0.0
Current electricity	0.24	0.2	0.09	0.28	0.15	0.05	0.02	0.2	0.28	0.2	0.28	0.07	0.05

Table 5-10. Frequency with value >0.50

Category	Unenjoyable	Not understood the theory	Uninteresting	Difficulty	No help from notes	No help from books	Not improved theory	Not enough time	Insufficient instructions	Waste of time	No help from demonstrator	Disorganized	Equipment not available
Unenjoyable		1	0	0	0	0	0	0	0	0	0	0	0
Not understood theory			0	0	0	0	0	0	0	0	0	0	0
Uninteresting				0	0	0	0	0	0	0	0	0	0
Difficulty					0	0	0	0	0	0	0	0	0
No help from notes						0	0	0	0	0	0	0	0
No help from books							0	0	0	0	0	0	0
Not improved theory								0	0	0	0	0	0
Not enough time									0	0	0	0	0
Insufficient instructions										0	0	0	0
Waste of time											0	0	0
No help from demonstrator												0	0
Disorganzied													0
Equipment not available													

Table 5-11. frequency with value >0.42

Category	Unenjoyable	Not understood the theory	Uninteresting	Difficulty	No help from notes	No help from books	Not improved theory	Not enough time	Insufficient instructions	Waste of time	No help from demonstrator	Disorganized	Equipment not available
Unenjoyable		1	2	0	0	0	0	0	0	0	0	0	0
Not understood theory			1	1	1	0	0	0	0	0	0	0	0
Uninteresting				0	0	0	0	0	0	0	0	0	0
Difficulty					1	0	0	0	0	0	0	0	0
No help from notes						0	0	0	0	0	0	0	0
No help from books							0	0	0	0	0	0	0
Not improved theory								0	0	0	0	0	0
Not enough time									0	0	0	0	0
Insufficient instructions										0	0	0	0
Waste of time											0	0	0
No help from demonstrator												0	0
Disorganzied													0
Equipment not available													

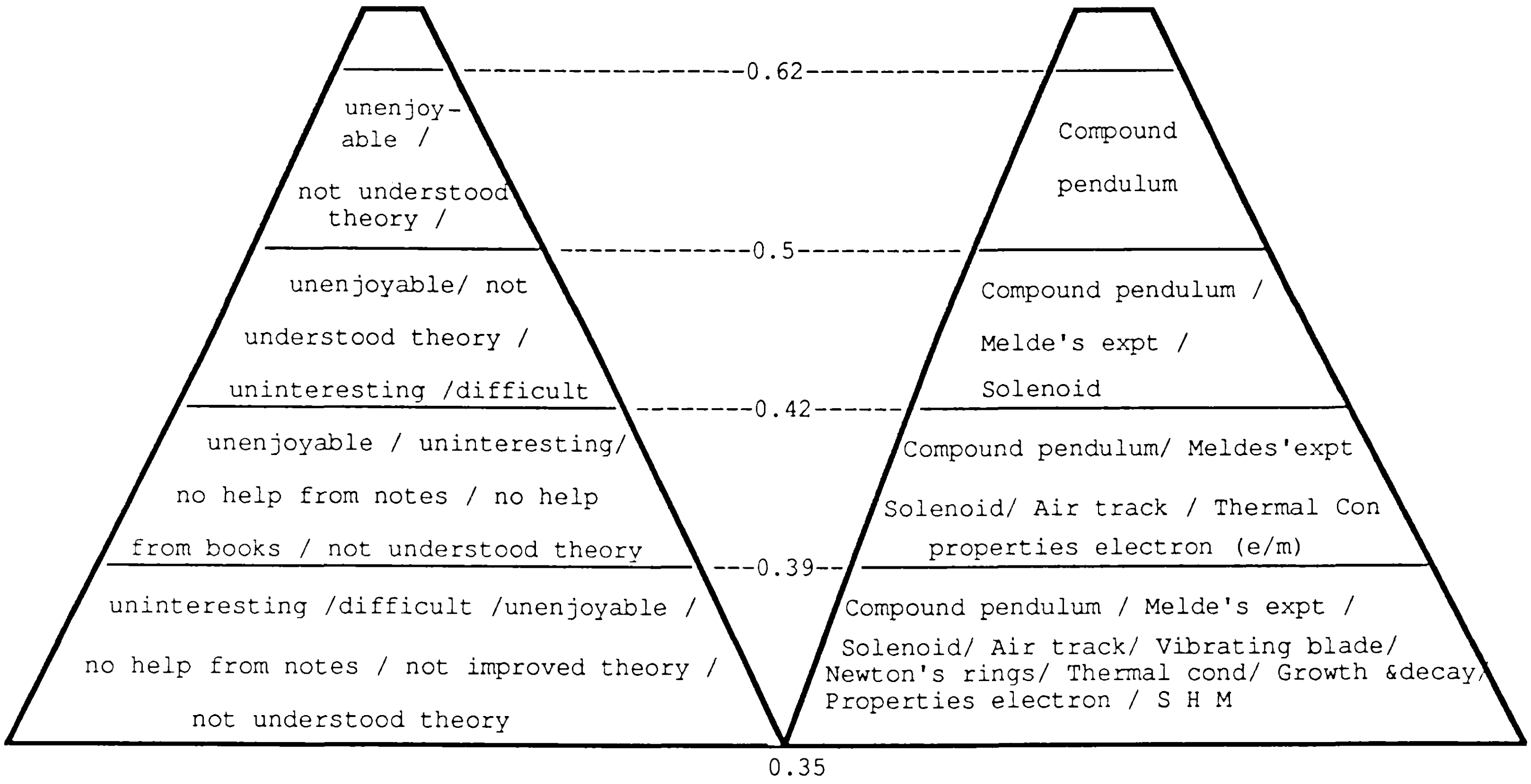


Figure 5-2

Figur 5-3

Relationship between frequency of responses and experiment

The table 5-12. % Frequency of total average students' responses

Category	Positive	Negative	Category
Interesting	76	23	Uninteresting
Easy	68	31	Difficult
Well organized	93	7	Not well organized
Enjoyable	65	35	Unenjoyable
Worthwhile	87	12	Waste of time
Enough time	74	25	Not enough time
Help from demonstrators	94	6	No help from demonstrators
Help from books	51	28	No help from books
Help from notes	54	33	No help from notes
Understood theory	65	32	Not understood theory
improved theory	76	23	Not improved theory
Object clear at the begining	55		
Object clear part way	34		
Object clear at the end	8		
		2	Object not clear at all
Enough time for recording	45	54	Not enough time for recording
Sufficient instructions	87	12	Insufficient instructions
New equipment	30	68	Not any new equipment
Equipment available	97	3	Equipment not available
New practical techniques	17	81	Not learned any new techniques

This helped to identify which experiments were causing students overload and hence contributing to lack of success.

The "pyramid" diagrams are shown in figures 5-2 and 5-3, where the highest negative value response comes at the top of the pyramid. In addition, figure 5-2 shows two categories which produced the highest values. These categories are; unenjoyable, and not understood background theory. Figure 5-3 shows the experiments which the students considered caused difficulty. The experiments which were given these values were then identified. As can be seen from figure 5-3 that the compound pendulum is on the top of pyramid with the highest value of 0.5. It was interesting to note that the students gave a very clear indication that the organization of the laboratory was superior to their earlier experience, and they were received sufficient help from demonstrators.

It can be concluded from table 5-12(on page 149)that:

(a) the highest number of negative responses were obtained from the three following categories:

1- New techniques

The students were asked about whether they had learned any new techniques in their experiments. For all experiments, 81 % of students said NO, but the students who claimed to have learned new practical techniques were asked which techniques.

2- New equipment

The students were asked to record whether or not they had encountered any new equipment. It was found 68 % of students had previously encountered the equipment in use in the university laboratories.

3- Time taken to write up record

It was found about half of the students did not have enough time to write up the record.

(b) The lowest percentages were found in the following categories.

1. Only 6 % of students felt that they did not received enough help from demonstrators.
2. The students expressed clearly that the organization of the physics laboratory was superior to their earlier experience, with only 12 % of the students indicating that it was not well organized.
3. 3 % of students felt that the equipment was not available for them to carry out the experiment in the laboratory.

For the question "*when did the objective of today's experiment become clear to you?*" there were four possible answers:

(a) at the beginning *(b) part way through*

(c) at the end *(d) or not at all*

The students' answers to this question are presented in table 5-13. The results obtained were not a surprise. About 50 % of students had no clear idea about the objective of the experiment at the start of their work. This could arise if the students had not prepared their work before coming to the laboratory, or if the guidance notes were not clear, or if they were unfamiliar with the physics involved, or perhaps they had not yet received a lecture on the physics of the experiment.

5-3-3 **CSYS/SCE Higher comparison**

Their previous experience in both theory and practical work gave the CSYS students an advantage over the SCE students, as shown by examination, practical record and report marks in table 5-14.

This table shows mean marks for each group and the whole sample, and averaged over two terms. The CSYS students had school experience of more independent working, including the practical project and the

Table 5-13. The percentage and frequency of students responses

Expt Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Obj clear at the beginning	34 59	29 48	28 51	38 66	37 55	36 51	28 45	40 61	19 40	20 44	23 62	12 54	25 66	32 63	37 58	23 46	33 61
Obj clear part way through	17 29	23 28	21 28	17 29	25 37	25 36	29 47	19 29	17 36	20 44	11 30	8 36	9 24	15 29	17 26	19 38	15 28
Obj clear at the end	6 10	5 8	3 5	2 3	4 6	5 7	3 5	4 6	7 15	1 2	3 8	1 4	1 3	1 2	5 8	8 16	4 7
Obj not clear at all	0 0	0 0	0 0	0 0	0 0	3 4	1 2	2 3	2 4	1 2	0 0	1 4	2 5	2 4	2 3	0 0	2 4

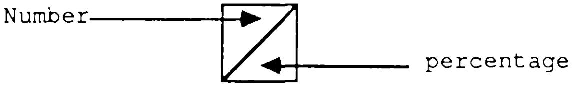


Table 5-14. Students' performance on different marks.

	Exam mark	Report mark	Record book mark
CSYS students	59.6 %	7.48 /10	7.52 /10
SCE Higher students	46.5 %	7.13 /10	6.99 /10
Whole sample of students	50.67 %	7.33 /10	7.11 /10

preparation of the report. They are likely to have had more previous instruction in taking measurements and in analysis of data. Generally they had more confidence in the laboratory, as seen from the fewer responses of having a shortage of time to carry out a given experiment. For example, the CSYS candidates commented on having plenty of time to perform the air-track experiment and the vibrating blade experiment. Familiarity with interference and simple harmonic motion meant that the CSYS students had better background knowledge for the Newton's rings and the spiral spring experiments, independent of any learning at university. The full details for the responses of CSYS and SCE students in every experiment are shown tables 5-15 and 5-16, pages 160 -162.

5-4 **Demonstrators' diaries**

Information was also sought from the demonstrators (staff members and postgraduate students) about their perception of students' difficulties. They were asked to comment on the most frequently asked questions in each experiment,see Appendix 5-6. Further, at the end of the second term, demonstrators were asked to summarize the reaction of the students in their charge in the

Table 5-15. Comparison between SYS and CSE students

% frequency of negative respoinses

Category Expt	Uninteresting	Difficult	Disorganized	Unenjoyable	Waste of time	No enough time	No help from demonstrator	No help from books	No help from notes	Not understood theory	Not improved theory	Not clear Obj at all	Not enough time for recording	Insuficient instructions	Not any new equipment	Equipment not available	Not learned any new techniques
Air track	10 17	29 43	10 9	24 35	19 17	38 30	5 13	24 39	24 17	10 13	45 39	0 0	45 52	10 30	65 52	5 4	90 61
S H M	30 17	25 33	15 3	30 20	15 7	55 57	10 7	40 27	25 40	10 33	35 10	0 0	45 57	20 10	30 67	0 7	65 63
Refraction	20 8	25 35	5 8	25 27	10 15	30 42	10 8	30 31	40 35	10 8	20 23	5 0	45 37	20 27	30 54	0 8	65 73
Lenses	13 10	30 28	40 10	26 28	0 7	65 59	4 0	4 31	26 28	9 10	0 21	0 3	43 59	9 10	74 76	4 0	74 72
Spectro-meter	17 12	50 47	12 6	42 19	21 6	25 12	8 3	37 25	37 31	29 37	8 19	0 0	62 47	21 3	50 53	0 3	62 62
Newton's Rings	9 17	43 34	0 3	30 20	9 6	13 20	4 0	22 40	30 34	39 34	17 17	0 0	56 54	9 8	65 63	4 0	91 80
Melde's expt	30 20	52 41	0 30	39 35	17 6	9 15	9 9	39 44	52 49	65 73	22 15	4 0	56 53	13 15	100 88	0 0	96 91
Vibrating blade	46 22	15 25	11 9	58 25	15 19	8 28	0 3	27 28	31 34	31 47	35 9	4 3	58 56	4 6	73 75	4 3	77 69

Table 5-15. Continued

Thermal cond	17 32	11 12	0 16	44 48	11 12	5 12	0 12	22 36	39 48	33 24	22 16	0 0	55 40	0 0	83 60	0 0	94 68
Compound pendulum	50 37	35 58	5 8	50 50	10 25	25 29	5 8	30 58	45 54	35 58	30 33	5 4	65 62	20 29	55 46	0 4	90 75
Force & potential	23 18	0 27	0 9	38 36	23 9	15 45	8 0	31 31	31 41	8 41	54 14	0 0	54 59	8 0	92 86	0 0	100 86
Sound	12 7	0 43	0 0	12 43	0 21	12 43	0 0	25 36	25 36	25 36	25 28	0 7	50 50	0 0	75 78	0 0	100 78
Growth & Decay	50 26	21 26	14 5	57 21	36 16	36 31	7 0	28 37	36 26	14 26	21 42	7 5	71 68	21 1	78 68	0 0	79 84
Radio-activity	19 21	14 21	5 0	33 21	5 8	19 17	0 4	14 69	24 26	24 35	9 8	5 0	52 39	9 0	33 22	0 0	76 83
e/m	30 32	56 29	4 6	48 45	13 16	13 19	0 6	22 32	30 26	43 42	17 32	4 3	78 58	17 13	69 68	4 0	96 97
Solenoid	66 34	40 21	7 10	20 38	66 14	7 10	0 3	33 24	27 34	40 48	40 24	0 0	53 48	13 3	80 76	0 0	100 90
Current electricity	29 24	23 21	12 9	29 27	17 12	0 9	6 0	12 27	23 33	12 21	29 18	0 6	53 27	23 0	82 85	12 3	82 91

CSYS students

SCE Higher students

Table 5-16. The % frequency of CSYS and SCE students' responses overall experiments.

Category	Positive		Negative		Category
	CSYS	SCE	CSYS	SCE	
Interesting	69	78	28	21	Uninteresting
Easy	71	68	26	32	Difficult
Well organized	94	93	6	6	Not well organized
Enjoyable	63	67	36	31	Unenjoyable
Worthwhile	86	85	16	12	Waste of time
Enough time	76	71	22	28	Not enough time
Help from demonstrators	92	94	4	4	No help from demonstrators
Help from books	53	48	30	36	No help from books
Help from notes	56	56	32	34	No help from notes
Understood theory	72	71	26	35	Not understood theory
improved theory	74	74	24	21	Not improved theory
Object clear at the begining	58	47			
Object clear part way	33	35			
Object clear at the end					
				22	Object not clear at all
Enough time for recording	43	46	55	51	Not enough time for recording
Sufficient instructions	86	88	13	9	Insufficient instructions
New equipment	29	32	66	66	Not any new equipment
Equipment available	97	96	4	2	Equipment not available
New practical techniques	14	19	77	75	Not learned any new techniques

following categories: interesting, boring; easy, difficult; confusing, understandable; sufficient instructions given, sufficient time allocated; enjoyable, as shown in Appendix 5-7.

The results obtained from demonstrators' diaries are presented as a number percentage in table 5-17, for every experiment.

The following general conclusion can be made

(a) per experiment:

the most frequently asked questions arose in four experiments: spectrometer, vibrating blade, Melde's experiment and Newton's Rings.

(b) per question:

The greatest number of questions were asked about the analysis of data, the use of apparatus and the actual doing of the experiment.

It is worthwhile to establish the demonstrators opinions from their observations during the physics lab sessions. Table 5-18 shows the frequency of demonstrators on particular categories set above for each experiment. The following conclusions can be made:

(a) the two experiments (Melde's experiment and Growth & Decay) were considered most confusing.

(b) the compound pendulum and current electricity appeared to be easy, although Newton's Rings, thermal conductivity and solenoid seemed to be more difficult.

(c) spectrometer and e/m for electron were found to be more interesting.

5-5 **Observation of the students as they carried out their practical work**

The author also gathered information by observing the students at work; sometimes interacting with them in response to questions. It was noted that some students, who started out well, got lost in a later stage of the work due to lack of understanding.

Table 5-17. The frequency of students asking common question in each experiment

Questions Expt	Responses on different questions							frequency of demons
	Q1-1	Q1-2	Q1-3	Q1-4	Q1-5	Q2	Total	
Spectrometer	24	17	14	8	-	12	75	9
Newton's Rings	10	15	15	15	-	5	60	7
Melde's expt	13	29	2	23	-	2	69	8
Vibrating blade	-	14	8	48	-	3	73	8
Thermal cond	3	13	13	7	-	3	39	8
Compound pendulum	-	4	-	9	4	-	17	3
Force & potential	8	5	5	5	-	5	28	6
Sound	-	2	12	10	-	-	24	3
Growth & decay	-	3	1	8	-	-	12	2
Radioactivity	-	-	25	8	4	3	40	10
e/m	-	4	6	15	-	1	26	4
Solenoid	-	16	2	9	-	2	29	5
Current electricity	3	7	8	3	2	4	27	5
Total	37	129	111	168	110	10	40	

Table 5-18. The frequency of demonstrators opinions for different experiment

Categ Expt	Boring	Interesting	Easy	Confusing	Enjoyable	Enough time	Understandable	Difficult	Not enogh time	TOTAL
Air-track			1				2		3	6
SHM	1	1			1	1			1	5
Refrac-tion			1		1		3			5
Lenses					1		1	3	2	7
Spectro-meter		3		2	2					7
Newton's rings	2	2			2			8		14
Melde's Expt	1			4			1	2	1	9
Vibrating blade	1		3				1	2		7
Thermal cond	1			1		1		4		7
Compound pendulum	2		4	2		1	1	3	2	15
Force & potential		2			1		1	1	1	6
Sound					3	1		1		5
Growth & decay	1		1	5	1		1	2	1	12
Radio-activity	1	2	3	1	2	2	1			12
e/m		3		2		1	1	2	3	12
Solenoid	1		1	2		2		4		10
Current electric			5		1		2			8

5-6 **Results and Conclusions**

An objective of the survey was to identify areas of the experimental work which were causing overload in demands on students in their experimental physics. It had been found previously[88] that the amount of the background theory necessary for the execution of some level of practical chemistry was so great as to cause an overload on students during the experimental work. In earlier work[89] we had established that working memory space cannot work well with more then (6 ± 2) pieces of information.

It was considered that sufficient useful information has been obtained (from students' diaries, demonstrators' comments and the authors' observations) to suggest making some changes in the introductory physics laboratory and hence at a later date to make comparison of students performance before and after such changes. A few experiments have been shown to be too demanding on the students in one way or another. In some of these the apparatus would not be altered but the instruction notes changed in the light of the above survey. In other experiments to which the common student reaction was that insufficient time was allowed, some part of the experimental work would be removed in the change.

In planning these suggestion consideration was given to the work expected of the students. This was divided into three headings, viz.

1. Theoretical background (prior or prepared knowledge)
2. Procedure (execution of the experiment)
3. Analysis of experimental data.

How can we improve learning in the laboratory ? We want to break down the instruction, and procedures into small manageable parts, to try and match the working memory space of the student. The following factors were proposed in attempting to translate these ideas into practice:

(a) the students would be more strongly encouraged to prepare the work before coming to the laboratory. This is already a general instruction but it needs to be reinforced and the students encouraged to see that it is a good means of self-help.

(b) use clear, simple language in the instruction notes, which should be attractively presented.

(c) make a clear initial statement of the objectives.

(d) seek a better match between a grasp of the basic physics background and that met in the experiment. This involves an optimization of the timing of the experiment in the overall teaching programmes. On the other hand it can be argued that the laboratory could reinforce the teaching of physics in the lecture course- this could be tested at a later time.

(e) reduce the amount of non-essential instruction and thereby reduce the information load on the students.

(f) make a clear statement of the background physics in the notes, perhaps in an appendix if it is particularly mathematical.

(g) break down the procedure in the experimental work into subsections

(h) early in the academic session , assist the student by defining the minimum steps necessary in the procedure. At a later stage in the year students might be expected to work out the procedure themselves.

(i) state clearly what experimental technique is being used in a given experiment.

(j) teach manipulative skills at the start of the experiment when the student is faced with unfamiliar equipment e g vernier microscope, electronic balance.

(k) allow enough time for the average student to carry out the work.

The overall goal is to bring more students into the categories of responses which indicate that they understood what they were doing, that they found experimental physics worth while, interesting and enjoyable (even exciting), and that they thought they had enough time to do the work.

In the spirit of the above suggestions General Notes were prepared for use in 1989/90 - as shown in Appendix 5-8.

With new style laboratory manual embodying, the above ideas, we can test whether the students perform better (as measured by their responses to the same questionnaire) under lower overload conditions-bearing in mind that it will be a different (but similar) student sample.

Regarding [b] for example in the Growth and Decay experiment where the students meet the exponential function it is a better procedure to have that experiment in the laboratory programme after the students have become familiar with that function in the concurrent university Mathematics course. This experiment was also improved by reducing from four to three the number of parts expected to be done, by omitting part (b). Here we can test whether the student performed better in the laboratory if he has already met the basic physics before, or not.

Again this can be tested by students' questionnaires. It is also planned to introduce a "further exercise" at the end of selected experiments (so as to avoid introducing a new overload situation). The purpose of these is to allow the students to apply their newly acquired skills to a new but cognate problem, thereby developing the students' independence and self confidence.

Chapter six

Second year of practical work

Section I

6-1 Introduction

This chapter describes the follow-up investigation of experimental physics work initiated in chapter 5.

As a consequence of this initial work, it had become clear that certain improvements could be made in the instruction notes and in the quantity of experimental work expected of the students so that their performance and attitudes might improve. The work was carried out again at first year level but clearly with a different population of students. As before it was important to establish the attitudes of this second group, in session 1989/90, to experimental work before coming to University. The same type of questionnaire and analysis was used as previously.

The previous study showed that there are many factors which influence successful experimental work in physics. We wished to identify some factors which could make an experiment difficult. The following observations can be made:

1. the students who had greater previous experience and knowledge (the effect of higher qualifications), allowed them to work efficiently, presumably with a reduced load on processing capacity.

2. the difficulties met in the laboratory perhaps depended on students having different disembedding ability (FD/FI) or limited capacity (X-space).

3. the approach to an experiment could be made more easily if the students tried to apply some strategies to break down the procedure and analysis into smaller parts.

6-2 **Sample**

135 first year physics students at Glasgow University were taken as a sample in this part of the investigation.

6-3 **Disembedding ability test**

Disembedding ability: The degree of field dependence(FD) /field independence (FI) was established using the Group Embedded Figure Test (GEFT) as was detailed in the previous chapter 3.

The performance of students on GEFT was used to classify them as field dependent (FD), field intermediate (F.Int) and field independent (FI). The test scores ranged from 2 to 15 (X = 10.0, SD =3.0).

According to Pascual-Leone's method, the sample was divided into 29 (16.5%) students who scored from 2 to 6 and were classified as field dependent (FD), 84 (62.2%) students who scored from 7 to 12 and were classified as field intermediate (F.int), while 22 (16.3%) students who scored from 13 to 15 and were classified as field independent (FI).

It was also interesting to gain information about students' academic level before coming to University. The sample was classified into two main groups as:

(a) 76 (56%) students with a Certificate of Sixth Year Studies (CSYS) in physics.

(b) 42 (31%) students whose most advanced entry qualification was SCE Higher physics

There were a few students 17 (13%) who did not fit either category.

One of the main aims of this present follow-up work is to establish whether there is an change in students'attitudes to practical work as they move from secondary school to University level, after certain changes had been made in the university practical class. The same questionnaire and method of analysis was used as in the first survey (Appendix 5-1-A, 5-1-B and 5-3).

The students were asked to complete the questionnaire indicating their opinions about their previous experience in practical work.

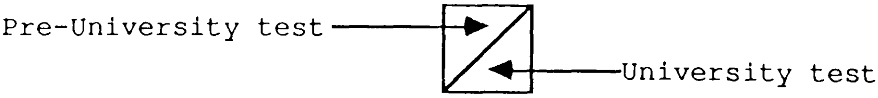
The same group of students responded to the same questionnaire after they had been through a university course of practical physics lasting one term.

6-4 **Pre-University / University test comparison**

It is interesting to find out whether there is a change in students'attitudes to practical courses as they move from secondary school to the end of one term of the university. To simplify the analysis, answers which were in categories A and B were classified as positive, and D and E as negative - as before. It should be noted that the size of the sample in the first test (pre-University test) was 131 students whereas that in the University test was only 106 students. As a consequence results are expressed as percentage for comparison. The results of the first comparison made are shown in table 6-1 as the percentage between previous data obtained from pre-University test compared with data obtained one term later for all the items used. The nature of these changes in attitudes can be illustrated by the diagram, shown in figure 6-1. Table 6-1 shows a comparison of responses for the whole sample for the ten items involved and includes the chi-Square values calculated on raw data for corresponding word-pairs. As can be seen from this table six differences were statistically significant at 5% level or better.

Table 6-1. Comparison between pre-university and University test

Categ-ories	Word pair	% Frequency of students'responses on				
		Positive	Neutral	Negative	X^2	Signi
1	Interesting/ boring	81 61.3	14 25.5	5 13.2	11.5	1%
2	Enjoyable / unenjoyable	71 40.5	24.2 42.4	4.6 17	24.0	1%
3	Difficult / easy	18.3 33	56.5 40.6	25.2 26.4	8.13	5%
4	Worthwhile / waste of time	71.8 68.9	22.1 19.8	6.1 11.2	2.11	NS
5	Satisfying / frustrating	48 39.6	38.2 37	13.7 23.6	4.11	NS
6	Confusing / understandable	13.7 17	21.4 25.5	65 57.5	1.34	NS
7	Well organized/ disorganized	39.7 70.7	34.3 20.8	26 9	24.0	1%
8	Adequate / inadequate instructions	55.7 60.4	22.1 22.6	22.1 17	1.01	NS
9	Enough help / not enough help from staff	56 74.5	28.2 21.7	16.8 3.8	17.4	1%
10	Exciting/ dull	41.2 14.1	45 52.8	13.7 33	25.2	1%



Not, NS not significant

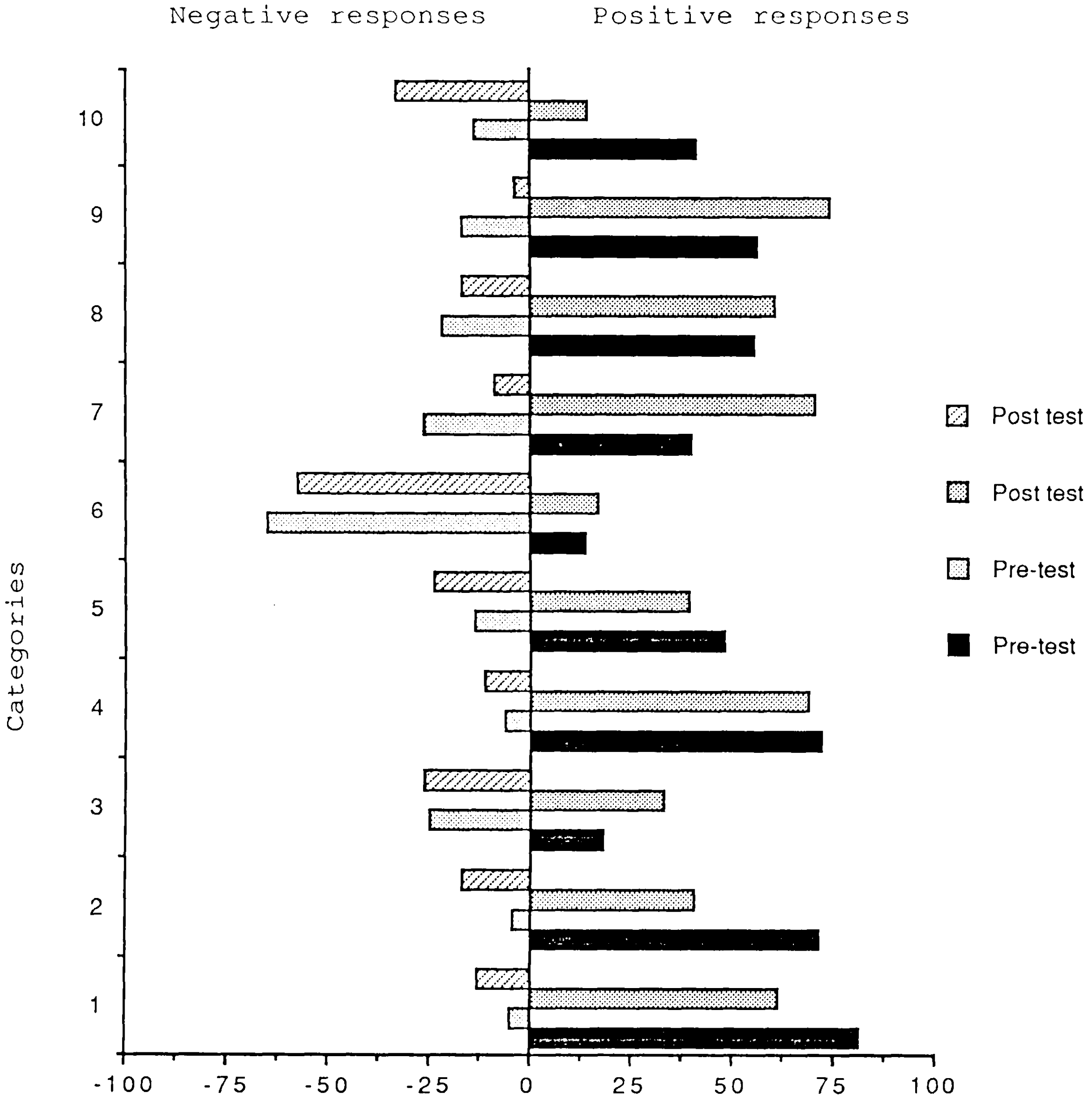


Figure 6-1.

Comparison between pre-University test (Pre-test) and the test taken after one term of University (Post-test)

The following conclusions can be made:

(a) the students found the University work interesting but less exciting and less enjoyable than school.

(b) the practical course in physics at the University level was reckoned to be more difficult that at school or college.

(c) the help from demonstrators in the University laboratory was sufficient.

(d) The students expressed the opinion that the physics laboratories in University were better organized than practical work that they had met in the school or college.

6-4-1 CSYS/SCE comparison

Differences in the attitudes of CSYS and SCE students to the practical work were again investigated, as discussed in chapter 5. A similar comparison was made between these groups for the pre-University and University tests. The result obtained from the comparison of word pairs frequency distributions from both tests are given in tables 6-2 and 6-3, and the distribution of students' responses was compared by the X^2 statistical test. If the expected value falls below 5, then the number of categories must be reduced by combining two or more categories into one. This was done by combining the neutral value with either the positive or negative value (which ever was the smaller).

As can be seen from table 6-2 no significant differences were found in frequencies between the CSYS and SCE Higher students in all items for University test.

For the pre-university test, it can be seen from table 6-3 that there were two differences which were statistically significant between the CSYS and SCE for the items worthwhile/waste of time and exciting/dull.

Table 6-2. CSYS/SCE comparison

Pre-University test

Word pair	% Frequency of students'responses on				
	Positive	Neutral	Negative	X^2	Signi
Interesting/ boring	58.3 67.9	27.8 23.2	13.9 8.9	0.5	NS
Enjoyable / unenjoyable	50 33.9	38.9 50	11.1 16.1	2.38	NS
Difficult / easy	25 33.9	50 39.3	25 26.8	1.18	NS
Worthwhile / waste of time	38.9 69.6	44.5 23.2	16.7 7.1	8.55	5%
Satisfying / frustrating	41.7 41.1	36.1 37.5	22.2 21.4	0.01	NS
Confusing / understandable	13.9 16.1	19.4 30.4	66.7 53.6	1.71	NS
Well organized/ disorganized	72.2 66.1	16.7 28.6	11.1 3.4	0.15	NS
Adequate / inadequate instructions	72.2 48.2	16.7 32.1	11.1 19.6	5.18	NS
Enough help / not enough help from staff	69.4 75	30.6 17.9	0 7.1	0.18	NS
Exciting/ dull	19.4 12.5	38.9 66.1	41.7 21.4	6.67	5%

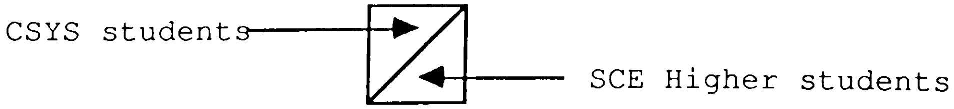
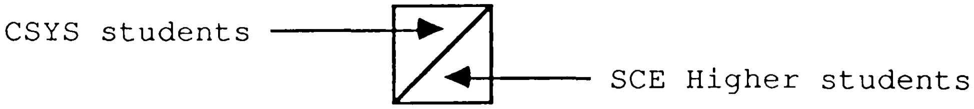


Table 6-3. CSYS/SCE comparison

University test

Word pair	% Frequency of students'responses on				
	Positive	Neutral	Negative	X^2	Signi
Interesting/ boring	83 80	12 16	5 4	0.05	NS
Enjoyable / unenjoyable	67 74	24 24	9 2	0.44	NS
Difficult / easy	9 19	41 55	26 26	1.89	NS
Worthwhile / waste of time	67 76	26 19	7 5	1.02	NS
Satisfying / frustrating	43 50	38 40	19 10	2.23	NS
Confusing / understandable	9 15	22 22	69 63	0.72	NS
Well organized desorganized	50 35	28 35	22 30	2.50	NS
Adequate / inadequate instructions	55 54	19 23	26 23	0.31	NS
Enough help / not enough help from staff	52 54	26 30	22 16	0.53	NS
Exciting/ dull	43 43	45 43	12 14	0.1	NS



As before, it is concluded that both groups found the University work better organized, but less exciting less enjoyable, and more difficult. More help was given from demonstrators at University compared to school/college.

6-4-2 **Change in attitude**

Comparison in the gain in achievement made by the whole sample of students, and by groups CSYS and SCE students was made. The gain was defined as the difference between the responses to the same item obtained from both pre-University and University tests. The results for the whole sample of students are presented in table 6-4, which shows the direction in which these changes took place and which ones were more marked. In table 6-4, the entry -16.68 in the category 1 in the interesting/boring distribution indicate that 16.68 % fewer of the sample chose category 1 (positive position) a term later.

An extension of table 6-5 was made by presenting the students'responses to the word pairs for the main groups in the sample. These tables shown the direction in which these change took place.

6-4-3 **Disembedding ability FD/FI comparison**

An extension of the analysis was made to attempt to determine whether the differences between attitudes to practical work were dependent on factors such as disembedding ability FD/FI. Hence the differences between attitudes of field dependent/field independent students to practical work were obtained, and the results are summarized in tables 6-6 and 6-7. It can be seen from these tables that:

(a) field dependent students found the practical work in the University difficult and confusing compared to their previous

Table 6-4. Comparison between pre-University and University test for the ***whole sample of students***

Word pair	% Frequency of students'responses on		
	Positive	Neutral	Negative
Interesting / boring	-16.68	+11.47	+8.21
Enjoyable / unenjoyable	-30.45	+18.45	+12.42
Difficult / easy	-14.69	-15.93	+1.2
Worthwhile / waste of time	-2.87	-.2.34	+5.11
Satisfying / frustrating	+8.37	-1.38	+9.84
Confusing / understandable	+3.25	+4.1	-7.45
Well organized/ disorganized	+31.06	-13.59	-17.47
Adequate / inadequate instructions	+40.38	+.5	-5.16
Enough help/ not enough help from staff	+18.57	-6,55	-13.01
Exciting/ dull	-27	+7.83	+19.26

Table 6-5. Comparison between pre-University and University test for CSYS and SCE students

Word pair	% Frequency of students'responses on					
	Positive		Neutral		Negative	
	SYS	SCE	SYS	SCE	SYS	SCE
Interesting / boring	-24.76	-12.14	+15.78	+7.21	+8.89	+4.93
Enjoyable / unenjoyable	-17	-40.07	+14.89	+26	+2.11	+14.07
Difficult / easy	+16	+14.93	+9	-15.72	-1.0	+0.7
Worthwhile / waste of time	-28.12	-6.36	-9.34	+4.21	+2.34	+2.14
Satisfying / frustrating	-1.33	-8.93	-1.89	-2.5	+3.22	+11.43
Confusing / understandable	+4.89	+1.07	-2.56	+8.36	-2.33	-9.43
Well organized/ disorganized	+22.22	+31.07	-11.33	-6.43	-10.89	-26.64
Adequate / inadequate instructions	+17.22	+5.78	-2.33	-9.14	-14.89	-3.36
Enough help/ from staff	+17.44	+21	+4.56	-12.14	-22	-8.86
Exciting/ dull	-23.56	-30.5	-6.11	+23.1	+29.67	+7.4

Table 6-6. % Frequency of students' responses

Comparison between disembedding ability (FD/FI)

Pre-University test

Word pair	Positive			Neutral			Negative		
	F.I	Fint	F.D	F.I	Fint	F.D	F.I	Fint	F.D
Interesting/ boring	91	80	68	0	16	23	9	4	9
Enjoyable / unenjoyable	69	71	63	22	25	27	9	3	9
Difficult easy	17	15	27	52	54	54	30	31	18
Worthwhile / waste of time	82	71	59	9	23	23	9	5	18
Satisfying / frustrating	47	57	45	35	30	32	17	13	23
Confusing / understandable	13	11	9	13	25	32	74	63	59
Well organized/ disorganized	30	43	45	35	35	18	35	21	36
Adequate / inadequate instructions	43	62	46	39	21	14	17	16	40
Enough help / not enough help from staff	56	65	54	35	17	14	9	17	32
Exciting/ dull	35	40	54	52	44	32	13	15	13

Table 6-7. % Frequency of students' responses

Comparison between disembedding ability (FD/FI)

University test

Word pair	Positive			Neutral			Negative		
	F.I	F.In	F.D	F.I	F.In	F.D	F.I	F.In	F.D
Interesting/ boring	70	63	53	30	23	26	0	13	21
Enjoyable / unenjoyable	60	38	32	35	45	37	5	17	37
Difficult easy	15	33	47	50	40	37	35	28	19
Worthwhile / waste of time	90	68	53	10	22	26	0	10	21
Satisfying / frustrating	55	38	26	30	37	42	15	25	32
Confusing / understandable	10	23	5	15	32	32	75	45	63
Well organized/ disorganized	80	68	58	10	25	32	10	7	10
Adequate / inadequate instructions	80	58	31	15	23	21	5	13	47
Enough help / not enough help from staff	90	68	68	10	25	32	0	7	0
Exciting/ dull	20	12	16	55	58	42	25	30	42

experience, and more confusing then field independent students.

(b) field independent students got more satisfaction from both their previous experience and University practical work than field dependent students.

(c) the practical course in both school and University was considered to be less interesting and less enjoyable by field dependent students.

(d) field independent students considered that the practical course was worthwhile and supported by adequate written instructions for carrying out the experiments.

At this stage, it is noted that, the X^2 test was not applied for the significance of differences between students groups of different disembedding ability (FD/FI) for each cell size is not allowed to fall below 5 either in the pre-University or University tests.

Section II

6-5 **Introduction**

The eleven experiments, which had proved difficult to students during the first year when practical work was investigated, were subject to further study (see Appendix 6-1, page 350). It was clear that another way had to be found to present these instruction notes. Several attempts were made to rewrite the notes of these experiments in an improved format, according to the guidelines previously discussed at the end of the chapter 5, keeping the contents basically the same. The new version of the experimental notes were accepted by the member of staff in charge of the physics laboratory.

The new version of the experiment notes were printed on coloured paper of A4 size, different colours being used for each group of experiments. The experimental notes which were revised are shown below:

1. Term one; Air track, Simple Harmonic Motion, Melde's

experiment, Spectrometer, Refraction, and Lenses.

2. Term two; Compound Pendulum, Solenoid, Vibrating blade, Growth and Decay and Properties of the Electron.

It was decided to follow up the above trial experiments during the first and second University term in the academic year 1989/90, by repeating the same questionnaires and method for collecting data from both students and demonstrators.

Eighty students were chosen from a class of 140 for testing the effectiveness of the new version of the experimental notes.

6-5-1 **Comparison between the original and the new versions**

It is useful to emphasis the difference between the new and original experimental instructions in certain experiments, as below:

1. ***Simple Harmonic Motion***. The original version is given in figure 6-2. These notes were printed on photo-reduced,A5 size. The new version of the same experiment is shown in figure 6-3 below.

According to the guidelines set out in chapter 5, the format of new text was different from the original style in the following ways:

1. The objectives of the experiment were clearly stated under the heading ***general aim***

2. The new version was divided into three separate parts, and each of these parts was divided into subsection such as ***procedure*** and ***analysis***. This could be helpful in controlling the load on students throughout the experiment.

3. Students were encouraged to take decisions. For example the students asked to consider the best size of the load (e.g 5,10,20 grams etc) to give a reliably measurable extension.

4. Explicit steps were given in the procedure section of the new version, to try to reduce the number of steps held in memory at a given time. Also the amount of information recalled would be decreased by defining only the necessary steps.

Figure 6-2. Original manual

SIMPLE HARMONIC MOTION

Introduction

The object of this experiment is to study an oscillating system, viz a mass suspended at the end of a vertical spiral spring. It is also an exercise on analysis of experimental data by graphical methods.

A body executes SHM when its acceleration varies directly with its displacement x, but opposite in direction. If a mass m moves under the influence of a force described by

$$F = -kx$$

and if the cause of the force is removed the mass will vibrate about its equilibrium position, with a period T

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where k is the force or elastic constant. You should be able to derive this relationship.

It is suggested you carry out parts (a) and (b), then try (c). It is better to study a few parts in full rather than treat the whole experiment qualitatively.

Procedure

(a) Find out the static behaviour of the spiral spring when stretched by observing the extension as a function of load by adding masses to it. What happens when you decrease the load? Devise a suitable method of measuring the extension. Draw a suitable graph and from it obtain the force constant k of the spring. Pay attention to units; it is simplest to work in newtons and metres.

(b) With a load on the spring (does it matter how large?) set the mass vibrating vertically. Measure the period T by timing many vibrations (how many?) using the stop clock, or by the photocell gate. Repeat for different loads. From a suitable graph obtain k. Compare with the value of k obtained in (a). The simple analysis assumes negligible mass of the spring, M'. If instead

$$T = 2\pi\sqrt{\frac{m+\alpha M'}{k}} \qquad (\alpha\ \text{constant})$$

what value of α do you obtain if you use k from part (a) and T and m from part (b)? Does this investigation show that the motion of the mass is SHM?

(c) Study the vibrating mass on the spiral spring by other means, e.g. suspended magnet vibrating in the coil. Do your oscilloscope measurements agree with the earlier parts of the experiment? What is the relationship between the motion of the magnet and the signal from the coil?

Figure 6-3. New version

HOOKE'S LAW and SIMPLE HARMONIC MOTION

GENERAL AIM : (i) to study Hooke's law in the extension of a spiral spring
(ii) to study the oscillations of a mass suspended at the end of a spring
(iii) to analyse experimental data by graphical methods.

INTRODUCTION

In general a mass will execute simple harmonic motion (SHM) when its acceleration a varies directly with its displacement x, but in the opposite direction

$$\underline{a} \propto - \underline{x} \qquad |1|$$

Thus if a mass M moves under the influence of a force F according to

$$\underline{F} = - k\underline{x} \qquad |2|$$

the mass will oscillate about its equilibrium position with SHM and will have a period T given by

$$T = 2\pi\sqrt{\frac{M}{k}} \qquad |3|$$

The minus sign in |2| indicates that the force is a restoring one, i.e. the force tends to restore the system to its initial configuration.

In this experiment k is the elastic constant of the spring.
If we wish to test whether an oscillating mass is executing SHM we can use relation |3|.

PART I

TO INVESTIGATE HOW THE LENGTH OF THE SPIRAL SPRING VARIES WITH LOAD ATTACHED AT ITS FREE END, AND HENCE TO DETERMINE THE ELASTIC CONSTANT k OF THE SPRING.

PROCEDURE

(a) Plan your experiment:

(1) With the apparatus provided decide what is the best method of measuring the extension produced in the spring.
The reference position from which extensions are measured can be taken as the position of the flag, or the base of the mass carrier (provided you arrange for parallax errors to be small).

(2) Perform a dummy experiment to find out what size of extension is produced by a given size of load. Decide what is the best size of load (eg 5 , 10, or 20 grams etc) to give an easily measurable value of the extension.

(b) Now take measurements of load and extension.
It is always a good procedure to tabulate data (include units).

ANALYSIS

(a) Plot a graph of extending force (the weights Mg of the masses M which formed the total loads) against extension x. Refer to |2| and note that

$$M\underline{g} = - \underline{F}$$

(b) From this graph obtain a value of the elastic constant of the spring k. In what units is k expressed ?

(c) Decide how accurately you have measured the extensions and plot these observational errors as error bars on your graph. Hence from the error of the gradient work out the observational error δk in k. [Refer to General Notes]. Here we assume there is no or negligible error in M.

NOTE

If your graph is a linear one you can deduce that

$$(\text{ extension }) \propto (\text{ extending force })$$

This is an example of Hooke's law.

PART II

TO MEASURE HOW THE PERIOD OF OSCILLATION OF A MASS SUSPENDED AT THE END OF THE SPRING VARIES WITH THE MASS , AND TO INVESTIGATE WHETHER THE OSCILLATION IS SHM.

PROCEDURE

(a) Note the mass of the mass carrier.

(b) Place a mass on the carrier attached to the spring and set it oscillating vertically. Avoid rotational oscillations, and swinging.

(c) Measure the period of oscillation T of the total mass and carrier, M, using

  (1) an electric stop clock/watch. Decide how many oscillations you should measure (for example 10). This method gives reliable data but not as accurate as the next method

  (2) a photo-diode gate and timer. This method, if correctly used, is designed to measure one period.

(d) Repeat (c)(2) for different masses M.

ANALYSIS

(a) From {3} we see that

$$T^2 = 4\pi^2 \frac{M}{k} \qquad \{4\}$$

(b) It is usually more useful to plot graphs that are linear. You have experimental data of T and M. Study {4}, and choose functions of T and M which will result in a straight line gradient from which k may be determined.

(c) What are the units of k here ? Are these the same as in part I ?

(d) Compare the values of k from part I and part II. Write a conclusion.

(e) Does your graph pass through the origin ?

(f) If it does not, let us consider a reason. Clearly in the oscillating system the mass of the spring, or part of it, must contribute to the total mass that is oscillating. Suppose we write now

$$T^2 = 4\pi^2 \frac{(M+m)}{k}$$

where m is part of the mass of the spring. If this is a valid supposition, you can determine m from your graph.

(g) Determine the mass of the spring in the electronic balance.

(h) Physically m must be less than the spring mass. Express this as a fraction of the mass of the spring.

REFERENCE : SZY, 7th ed pages 271 and 272. Or 6th ed section 11-6.

FURTHER EXERCISE

Study a vibrating mass at the end of the spring using a magnet in a coil with an oscilloscope. Observe the waveform, and the period of oscillation using the calibrated timebase. Discuss with your demonstrator.

APPENDIX

THEORY

PART I

Hooke's law can be written

$$\underline{F} = -k\underline{x}$$

This is valid for positive and negative x; F and x have opposite signs. In Part I the weight Mg of the added mass M acts in the same direction as the displacement of the spring (positive downwards). Hence

$$M\underline{g} = -\underline{F}$$

PART II

Figure (a) shows a spiral spring of length L, suspended from a rigid support and hanging vertically.

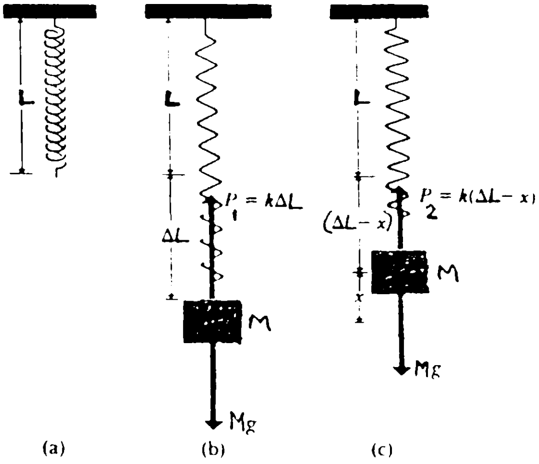
Figure (b) shows a mass M hanging in equilibrium from the spring which has an elastic constant k. In this position the spring is stretched by an amount ΔL just great enough so that the upward vertical force ($k\,\Delta L$) on the mass balances its weight Mg. Hence

$$k\,\Delta L = Mg$$

Figure (c) shows the situation when the mass is oscillating vertically and at a position x above its (stretched) equilibrium position. The total extension of the spring is

$$(\Delta L - x),$$

and the resultant force F on the mass is



(a) (b) (c)

$$F = k(\Delta L - x) - Mg = -kx$$

i.e. a net downward force of magnitude kx.
Likewise when the mass is below the equilibrium position there is a net upward force proportional to x.
If the mass is set in vertical motion it oscillates with simple harmonic motion of period T, where its acceleration $\underline{a}$ is given by

$$\underline{a} = -\omega^2 \underline{x}$$

Using Newton II

$$\underline{F} = M\underline{a}$$

Hence

$$-kx = (-\omega^2 x)M$$

where

$$\omega = 2\pi/T$$

Hence

$$T = 2\pi\sqrt{\frac{M}{K}}$$

5. The background theory was given in an Appendix (see page 187).

From the first investigation it had been noted that the majority of students had carried out this experiment either well before the corresponding lecture or a long time afterwards. The students referred to the theory section of the experimental notes when they had not enough knowledge about the background theory of this experiment. Hence it is essential to give an explanation about the physical situation, with diagrams to help the students to visualize the description. By this means the students should understand both theoretical and practical aspects of the work when they attempt the experiment.

The following general conclusions can be made from this comparison between these versions of notes for the SHM experiment:

1. The students felt that they had now sufficient time to carry out the experiment using the new version ($\sum X^2$ =26.0, statistically significant at 0.001 level) in favour of notes of the new version, as shown in table 6-9 below.

2. The new version of notes appeared to be much more helpful than the original form ($\sum X^2$ =8.1, significant at 0.01 level), as shown in table 6-9 (page 199).

Overall the new version of the SHM was found to be easier, more interesting, the instructions were adequate, and the objective was clearly understood at the beginning of the experiment. Further, a short practical problem (further exercise) was given to the students in the application of some experimental work they had experienced during that experiment.

Another example of changed format is shown below in figures 6-4 and 6-5 for the spectrometer experiment.

In referring to our guidelines, the following steps were included in the revision of the instructions for this experiment:

1. Again the instructions were divided into three parts, each part in turn was divided into **procedure** and **analysis**.

2. Only the necessary steps were included and these were explicitly stated.

3. The instructions were augmented by several diagrams, designed to enhance the students' understanding of the basic parts of the instrument and the techniques needed to use this equipment.

4. More detailed instructions were also included about how to focus the collimator and the telescope. We wished to avoid adding to the material instructions of the text of the experiment, to try to prevent overload of the students while doing practical work. This was accomplished by

1. Giving the students a better understanding of the aims and explaining the main points involved in the experiment

2. Teaching them how to use the apparatus and how to read the scales for the measurement of angle. This was very important, because it had been observed that many students were not familiar with the latter procedure. It was also found in this investigation that the majority of students had difficulties in calculating the errors.

The following experiments would still benefit from a revision of the notes.

Newton's rings, thermal conductivity, sound, force and potential, radioactivity, current electricity.

Figure 6-4. Original version

THE SPECTROMETER

1. Introduction

The purpose of this experiment is to set up a prism spectrometer and to measure the index of refraction of the prism for various colours and hence obtain a value for the dispersive power of the prism.

2. Apparatus

The essential parts of a spectrometer are:

(a) a horizontal collimator, at one end of which is a lens whose focal length is the length of the tube, and at the other end of which is a narrow vertical slit illuminated by light either from a hot solid (e.g. a metallic filament of a lamp) or from a hot gas (e.g. the gas in a helium lamp);

(b) a prism with vertical edges and resting on a table that may be rotated round a vertical axis. A graduated scale enables the rotation to be measured;

(c) a horizontal telescope focussed for infinity, and capable of being rotated round the same axis as the prism table. The rotation of the telescope can be measured by means of the scale.

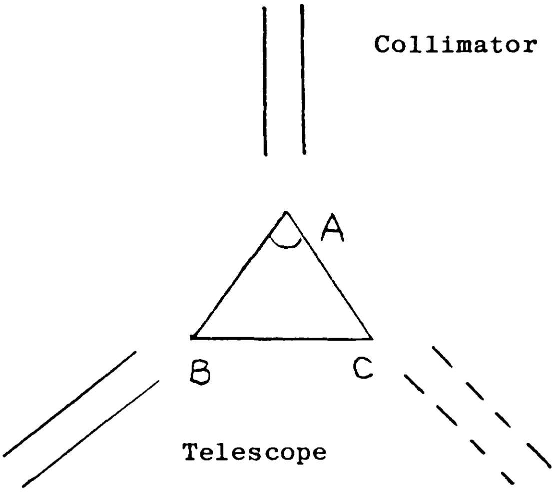
3. Schuster's method for focussing telescope and collimator. View the spectrum from the helium lamp, through the telescope, and focus the cross wires. Turn the prism to the angle for minimum deviation (see later). Turn the prism slightly (about 5 degrees) away from minimum deviation and focus the collimator. Turn the prism through minimum deviation to a small angle on the other side. If the system did not happen to be focussed properly at the beginning, then the spectrum will now be out of focus. Now focus the telescope.

Repeat this alternating procedure until no further improvement in the focus can be made by this method. The telescope and collimator are then both focussed for parallel light.

Note: If it is found, in the course of this procedure, that the focus gets progressively worse, then interchange the rotations of the prism when the telescope and collimator are being focussed.

4. Measurement of the Prism Angle

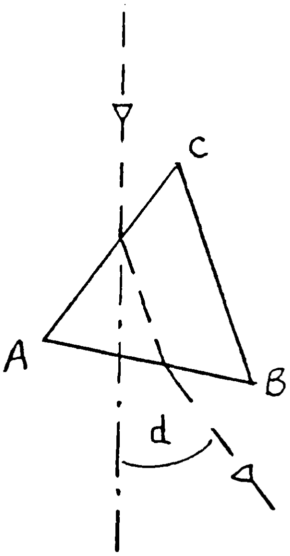
Illuminate the slit, which should be as narrow as practicable, by means of a metallic filament lamp. Set the prism so that the beam of light from the collimator is reflected from each of the two faces adjacent to the angle A that is to be measured. Turn the telescope until the right-hand edge of the image of the slit reflected from face AB coincides with the vertical wire in the field of the telescope.



Read the two vernier scales. (Why two?) Repeat for the reflection from face AC. The difference in corresponding readings is twice the angle A.

5. Measurement of Index of Refraction

Set the instrument so that the light from the collimator falls on face AC as shown. The beam will be refracted at surface AC, and at surface AB; the total angle through which the light has been turned is called the deviation. Turn the telescope until the light is seen. It will be noticed that a continuous spectrum has been formed, the red rays being least deviated. Replace the filament lamp by a helium lamp. A bright line spectrum will now be seen. Turn the prism table from one extreme position to the other extreme and note that the deviation first decreases and then increases, that is, there is a *minimum deviation*.



Set the prism table for minimum deviation of the yellow line, and clamp the prism table. Consider the best procedure for accurate alignment of the vertical cross-wire on the image of the slit. Note the two vernier readings. Move to a red image, and then to a violet or blue image, and repeat measurements. *Keep the prism table clamped,* remove the prism carefully and view the slit in the straight-through position by rotating the telescope. Again take two readings. Hence determine the deviations for yellow, red and violet (or blue) light. Calculate the indices of refraction of the prism for these colours. For the particular case of minimum deviation and for yellow light:

$$\mu_Y = \frac{\sin \frac{(A + d_Y)}{2}}{\sin \frac{A}{2}}$$

6. Obtain a value of the dispersive power D of the prism.

$$D = \frac{\mu_V - \mu_R}{\mu_Y - 1}$$

What is the significance of the dispersive power?

7. The angle A can also be measured by keeping the telescope fixed and rotating the prism. Verify this if time permits.

8. Errors

Error on μ

The error on μ due to that on A is:

$$\Delta_1 = \frac{\partial \mu}{\partial A} \Delta A = - \frac{\sin d/2}{2 \sin^2 A/2} \Delta A \qquad \text{(check this if you can)}$$

The error on μ due to that on d is:

$$\Delta_2 = \frac{\partial \mu}{\partial d} \Delta d = \frac{\cos (A + d)/2}{2 \sin A/2} \Delta d$$

where ΔA and Δd are the errors, in radians, on A and d. Since these two errors are independent, it can be shown that the total error in μ is:

$$\Delta\mu = \left[\Delta_1^2 + \Delta_2^2\right]^{\frac{1}{2}}$$

Figure 6-5. New version

THE SPECTROMETER

GENERAL OBJECTIVES

(i) to set-up a prism spectrometer
(ii) to measure the index of refraction of the prism for various wavelengths
(iii) to obtain a value of the dispersive power of the prism.

INTRODUCTION

A spectrometer is basically an instrument for observing spectra and measuring angles of deviation of light by a prism.

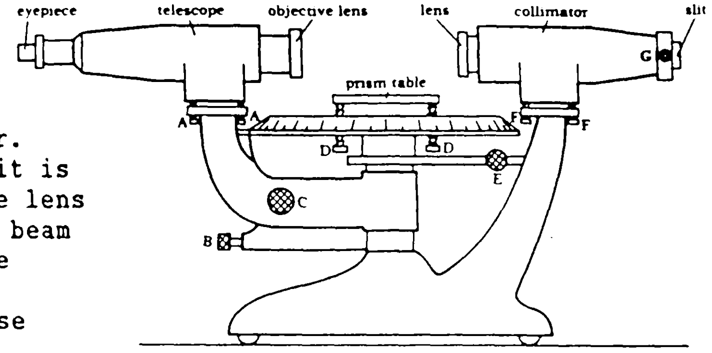


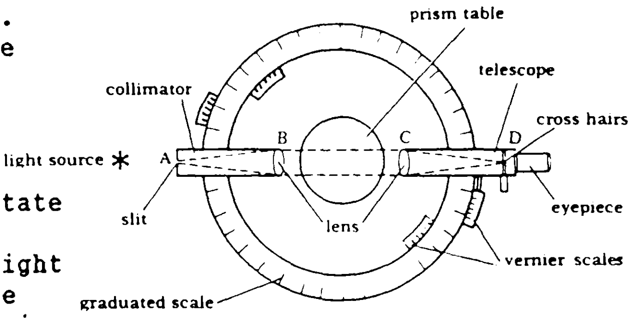
Fig 1

The essential parts of a spectrometer, shown in figure 1, are

(a) a collimator.
This is a tube with an adjustable slit at one end and an achromatic convergin lens system at the other.
The slit should be vertical, and it is usually placed at the focus of the lens so that when it is illuminated a beam of parallel light emerges from the collimator.
The collimator is fixed to the base of the instrument.

(b) a prism table.
This should be horizontal (use a spirit level) and can be rotated about a vertical axis.
A vernier scale allows the rotation to be measured with respect to the collimator.
Note that
1 degree = 60 minutes of arc.

(c) a telescope.
This is mounted so that it is free to rotate about the same axis as the prism table.
It may be focussed to receive parallel light from the collimator. The rotation of the telescope can be measured by another vernier scale. There are cross-wires in the eyepiece of the telescope and these should be vertical and horizontal.



The basic parts of the spectrometer.

PROCEDURE

In order to achieve the above objectives the following steps must be made:

1 focus the cross-wires
2 focus the telecope and collimator for parallel light
3 measure the angles of deviation for different wavelengths
4 measure the angle of the prism
5 calculate the dispersive power of the prism.

1 Cross-wires.

(a) Rotate the telescope to view a point within the laboratory as distant as is convenient.
(b) Focus the telecope to give a sharp image.
(c) Now focus the cross-wires by adjusting the eyepiece of the telescope until the cross-wires appear sharp. The cross-wires should be horizontal and vertical. The eyepiece should not be touched after this adjustment has been made.

2 To focus the collimator and telescope.
First of all you must understand what is meant by **minimum deviation.**

(a) Place the prism on the prism table with the ground glass face next to the support bracket.
(b) Place a filament lamp at the slit.
(c) Set the instrument so that white light (from the filament lamp) from the collimator falls on the face AC as shown. Turn the telescope until the image is seen. You will observe a **continuous spectrum,** the red light being least deviated.
The beam will be refracted at surface AC and at surface AB. The angle between the incident and the emergent direction of the light through the prism is called the angle of deviation, d [see figure 2].

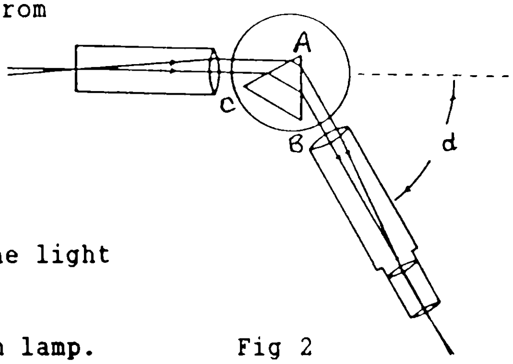


Fig 2

(d) **Replace the filament lamp with the helium lamp. A line spectrum will now be observed.** Make the slit width as narrow as practicable.
(e) Rotate the prism table clockwise and anticlockwise without losing the spectrum viewed through the telescope.
Observe that the deviation should decrease and then increase, i.e. there is a **minimum deviation.**

Now you are ready to focus the collimator and the telescope.
The following method (called Schuster's method) can be used:

(a) View the spectrum from the helium lamp through the telescope, and turn the prism to the angle for minimum deviation.
(b) Turn the prism table away by about 5 degrees from the minimum deviation position so that the ground glass face of the prism is more nearly parallel to the axis of the collimator. Focus the collimator.
(c) Now turn the prism through minimum deviation to a small angle on the other side. Focus the telescope.
(d) Repeat this procedure a few times until no further improvement in the sharpness of the image can be made.

The telecope and collimator are then both focussed for parallel light.

If in doubt ask your demonstrator, especially to check step (d).

3 To measure the angle of deviation d for different wavelengths.

(a) Place the helium lamp at the slit.
(b) With the prism removed from the prism table view the image of the slit through the telescope in the straight-through position,[see figure 3]. Take readings of the telescope position on the pair of diametric vernier scales attached to the telescope.
(c) Replace the prism on the prism table.
(d) Set the prism table for minimum deviation of the yellow line, and align the vertical cross-wire with the image.
Consider the best procedure for accurate alignment of the vertical cross-wire with the image of the slit.

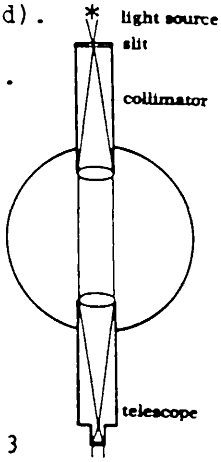


Fig 3

(e) Read the position of the telescope on the pair of diametric vernier scales (attached to the telescope).
(f) Repeat this procedure for a strong red line.
(g) Repeat for a violet line.
(h) By subtracting corresponding readings calculate the angles of deviation for yellow d_Y, red d_R and violet light d_V. You should expect these values to agree within 1 to 3 minutes of arc - if not, talk to your demonstrator. From the pairs of values calculate the mean angles.

4 To measure the angle A of the prism.
A is the angle opposite the ground glass face.
Refer to figure 4.

(a) Use the filament lamp to illuminate the slit.
(b) Set the prism so that the beam of light is reflected from each of the two faces adjacent to the angle A.
(c) Rotate the the telecope and check that you can see the reflected image from both faces. Clamp the prism table.
(d) Align the vertical cross-wire with the reflected image of the slit. For both reflected positions read the diametric vernier scales.
(e) The difference of corresponding readings is twice the angle A.

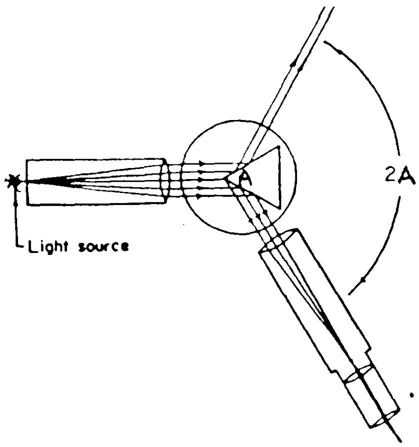


Fig 4

ANALYSIS

5 To calculate the value of the dispersive power of the prism you need first of all to calculate the index of refraction for yellow, red and violet light, n_Y, n_R and n_V, respectively.
For the case of yellow light

$$n_Y = \frac{\sin \frac{(A + d_Y)}{2}}{\sin \frac{A}{2}}$$

Check that n_V is greater than n_Y which is greater than n_R.
Now calculate the value of the dispersive power D of the prism

$$D = \frac{n_V - n_R}{n_Y - 1}$$

What is the significance of the dispersive power ? Discuss with your demonstrator.

6 The angle A can also be obtained by keeping the telescope fixed and rotating the the prism, and measuring the reflected angles. If time allows carry out this measurement.

7 Discuss with your demonstrator whether you should calculate the observational error in the indices of refraction. As the indices are all of the same size only one set of calculations is necessary.

Note that n depends on two measured quantities, d and A.
The error in n due to the observational error in A, δA, is

$$\delta_1 = \frac{\partial n}{\partial A} \delta A = - \frac{\sin d/2}{2 \sin^2 A/2} \delta A$$

and the error in n due to the observational error on d, δd, is

$$\delta_2 = \frac{\partial n}{\partial d} \delta d = \frac{\cos (A + d)/2}{2 \sin A/2} \delta d$$

where δA and δd must be expressed in radians.
Since these two observational errors are independent we can express the combined error in n, δn, as

$$\delta n = [\delta_1^2 + \delta_2^2]^{1/2}$$

6-6 Data from second experimental year

6-6-1 Frequency of responses

A comparison was also made of the students'responses to the diary questionnaires between the original and new versions for the eleven experiments. The distributions of responses between corresponding categories are presented in table 6-8 and these are also shown graphically in figures 6-6 to 6-15. The results show that the percentage of students responding favourably to the new version only in certain categouries such as "enough time" 'enough help from notes" and "easy".

The data were statistically analysed. A X^2 test carried out on the two forms of experiments. No frequencies fell below 5 in any cell, therefore X^2 was valid. The value and the level of significance for the ten categories are shown in table 6-9.

The results from both versions indicate that practical courses in physics are still favoured by the majority of students. However, in some cases the new version shows a desirable change which will indicate the direction for future research to improve practical work.

Table 6-8

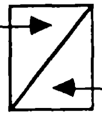
Percentage frequency of positive responses

Comparison between original and new version experiment

Category / Expt	Interesting	Easy	Well organized	Enjoyable	Worthwhile	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Theory improved	Obj clear at the begining	obj clear part way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
1.Air track	86 / 75	59 / 68	93 / 96	71 / 71	83 / 71	72 / 70	79 / 98	50 / 61	64 / 83	90 / 92	57 / 65	59 / 55	29 / 35	10 / 4	45 / 22	69 / 98	33 / 31	91 / 98	26 / 39
2.S H M	80 / 81	73 / 76	93 / 97	72 / 77	92 / 92	48 / 90	88 / 97	57 / 55	62 / 82	75 / 83	75 / 72	48 / 68	38 / 19	8 / 1	52 / 56	85 / 95	30 / 35	90 / 97	23 / 22
3.Melde's expt	73 / 71	55 / 67	98 / 89	61 / 91	87 / 80	87 / 93	90 / 93	40 / 67	43 / 76	35 / 65	82 / 75	45 / 58	47 / 29	5 / 4	44 / 51	87 / 87	8 / 9	100 / 91	8 / 2
4.Spectr-meter	87 / 79	52 / 75	91 / 94	73 / 71	94 / 83	84 / 91	97 / 95	49 / 62	52 / 75	70 / 67	87 / 71	55 / 46	37 / 38	6 / 3	43 / 37	88 / 94	48 / 64	99 / 100	36 / 35
5. Refrac-tion	82 / 77	62 / 68	93 / 85	74 / 55	87 / 80	64 / 61	89 / 92	53 / 59	56 / 70	91 / 79	80 / 73	51 / 55	38 / 39	5 / 2	51 / 35	76 / 80	49 / 29	96 / 88	33 / 20

Table 6-8. Continued

6. Lenses	90 69	69 65	90 89	72 68	98 81	34 60	98 93	62 51	69 73	91 80	90 83	66 56	29 35	3 7	47 36	89 85	22 21	98 92	28 11
7. Compound Pendulum	66 48	86 83	91 89	51 55	86 78	91 98	93 91	47 45	41 91	47 36	82 73	44 53	44 39	2 5	46 33	91 94	18 17	95 95	4 8
8. Solenoid	54 56	72 63	90 95	46 48	80 76	90 78	98 97	50 49	56 81	54 49	70 78	46 39	38 53	16 3	48 32	94 83	24 51	100 95	6 5
9. Vibrating blade	68 56	77 82	91 91	62 64	85 82	80 91	98 100	48 61	50 91	56 85	77 88	61 58	29 36	6 3	39 45	91 94	24 10	98 97	29 18
10. Growth & Decay	63 46	74 76	92 95	60 59	79 68	66 78	97 92	37 54	52 65	66 78	63 81	66 57	24 30	3 3	26 51	84 89	18 35	100 92	13 11
11 Proper-ties electron	65 86	64 75	95 95	55 50	81 82	84 95	95 98	50 66	61 75	60 45	70 77	58 61	26 27	8 5	40 55	86 82	37 39	98 84	8 11



Original expt

New version expt

Table 6-9. The significance of the difference between original and new version experiment

Categ Expt	Interesting	Easy	Enjoyable	Worthwhile	Enough time	Help from notes	Understood theoy	Theory improved	Enough time to record	Sufficient instruction
1. Air track	5.46 S*								6.72 S**	18.6 S**
2. S H M					26.0 S**	8.09 S**				
3. Melde's expt			12.17 S**			10.37 S**	9.31 S**			
4. Newton's Rings		6.04 S**								
5. Refraction	6.81 S**		4.36 S*				4.0 S*			
6. Lenses				7.76 S**	6.62 S**					
7. Compound Pendulum						19.1 S**				
8. Solenoid						4.51 S*				
9. Vibrating blade						8.23 S**	6.44 S**			
10. Growth & Decay									4.03 S*	
11. e/m							4.31 S*			

Empty cell, not significant

* Significant at 5 % level

** Significant at 1 % level

▨ New version
■ Original version

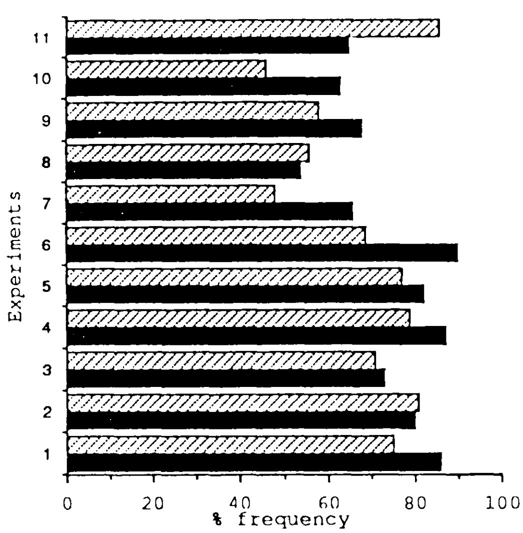


Figure 6-6. Interesting

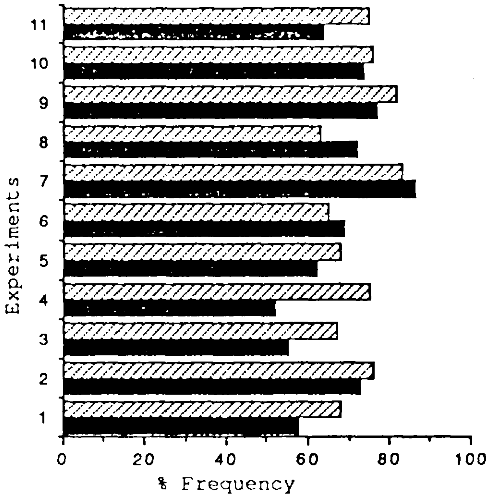


Figure 6-7. Easy

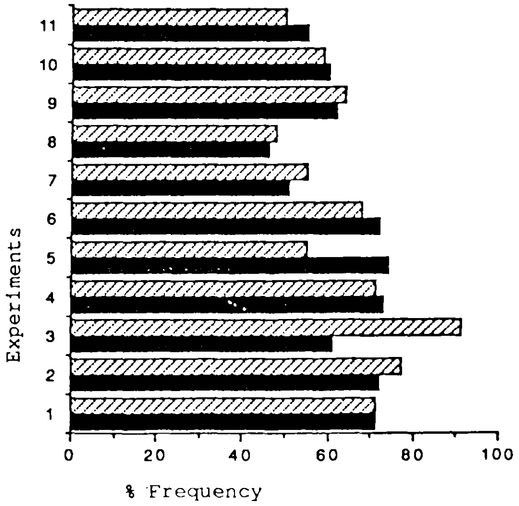


Figure 6-8 . Enjoyable

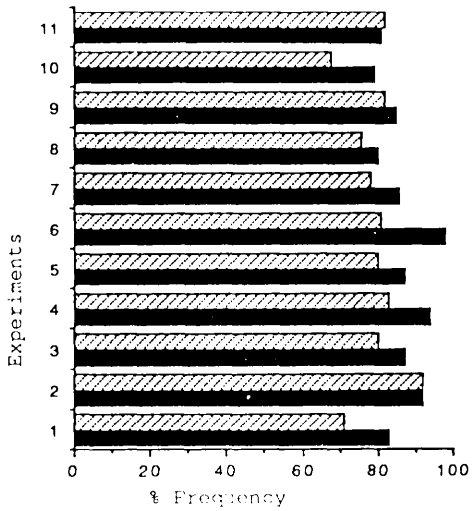


Figure 6-9. Worthwhile

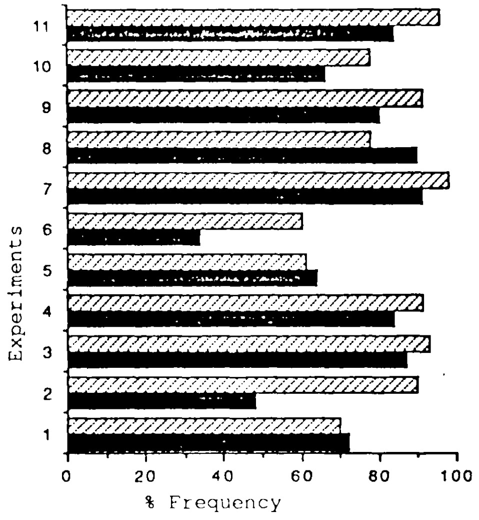


Figure 6-10. Enough time

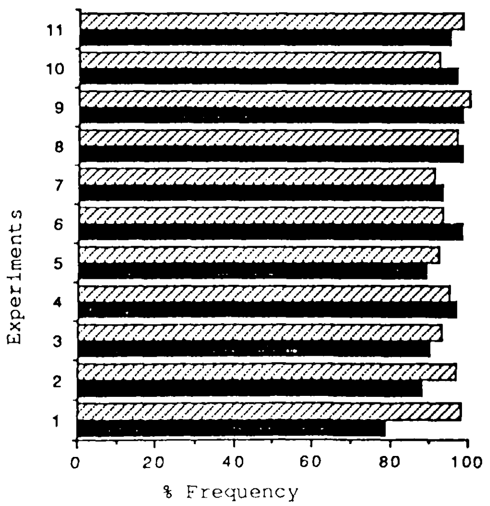


Figure 6-11.Enoughhelp from demonstrators

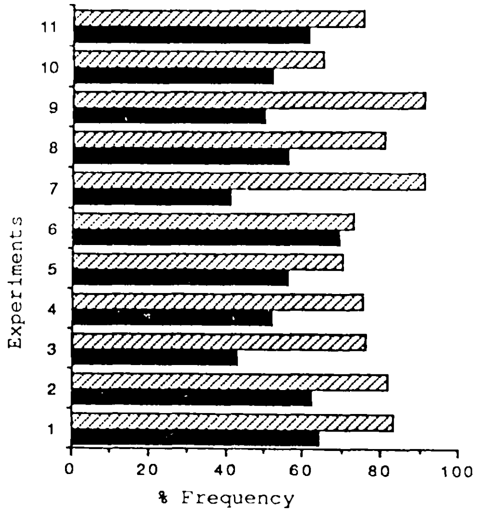


Figure 6-12. Enough help from notes

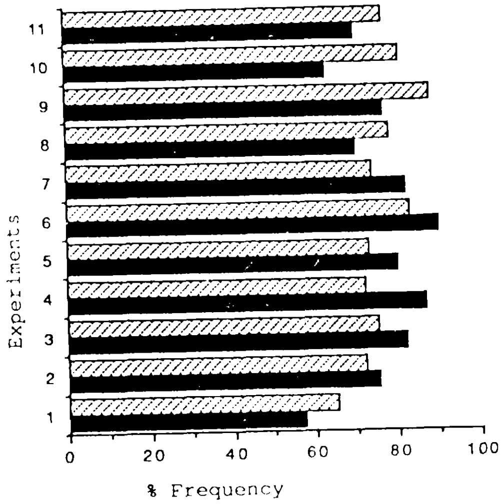


Figure 6-14. Improved the theory

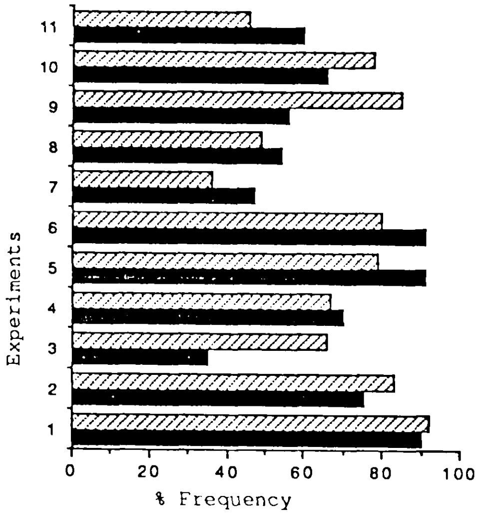


Figure 6-13. Understood the background theory

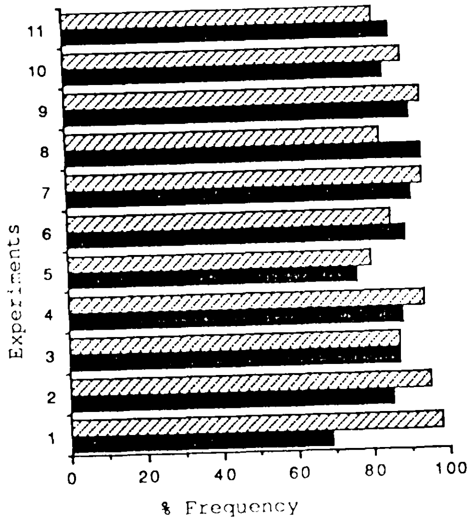


Figure 6-15. Sufficient instructions

The following general trends can be observed:

1. The students claimed they got more help from the new version of the notes (figure 6-12).

2. The students found that they had enough time to complete the experiments in their altered form (figure 6-10)

3. Although less pronounced than above, the students claimed they understood the background theory better from the revised version of the notes.

Other categories are more subjective (e g enjoyable, interesting) and no clear distinctions between the former and the revised notes / experiments were found.

The main objectives of the work have been achieved as seen from the improvements as shown in figures 6-12, 6-10 and perhaps 6-13.

6-6-2 **CSYS/SCE comparison**

It was useful to look for confirmation of the findings in the previous work whether school experience could be important in practical work at University level.

An attempt was made to compare the performance of the main groups in the sample between the two experimental versions. It was hoped this study would indicate whether there was any relationship between the background experience and University experience for the CSYS students and SCE Higher students. It should be noted from the previous experience, in both theory and practical work, CSYS students had an advantage over the SCE Higher students, as shown by the examination, practical record and report marks (see chapter 5, page 158).

This is illustrated in two examples below in the comparison of the responses obtained from both versions for the two groups separately. Two experiments were chosen; Simple Harmonic Motion (SHM) and the Spectrometer. The detailed results for the eleven experiments are presented in Appendix 6-2-A and 6-2-B.

Table 6-10 shows the comparison of percentage frequency of positive responses between the two versions for each student group.

1. For CSYS students, there was a distinct difference in the responses of the two versions of the same experiment. The CSYS students found the new versions of the two experiments more enjoyable, less difficult, and they had sufficient time compared to original versions.

2. For SCE Higher students, these students found greater understanding of the background theory in the new version of the two experiments, but the change did not lead to a greater grasp of theory. They received more help from the new notes compared with the original experiments.

Tâble 6-10

% Frequency of positive responses

Comparison between origenal and new experiments

1- CSYS students

Category / Expt	Interesting	Easy	Well organized	Enjoyable	Worth while	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Theory improved by this expt	Obj clear at the begining	obj clear par way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
S H M	70 64	75 68	85 100	60 72	85 84	45 96	80 96	45 80	70 84	90 80	65 60	55 72	44 20	5 9	50 56	90 92	20 20	90 100	10 20
Spectro-meter	83 76	50 86	87 86	58 71	92 86	75 95	92 95	46 71	54 76	71 87	92 71	54 48	37 29	8 10	37 67	79 81	50 43	100 95	37 29

2- SCE Higher students

S H M	80 86	67 62	97 90	80 76	93 86	40 83	93 98	63 38	57 83	60 83	87 81	40 62	43 19	17 5	43 57	87 76	30 38	93 76	27 21
Spectro-meter	87 84	53 65	93 94	81 77	93 77	87 84	97 94	53 58	53 77	62 82	81 74	53 48	41 42	6 3	53 42	97 90	47 68	97 100	37 32

Original version

New version

6-6-3 **FD/FI comparison**

A further investigation was made in terms of FD/FI factor. The analysis was made of the responses of students in the separate groups of field dependent, field intermediate and field independent for every category involved in the new version of the experiments.

In the example given below, comparison is made between the performance of FD/FI students in the two experiments as; Simple Harmonic Motion and Spectrometer shown in table 6-11.

The results for all experiments are given in Appendix 6-3. Here the X^2 test was not applied to these comparisons because the sample was too small. The following conclusion can be made from this example.

1. The percentage of positive responses of FI students in both experiments was higher and they assessed the experiments as more interesting, more enjoyable and more worthwhile that the FD students.

2. The FD group students expressed that they did not have enough time, insufficient instructions to work from, and they found the experiments difficult. They thought that they had received enough help from the notes. These students claimed to have a better grasp of SHM after carry out that experiment.

3. The objective seemed to be more clearly understood at the beginning by FI group who generally were more aware of what they were doing during the practical work as confirmed by their answer to the category; objective clear at the beginning.

4. The background theory was considered to be better understood by the FI than the FD students.

Table 6-11

% frequency of positive responses

Comparison between students'groups of different disembedding ability

1- S H M

Category / Expt	Interesting	Easy	Well organized	Enjoyable	Worth while	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Theory improved by this expt	Obj clear at the begining	obj clear par way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
F.I	89	89	100	89	95	95	100	67	95	83	61	83	33	5	50	100	25	95	22
F.int	80	80	80	70	92	90	97	47	75	82	67	67	30	10	52	92	37	100	17
F.D	75	62	94	75	75	87	94	44	81	81	87	56	25	12	56	100	44	100	31

2- Spectrometer

F.I	100	83	100	83	100	92	100	83	83	67	83	50	42	0	50	92	42	100	25
F.int	76	76	91	74	79	91	91	56	74	68	65	41	32	6	38	88	74	85	30
F.D	67	58	92	58	75	83	100	50	75	75	67	42	42	8	25	83	58	100	25

6-7 Comparison between the old and new version from demonstrators'dairy

A comparison was also made between the two versions from the responses of the diaries of demonstrators. These responses gave information about their perception of students' difficulties to both the original and the new version, on six questions involved to find out whether there is a difference in the frequency of students asking their demonstrators questions when they are carrying out an experiment. An example was chosen here for this comparison. The two experiments, SHM and spectrometer experiments showed the greatest improvement from the old to new version.

The results are presented in the figures 6-16 and 6-17 as well as table 6-12. As can be seen from these results, in each case, there were more students asking questions and requiring the assistance from demonstrators when the experiments and the notes were presented in their original form than in the new versions.

Table 6-12. Comparison between original and new version of spectrometer experiment

Ques / Expt	Total frequency on different questions:						
	1-1	1-2	1-3	1-4	1-5	2	Total
Original experiment	24	17	14	9	0	17	81
New version experiment	9	9	8	6	0	8	40

Figure 6-16. The original spectrometer experiment

	Frequency of students
1-1 About the written instructions:	
- difficulties of understanding Schuster's method	6
- angle of the prism	4
- other questions	14
1-2 About the actual doing of the experiment:	
- how to find the spectra	7
- difficulties in obtaining the line spectrum	5
- the prism orientation	5
1-3 About the use of apparatus:	
- vernier scale	6
- adjusting the prism, collimator and slit	2
- setting up spectrometer	6
1-4 About analysis of data:	
- calculation of index of refraction	3
- scale from the graph	3
- number of spectrum lines to analyse	3
2 About stupid things were they doing without asking:	
- using ground glass face of prism	6
- reading angles incorrectly	4
- looking for image on wrong side of prism	4
- forgetting to lock the prism table	3

Figure 6-17. New version spectrometer experiment

1-1 About the written instructions:	Frequency of students
- difficulty in understanding the instructions	4
- other questions	5
1-2 About the actual doing of the experiment:	
- Schuster's method	9
1-3 About the use of apparatus:	
- reading vernier incorrectly	8
1-4 About analysis of data:	
- errors analysis	6
2 About stupid things were they doing without asking:	
mixing up left and right the scale	
- reading incorrectly	2
- not working at the min deviation	3
- putting the prism at wrong position	3

6-8 **Conclusion**

In this part of the investigation it was proposed that the experimental instructions were an important factor in the success of students in developing their ability in practical physics. This study was an initial effort to give some insight into several variables which could be essential to the success in practical work. It was found that the background physics relevant to the experiment helped students close the gap between the fundamental theory and practical aspects of physics. In other words, the reason for doing practical work should be to give them insight about how that theory relates to reality.

The difficulties met in the laboratory and the overload on their working memory space can be decreased as suggested by this research. The students' attitudes and their responses to experimental work in physics are more positive as far as help from notes and time to do the experiment are concerned when given the revised version of notes and / or experiment. It was found that students showed an improvement in their understanding of the background theory and overall theory in half of the experiments by giving them the new version.

The following conclusions can be made:

1. The previous experience and the students' qualification of CSYS or SCE are important influences in success in practical work in the first year of University level.

2. The difficulties which students met during the practical work could be decreased and the load on students working memory space reduced by:

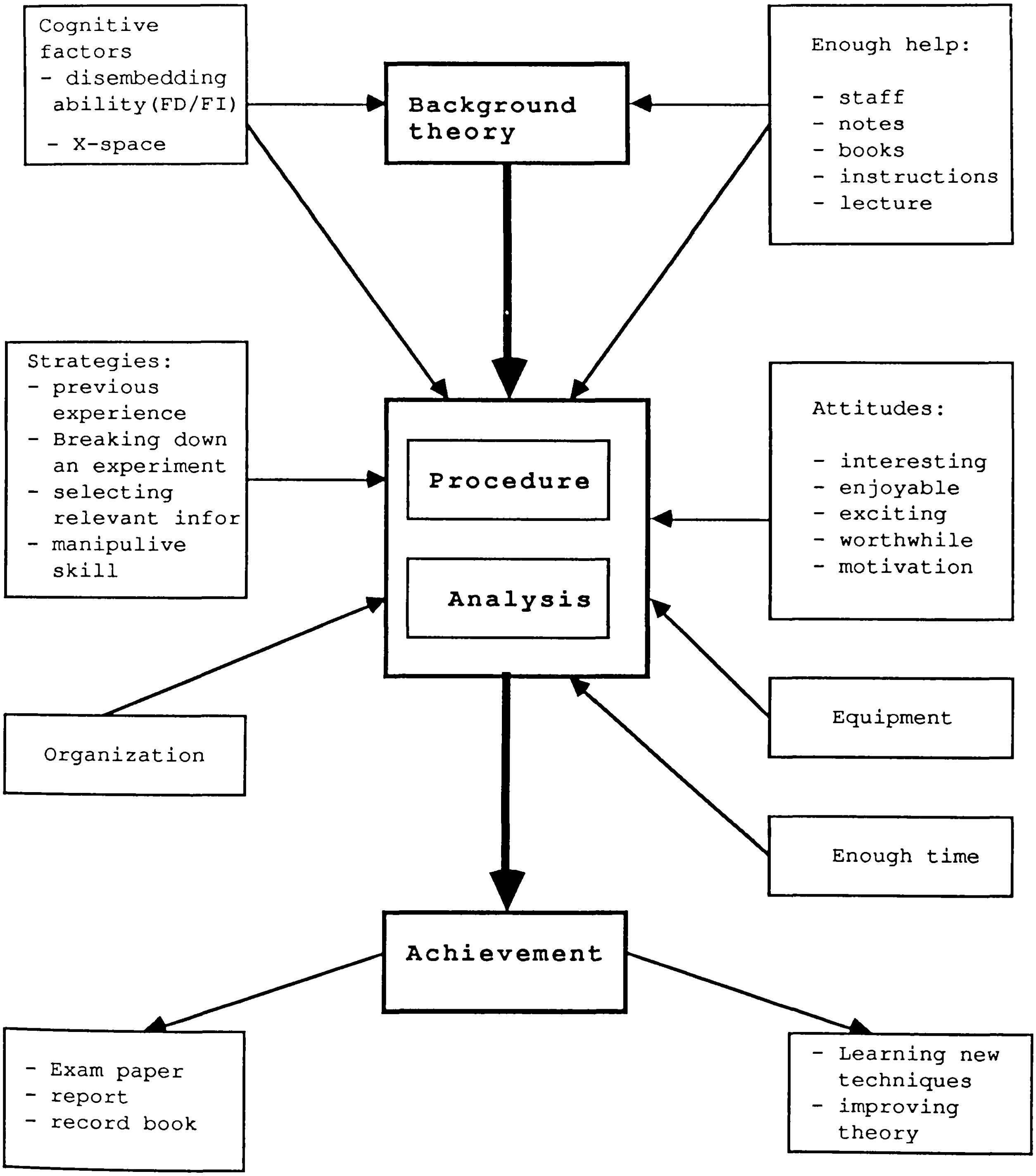
(a) dividing the experiment into several small parts, and within each part dividing the notes of experiment into ***procedure*** and ***analysis*** with explicit steps. This change in style seemed to be helpful in increasing the understanding of students in what they are doing from the beginning. This may have been the result of decreasing the number of thinking stages and in reducing the load of information they had to recall from their long term memory.

(b) removing most of the background theory section into an appendix but still presenting the relevant relations with some detail in the main part of the notes. This is particularly important when students have not enough knowledge of the physics involved in the experiment.

(c) adding certain diagrams in the experimental notes. This helps students to grasp the physical situation and visualize the description stated in the experimental instruction. A large amount of words can be condensed into a simple diagram and thereby reduce load.

We have presented evidence which shows that carefully structured and well illustrated experimental notes can cause improvement in their attitudes to experimental work. The diagram in figure 6-18, illustrates the different aspects of the practical course which represent the most important factors that influence students' working with less load.

Figure 6-18. The different aspects of the practical course.



Chapter seven

Problem solving

First year students (Glasgow University)

7.1 Introduction

During the last decade a large number of investigations have been carried out into problem solving ability. Some of those studies have attempted to give an explanation of the performance of students in physics. It was observed earlier in this thesis that the ability to solve physics problem depends on at least two important factors:

(a) The dependent factors. These relate to the intrinsic ability of the student and can be described in terms of the field dependence/field independence factor and the working memory space.

(b) The independent factors. These have to do with the nature of the question. I attempted to find ways of assisting students by designing different representations of the same physics problems, in the expectation that greater success in one type of representation would allow these students to see general strategies for problem solving.

This part of the study addresses the difficulty met by students during problem solving. Often the student does not understand or fails to visualize the physical situation described in the statement. This can be due to a number of features, such as the data not being explicitly given in the statement,or because of the actual difficulty of expressing the physical situation clearly in words. It is often helpful to visualize the situation described in the statement before starting the problem. Hence, it is easier to grasp the ideas by looking at a diagram rather than by reading the words given in the statement. Therefore, in general, a major source of difficulty and confusion in physics problems seems to arise from the physical situation. Cassels and Johnstone[86] suggested that the language in questions was influencing the thinking processes necessary to solve the question. For example long sentences and negative forms of statements required more working space.[86]

Kempa and Nicholls[95] explained how the students' ability to solve examination type problems relate to their cognitive structure, since they found that good problem-solvers had a more complex cognitive structure than did poor problem-solvers. In addition to that, Sleet et al[96,97] have shown that students could solve separately each step in a given a problem, but some of them were still unable to solve the whole problem in undivided form. Novak and Bascones[98] strongly supported the hypothesis that there was little difference in the response of solvers when the problem presented either as a question or as a statement.

The data obtained in this part of this study was designed to give insight into methods which can be developed by students to give greater success in solving problems. We sought an answer to the following question:

Which form of the representation of data has the greatest potential for success in solving physics problems?.

Here clear evidence will be presented for improvement in performance when the problem is given in the particular way to the students, so that the overload could be reduced on students' working memory space. We can increase students' success by reducing the difficulty in the problem without changing the logical structure of the item for processing.[34]

7.2 **Questions to be investigated**

For this study, it was proposed to check the following two questions:

I Does it matter if the information and data in the physics problems are presented in:

(a) statement form (original form)

(b) diagram form

(c) statement plus diagram form.

II What is the effect of the question when it is posed in a:

(a) direct form (traditional form)

(b) direct form, but the answer to an intermediate step is given.

(c) structured form with explicit steps.

It is also possible in this part of the investigation to focus attention on two other dependent factors which could have an influence on students' performance.

(a) The effect of degree of their field dependence/field independence on students' ability to solve a set of physics problems in different forms. This study was done with undergraduate students at Glasgow University.

(b) A further test to measure the working memory space of students was carried out to find out the function of working memory space on pupils' performance in solving different problem forms. This study was done with "terminal mathematics students" at Lycée El-Moukrani, Ben-Aknon in Algeria.

7.3 **Hypotheses investigated**

In order to attempt to find answers to the questions stated above two hypotheses were formulated:

Hypothesis one

The performance of students in solving a given problem should depend on the style of presentation, i.e whether the problem is presented in either:

(a) ***Form A***- the original statement form; or

(b) ***Form B***- the diagram form; or

(c) ***Form C***- the statement plus diagram form

Hypothesis two

The performance of students in solving a given problem should depend on the style of question, i.e whether the question is presented in either

(a) ***Form A*** the direct traditional form; or

(b) ***Form B*** the direct form but with the answer to an intermediate part of the problem given; or

(c) ***Form C*** the structured form with explicit steps.

7.4 Disembedded ability test (GEFT)

We investigated the influence of disembedding ability (the degree of field dependence (FD)/field independence (FI)) upon the improvement of problem solving ability. This was assessed using the Group Embedded Figure Test (GEFT). The details for this test have been described chapter 3.

7-5 Sample

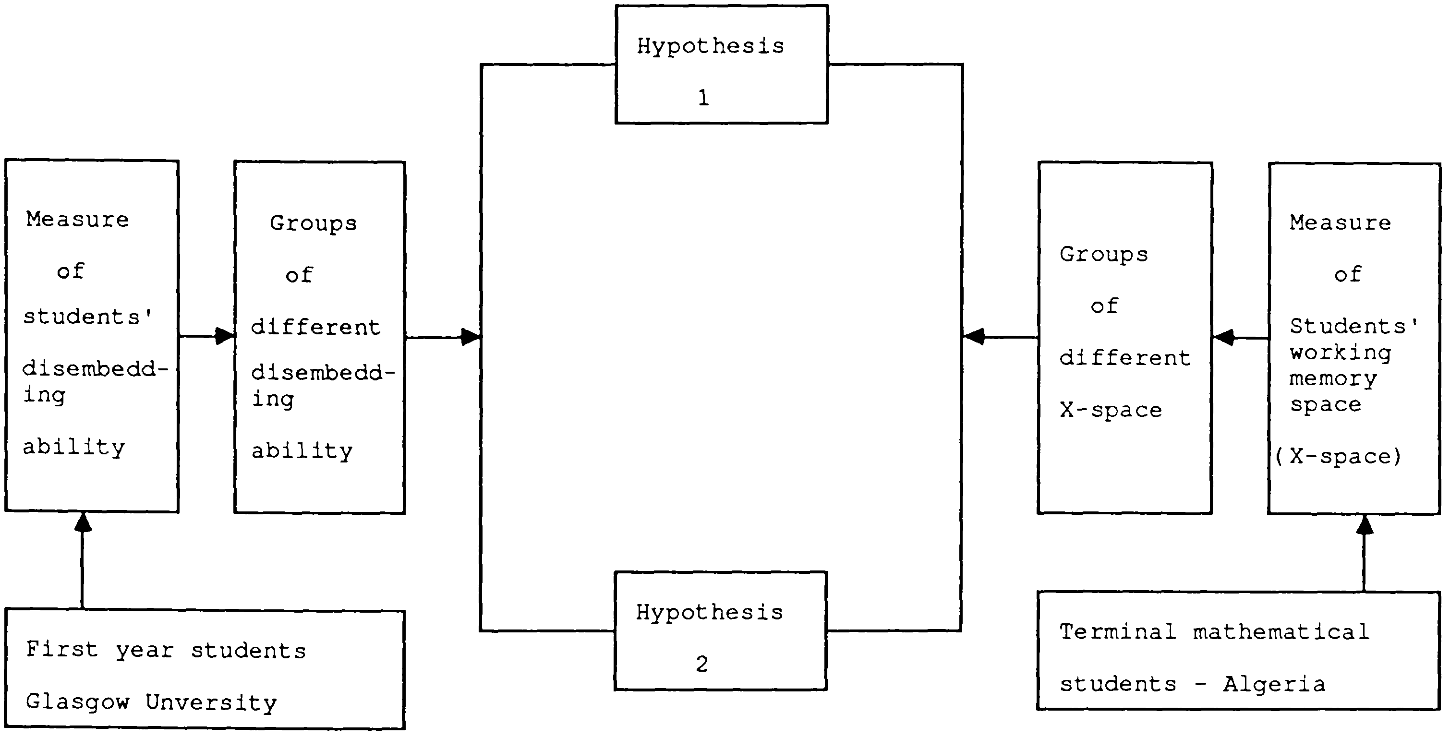
The same group of students was chosen as in the previous study in chapter 6 to test the validity of both hypotheses over a period of one term during the academic year 1989/90.

The sample was divided into three random groups which were further divided into three sub-groups of different disembedding ability (FD/FI) for the analysis.

Comparison of problem solving ability could then be made in students' performance between the whole sample and between the sub groups, for each form of problem.

In order to administer each of the three forms of the same

Diagram 7-1. For testing the two hypotheses in different samples



problem to test both hypotheses, an experimental design was devised for testing those forms, as shown in tables 7-1.

7-6 **Problems**

Six different problems in different areas of physics were chosen, three problems for each hypothesis. This reduced measurement errors and gave confirmation of the value of the findings. The problems are given in Appendices 7-1-A and 7-1-B. Each problem was taken by three separate groups of students simultaneously, meeting in different rooms. About fifteen minutes were allowed to answer each problem.

Table 7-1. Timetable for testing the two hypotheses

Hypothesis	Problems	Groups of students		
		1	2	3
1	1	form A	form B	form C
	2	B	C	A
	3	C	A	B
2	1	A	B	C
	2	B	C	A
	3	C	A	B

The physics content of the problems had been previously covered in course work and in preparation work for the tutorial which immediately preceded the test. For example one of the problems was based on simple harmonic motion (S H M). In the tutorial prior to the tests, S H M was one of the topics discussed by the tutor. In the administration of these tests, the different forms of a given problem were duplicated on colour coded paper, and the students made carbon copies of their answer.These copies were taken in from the group, and marked on a ten point scale.

The feedback to the students was either in the form of printed full solutions and /or discussion of the work at the next weekly problem solving tutorial. In other words the testing was part of a learning procedure.

7-7 **Confidence questionnaires**

The general aim of the confidence questionnaires was to obtain clear understanding of the students' ability to solve different forms of the same problem. It is useful to let students express themselves on their confidence level to the problem before and after attempting the problem. There were two confidence questionnaires used with every problem.

Before the students had attempted the problem, they were asked to read through the problem and then answer the first question.

"***How sure are you that you will be able to do this problem?***"

The students responded to this question by selecting the best answer by circling only one number 1 to 5, which represented the degree of their confidence to the problem. See Appendix 7-2. Immediately after they had answered this first question, it was collected from the students.

After attempting the problem the second confidence question was given on the last sheet of the answer booklet.

"***How sure are you that your answer is correct?***"

They responded to this question in the same way as the first question.

The data from the confidence questionnaires did not result in clear conclusions, sometimes due to small numbers in a given response cell. They have not, therefore, been included in the report of this work either in this chapter or the following one.

7-8 Testing Hypothesis one

7-8-1 Problem forms

There were three different instructional forms used:

(a) ***Form A***- the original statement form

(b) ***Form B***- the diagram form

(c) ***Form C***- the statement plus diagram form

Overall it was observed that from responses of the students to the example below (page 220), the majority could not solve the problem in either form A or form B, but most students answered the problem successfully when in the form C. i.e statement plus diagram. It could also be argued that the diagram chunks the information in the statement and so reduces the mental load.

It was concluded that when information is presented in either form A or B the majority of the students could not organize their thinking and suffered overload.

7-8-2 Analysis, results and discussion

The data obtained from testing the first hypothesis was computer analysed, yielding mean scores.

By this means it was possible to compare the performance in terms of several variables. The data were analysed in three ways:

1. For the whole sample in each problem form.
2. For each of three disembedding ability groups (field dependent, field intermediate and field independent) for every problem used.
3. Within each of the three forms separately.

Problem 2:

FORM A [Original form]

A lorry and a bus are each travelling at constant speed of 16 m s^{-1} in the same direction along a straight horizontal road. The bus is 14 m directly behind the lorry.

A back wheel of the lorry throws a stone backwards into the air and when it reaches its highest point it hits the front of the bus. The impact occurs 0.60 s after the stone has left the road.

(a) How high above the road does the stone hit the bus ?
(b) How far does the bus travel in the time between the stone leaving the road and hitting the bus ?
(c) Find the minimum safe distance between the bus and the lorry to avoid direct impact between the stone and the bus? [Clearly explain your reasoning].

FORM B [Information mainly given in diagram]

Consider the situation shown in the figures.

figure 1

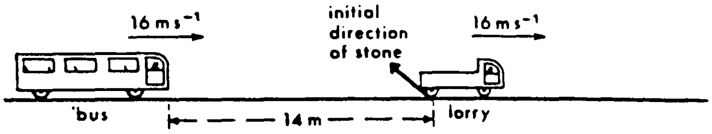
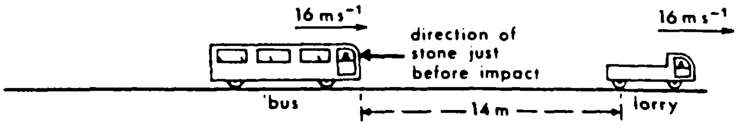


figure 2



A back wheel of the lorry throws a stone backwards into the air and when it reaches its highest point it hits the front of the bus. The impact occurs 0.60 s after the stone has left the road.

(a) How high above the road does the stone hit the bus ?
(b) How far does the bus travel in the time between the stone leaving the road and hitting the bus ?
(c) Find the minimum safe distance between the bus and the lorry to avoid direct impact between the stone and the bus? [Clearly explain your reasoning].

FORM C [Information given in words and in diagram]

A lorry and a bus are each travelling at constant speed of 16 m s^{-1} in the same direction along a straight level road. The bus is 14 m directly behind the lorry.

A back wheel of the lorry throws a stone backwards into the air in the direction shown in figure 1. When the stone reaches its highest point it hits the front of the bus as shown in figure 2. The impact occurs 0.60 s after the stone has left the road.

figure 1

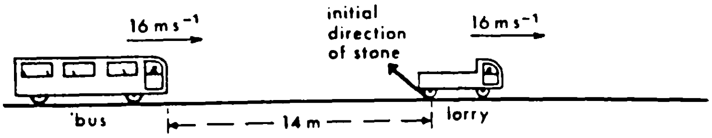
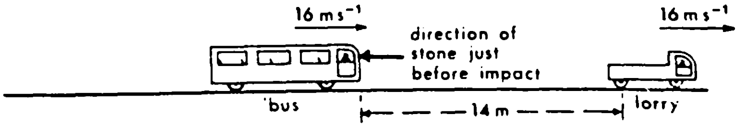


figure 2



(a) How high above the road does the stone hit the bus ?
(b) How far does the bus travel in the time between the stone leaving the road and hitting the bus ?
(c) Find the minimum safe distance between the bus and the lorry to avoid direct impact between the stone and the bus? [Clearly explain your reasoning].

Analysis I

Here all students in a given tutorial group were taken collectively and their performance within each of the three problem forms was obtained.

Table 7-2 shows the percentage mean scores for the three problems. It can be seen from this table that the students have higher percentage mean in problem form C than either form B or form A. There was little difference between performance in form A and form B.

Table 7-2. Relation between the problem forms and success (% mean) of students for whole sample of students

Problem form	% mean score on different problems			
	1	2	3	Average
A	45.4	47.6	53.6	48.8
B	42.4	47.0	54.3	47.9
C	66.0	63.7	68.0	65.9

A t-test (two tailed) was applied to find out whether these differences in performance are significant. These results are given in table 7-3 from which it can be seen that, in each case, higher significant differences were found between the forms C and B, and C and A, whereas there was no significant difference between form A and form B.

Table 7-3. The significance of the differences in mean scores for the whole sample of students between problem forms in solving different problems.

Problems	Problem forms		
	A and B	A and C	B and C
1	0.38	2.17 *	3.05 **
2	0.12	2.89**	3.09 **
3	0.13	2.77**	2.88**

* significant at 5 % level

** significant at 1 % level

Analysis II

Other comparisons were made to find out whether the cognitive style (FD/FI) influenced significantly the students' performance within each of the problem forms. The results are presented in table 7-4 as well as figures 7-1, 7-2 and 7-3. The results indicate that the mean of field independent group is higher than field dependent group for each physics problem.

Table 7-5 shows that, for problem 1 there were significant differences between field independent and field intermediate in the form C, as well as between field independent and field dependent in the form A. For problem 2, there were significant differences between field intermediate and field dependent groups in the form A as well as between field independent and field dependent groups in both forms A and B. In problem 3, however, there were significant differences in mean between field independent and field intermediate groups in both form A and form C.

Table 7-4. Relation between the disembedding ability (F.D/F.I) and success (% mean) of students in solving different forms in the same problem.

Problem forms	Groups	% mean score on different problems			
		1	2	3	Average
A	F.I	59.3	58.3	66.6	61.4
	F.Int	49.7	48.9	47.0	48.5
	F.D	27.3	32.8	47.5	35.9
B	F.I	41.6	56.6	57.1	51.6
	F.Int	55.1	51.2	56.0	54.1
	F.D	30.5	33.3	50.0	37.9
C	F.I	83.7	68.6	80.0	77.4
	F.Int	49.2	54.8	67.1	57.0
	F.D	65.0	67.7	57.1	63.3

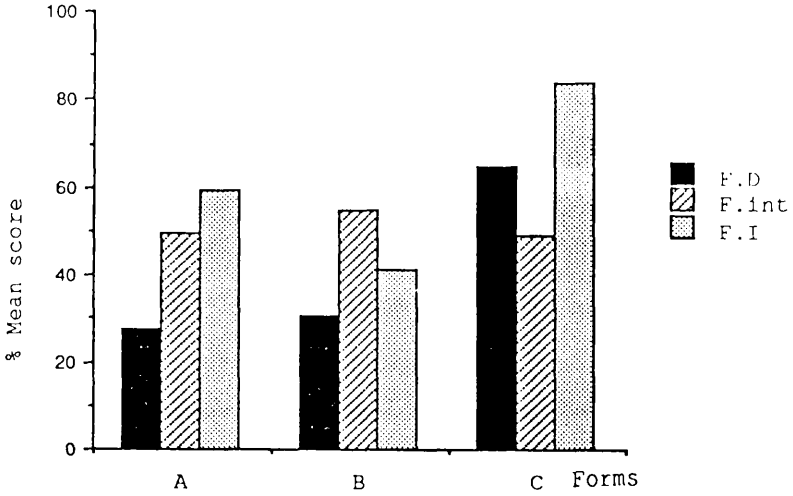


Figure 7-1. A comparisons of mean score between students groups of different disembedding ability (FD/FI) in the *problem* 1

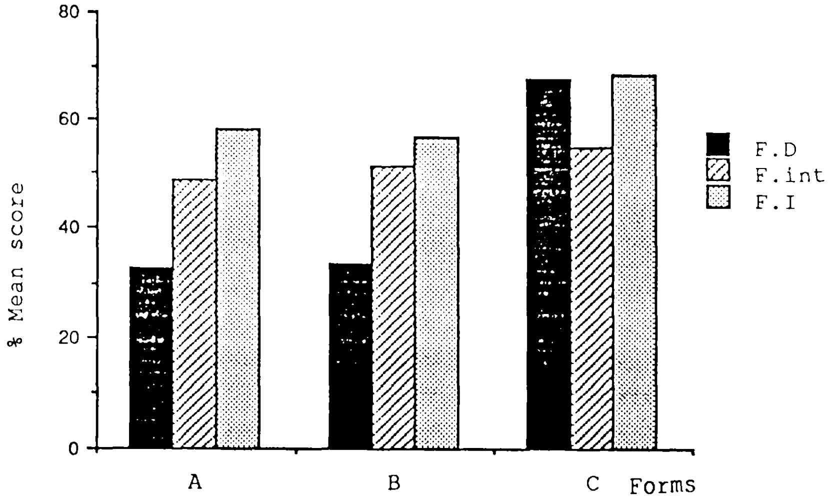


Figure 7-2. A comparisons of mean score between groups of different disembedding ability (FD/FI) in the *problem* 2.

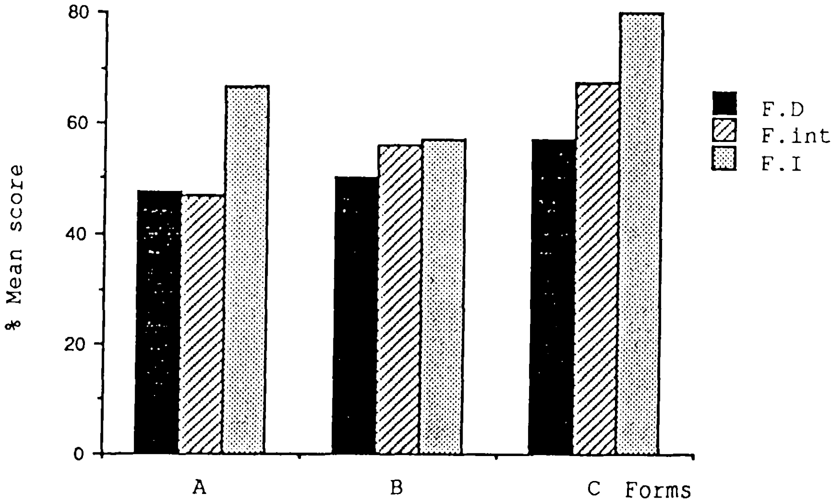


Figure 7-3. A comparisons of mean score between groups of different disembedding ability (FD/FI) in the *problem* 3.

Table 7-5. The significance of the differences in means between groups of FD/FI students for each problem form.

Problem	Problem forms	Groups of(FD/FI) students		
		F.I &F.Int	F.Int&F.D	F.I & F.D
1	A	0.80	1.70	2.52*
	B	1.17	1.70	0.72
	C	3.01*	1.22	1.26
2	A	0.88	2.77*	2.65*
	B	0.61	2.23	2.35*
	C	1.37	1.56	0.11
3	A	2.22*	0.05	1.59
	B	0.20	0.70	0.96
	C	2.58*	0.61	1.41

* significant at 5 % level

Analysis III

In this analysis, comparisons were made between problem forms within each problem for each sub-groups of field dependence/field independence.

The results are given in tables 7-4 as well as in figures 7-4, 7-5 and 7-6.

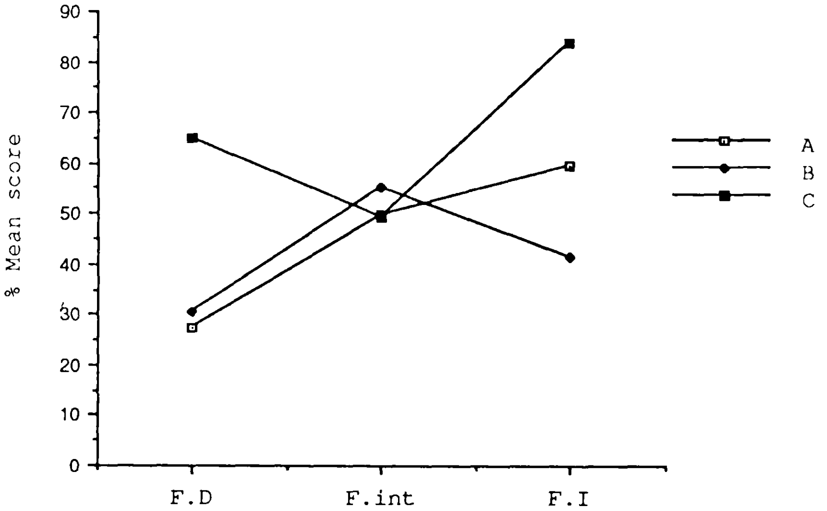


Figure 7-4. A comparison of mean score between the three forms in *problem* 1

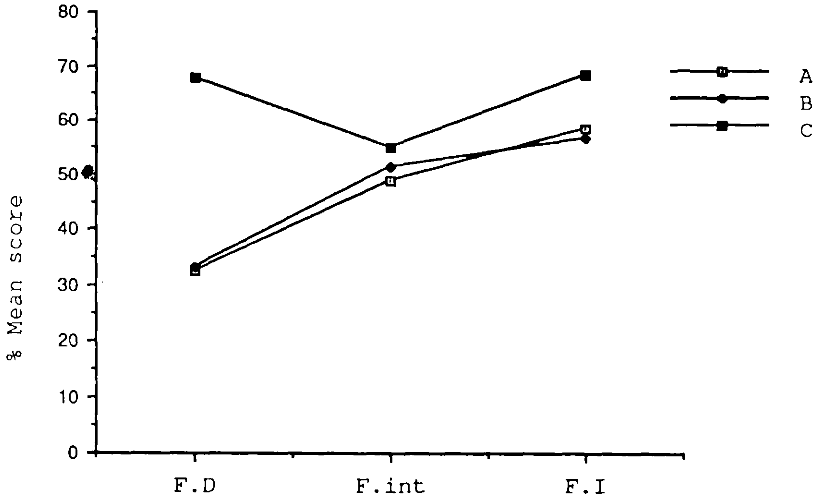


Figure 7-5. A comparison of mean score between the three forms in *problem* 2

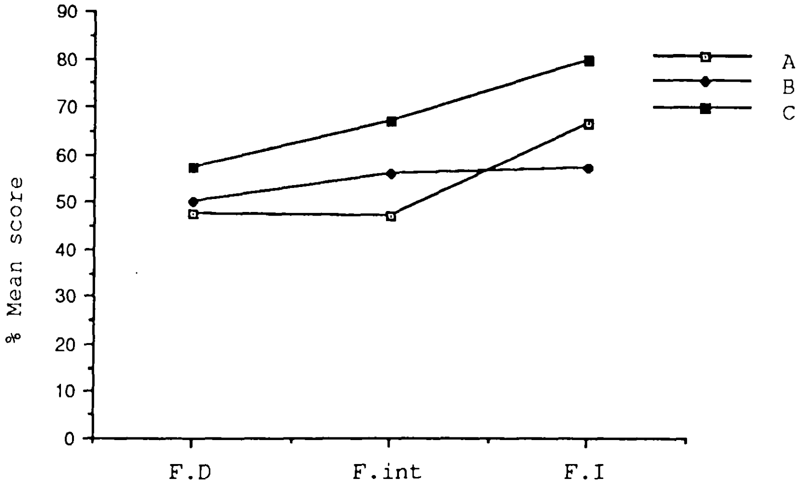


Figure 7-6. A comparison of mean score between the three forms in *problem* 3

Table 7-6. The significance of the difference between problem forms for each groups of disembedding ability students in solving different physics problems.

Group	Problem	Problem forms		
		A and B	B and C	A and C
F.I	1	1.38	3.22*	1.85
	2	0.14	1,05	0.82
	3	1.20	5.23**	1.62
F.Int	1	0.51	0.60	0.05
	2	0.33	0.50	0.82
	3	1.28	1.85	3.24**
F.D	1	0.18	2.03	2.42*
	2	0.07	3.83**	5.02**
	3	0.21	0.41	0.52

* significant at 5 % level

** significant at 1 % level

In general, of the three sub-groups the field independent students performed better overall, and all students performed better in the form C.

As can be seen from table 7-6 that for field independent students there were significant differences in performance between the forms B and C for both problems 1 and 2. For the field intermediate group there was only one significant difference in responses between the form A and form C in problem 3.

For field dependent students, there were three significant differences in means found between the form A and C in both problems 1 and 2, as well as between the form B and C in problem 2.

For any sub-groups of students no significant differences were found in means between the form A and B in all the problems.

From figure 7-4, 7-5 and 7-6 the important features are

(a) FI students perform best.

(b) FD students increase dramatically their performance when the problem is in form C. It would appear that the diagram is very helpful to the field dependent students presumably because it presents information which otherwise such students would have to extract for themselves from the statement of the problem. In other words, it helps them to "chunk" the information.

(c) Because the F Int group contain both FI and FD students the results of F Int are slightly ambiguous.

7-8-3 **Conclusions**

The results obtained from this investigation gives insight into the difficulty met by students during problem solving.

The data present evidence that the style of presentation of a given problem greatly influences the performance of students i.e the data supports hypothesis one.

For every problem, the students showed much improvement when they were given a problem in the form C.

Field dependence /field independence was found to have a great influence on students'success in all problems used. The performance of field independent students is significantly better than the performance of field dependent students.

7-9 **Testing hypothesis two**

7.9.1 **Question forms**

There were three different styles of same problem used:

(a) ***Form A*** the direct traditional form

(b) ***Form B*** direct form but with the answer to an intermediate part of the problem given

(c) ***Form C*** the structured form with explicit steps

(a) ***Form A*** In this form the question was given in a direct traditional form. In this case, students have to work through the problem devising a method and finding certain intermediate variables needed for the final solution, as shown in the example below (problem 2):

An inextensible light string passes over a smooth light pulley. To one end of the string is attached a mass of 1.5 kg, and to the other end two masses of 1.0 kg. The system is released from rest. After 5.0 s one of the 1.0 kg masses becomes detached from the string. Calculate the further time elapses before the system comes instantaneously to rest.

The answer to the question required four stages. Marks were allocated to this question as shown in the right margin.

Stage 1. finding the initial acceleration

$$T - m_1g = m_1a_1$$

$$T - (m_2+m_3)g = -(m_2+m_3)\ a_1$$

$$a_1= \frac{m_2+m_3-m_1}{m_2+m_3+m_1}\ g$$

a_1=1.4 m s $^{-2}$ 3 marks

Stage 2. finding the velocity

v=7 m s $^{-1}$ 2 marks

Stage 3. finding the new acceleration

$$a_2 = \frac{m_2-m_1}{m_2\ +m_1}\ g$$

a_2 = -1.96 m s^{-2} 3 marks

Stage 4. answer the question

t = 3.57 sec 2 marks

Total marks 10

(b) ***Form B***. Here the same question is presented as a direct form but the answer to the first step is given, as seen in the example below. In consequence, the possible mark for the question is reduced by the number of marks originally allocated to the first step.

An inextensible light string passes over a smooth light pulley. To one end of the string is attached a mass of 1.5 kg, and to the other end two masses each of 1.0 kg. The system is released from rest and moves with an acceleration of 1.4 m s^{-2}. After 5.0 s one of the 1.0 kg masses becomes detached from the string. Calculate the further time which elapses before the system comes instantaneously to rest.

Now the answer to this question form required only three stages

Stage 1 finding the velocity

v=7 m s^{-1} 2 marks

Stage 2 finding the new acceleration

a_2 = -1.96 m s^{-2} 3 marks

Stage 3 t= 3.57 sec. 2 marks

Total marks 7

This reduced mark of 7 was then scaled to 10.

(c) ***Form C***. In this form, the same question was given as a structured form where explicit steps are asked. This is illustrated in the example below:

An inextensible light string passes over a smooth light pulley. To one end of the string is attached a mass of 1.5 kg, and to the other end two masses each of 1.0 kg. The system is *released from rest.*

(1- a) Calculate the acceleration of the system

(1- b) Calculate the velocity after 5.0 s

(1-c) At this instant one of the 1.0 kg masses becomes detached from the string. Determine the new acceleration of the system

2) Calculate the further time which elapses before the system comes instantaneously to rest.

Overall, it can be seen that from students' responses to the example above, the majority could answer the question in either form B or form C, whereas most students could not successfully answer the question in the form A i.e the direct form.

In the above problem either in the form B or form C there are fewer thinking stages in order to find the correct answer but in the question form A, it appears that there are more thinking stages. Hence this form probably needs more working memory capacity.

This indicates that the structure of the question influences the thinking necessary to answer the question.

7.9.2 **Analysis results and discussions**

The data provided from testing hypothesis two was computer analysed yielding mean score. As before it was possible to use three ways to present the data:

1. For the whole sample of students in each question
2. For each of the three disembedding ability groups- field dependent, field intermediate and field independent students

for every physics problem used.

3. Within each of the three forms separately.

Analysis I

Here the performance of the complete groups of students who answered each form of a given problem was calculated. Table 7-7 shows the percentage of mean score for every question form. It is evident that students answered the problem in form C more successfully than in forms A or B.

Table 7-7. Relation between the question forms and success (% mean) of whole sample of students in solving different physics problems

Question form	% mean score on different problems			
	1	2	3	Average
A	10.6	42.3	28.8	27.3
B	40.3	52.7	38.4	43.8
C	51.3	59.2	46.6	52.4

The statistically significant differences in performance among the three forms were calculated. The results are given in table 7-8, from which it can be seen that high significant differences were found in mean scores between the form A and form C in all the problems used. One significant difference in means between form A and form B in the problem one was found. This might be accounted for by the topic of the problem, viz simple harmonic motion. The direct traditional form A appears difficult to students (mean score 10.6 %) whereas form B has helped (40.3 %).

Table 7-8. The significance of the difference in mean score between question forms for the whole sample of students

Problem	Question forms		
	A and B	B and C	A and C
1	5.15**	1.29	5.73**
2	1.28	1.02	2.16*
3	1.55	1.13	2.88*

* significant at 5 % level

** significant at 1 % level

Analyses II

Again analyses was performed to investigate the performance of subgroups (FD/FInt/FI) in the three forms of the three problems.

The mean score are given in tables 7-9 as well as figures 7-7, 7-8 and 7-9. The results indicate that the field independent students produced higher mean scores than field dependent students in all problems. The most significant result is that the performance of field dependent students increased remarkably when the questions were presented in form C. This form allowed field dependent students to achieve mean scores nearly as good as field independent students.

In each case, there were no significant differences in mean scores between field independent and field intermediate students on any of the three problems. While for problems 1 and 2 significant differences were found between field intermediate and field dependent students in the form A, as well as in the form B for problem 3. For form A significant differences were found between field independent and field dependent students in problem 1 and 2 as well as in the form B for problem 3.

Table 7-9. Relation between groups of disembedding ability (FD/FI) and success (% mean) of students on solving different question forms.

Question forms	Groups	% mean score on different problems			
		1	2	3	Average
A	F.I	10.0	68.0	35.6	37.9
	F.Int	20.7	48.4	24.4	31.1
	F.D	1.1	10.4	12.5	8.0
B	F.I	58.3	67.1	53.3	59.6
	F.Int	32.6	54.3	46.8	44.5
	F.D	30.4	36.8	15.0	27.4
C	F.I	54.2	57.7	56.7	56.2
	F.Int	46.5	57.5	38.4	47.4
	F.D	53.1	63.3	44.6	53.6

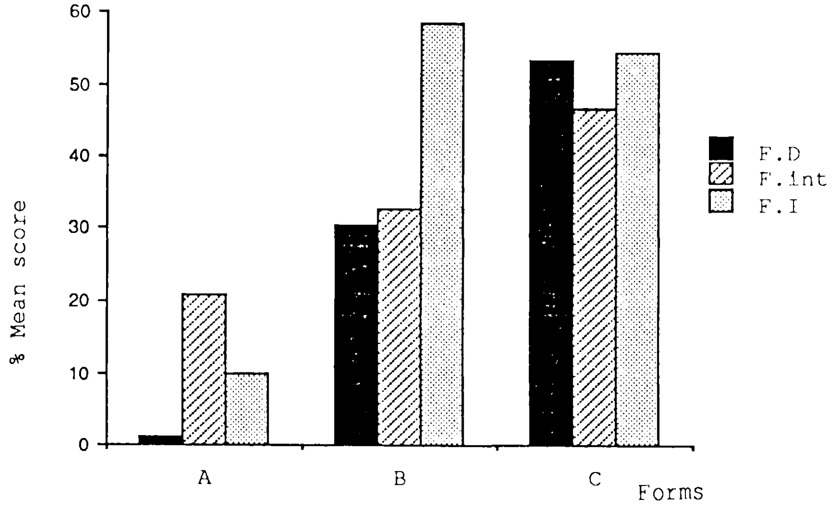


Figure 7-7. A comparisons of mean score between students groups of different disembedding ability (FD/FI) in *problem* 1

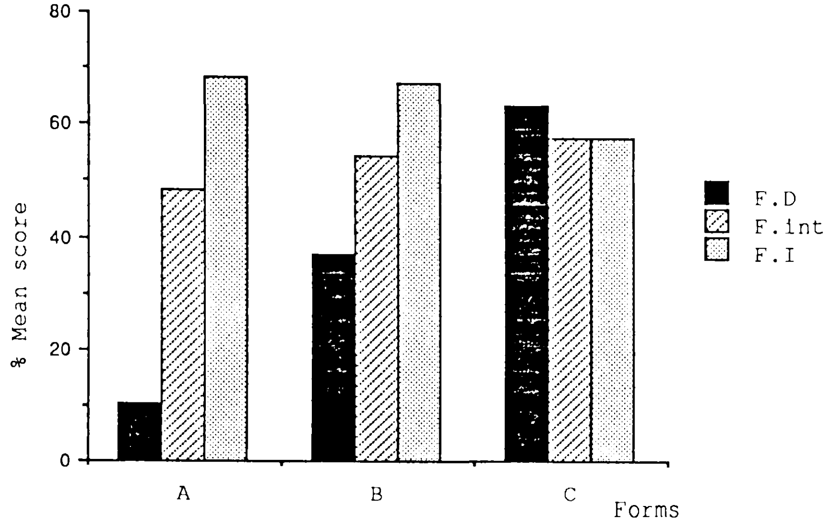


Figure 7-8. A comparisons of means score between students groups of different disembedding ability (FD/FI) in *problem* 2

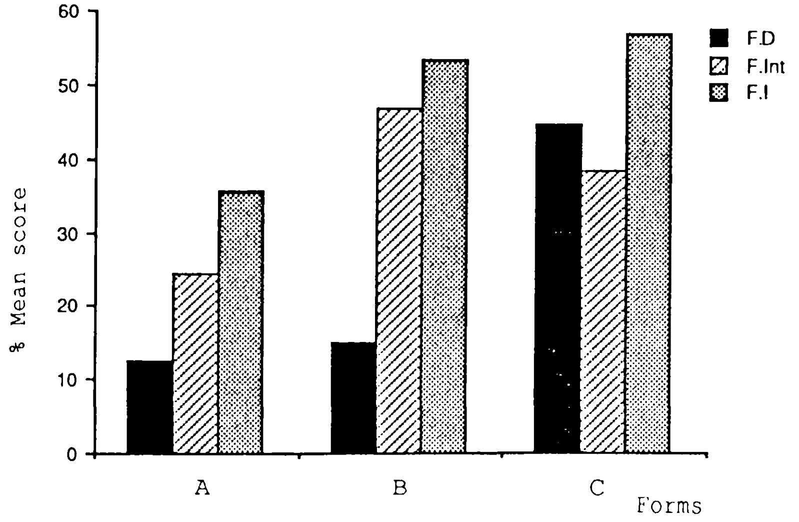


Figure 7-1. A comparisons of mean score between groups in of different disembedding ability (FD/FI) in *problem* 3

Table 7-10. The significance of the differences in mean score between groups of (FD/FI) students for each question form

Problem	Question form	Groups of (FD/FI) students		
		FI & FInt	FInt & FD	FI & FD
1	A	1.60	2.55*	2.83*
	B	2.06	0.114	1.58
	C	0.66	0.94	0.06
2	A	1.0	4.37**	3.15*
	B	1.15	1.03	2.23
	C	0.02	0.46	0.39
3	A	1.34	1.35	2.12
	B	0.49	3.59**	2.81 *
	C	1.32	0.46	0.69

* significant at 5 % level

** significant at 1 % level

Analysis III

In this alternative analysis comparisons were made between forms within each problem for each sub-groups of disembedding ability (FD/FI).
The results are shown in tables 7-9 as well as in figures 7-10, 7-11 and 7-12. As can be seen from these results each sub-group of student separately performed better in the forms B and C than in the form A in all problems used. Most markedly, field dependent students showed much improvement when they were given question in the form C, for every problem.

Again t test (two tailed) was applied to find out whether those differences are significant- presented in Table 7-11. No significant differences were found in means between the form B and form C in any problem. For field independent students, there were significant differences in performance between the forms A and B in problem 1 as well as between the form A and C. While for field intermediate students, a significant difference were found between the form A and form C in both problems 1 and 2, whereas for field dependent students, three significant differences were found between the forms A and B in problem 2 as well as between the forms A and C in problems 1 and 2.

From figure 7-10, 7-11 and 7-12 the mean score of

(a) field independent students generally performed best in all these problems

(b) field dependent students improved their score progressively as the problem was presented in forms B and C. Field dependent students show the greatest improvement in going from form A to form C.

(c) again ambiguity of the results of field intermediate students.

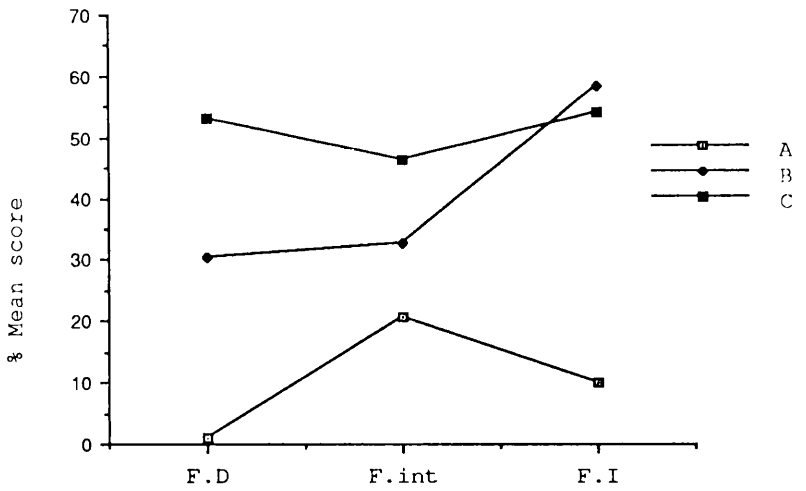


Figure 7-10. A comparison of mean score between the three forms in *problem* 1

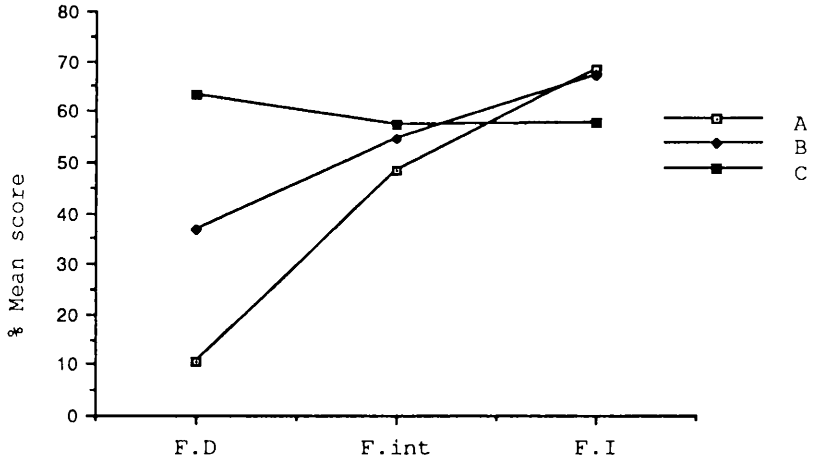


Figure 7-11. A comparison of mean score between the three forms in *problem* 2

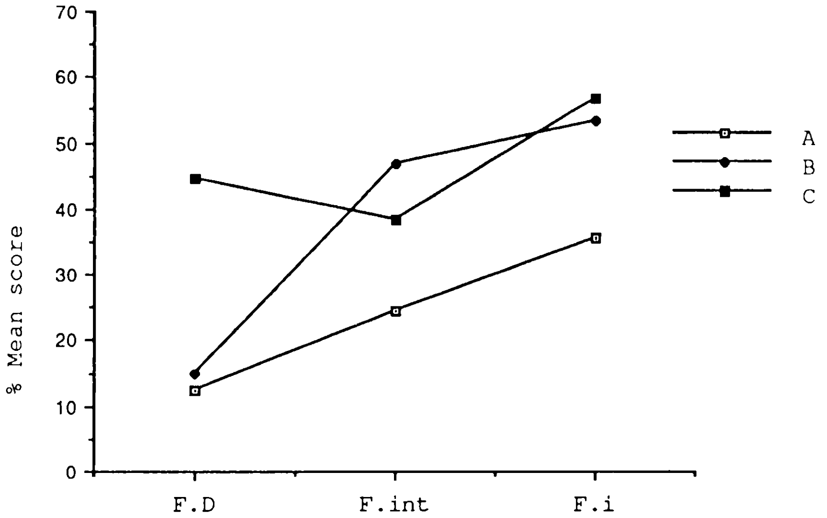


Figure 7-12. A comparison of mean score between the three forms in *problem* 3

Table 7-11. The significance of the differences in mean score between the question forms in solving physics problems.

Group	Problem	Question forms		
		A and B	B and C	A and C
F.I	1	4.39**	0.20	2.57*
	2	0.05	0.85	0.56
	3	1.28	0.18	1.32
F.Int	1	1.16	1.46	2.53*
	2	0.54	0.37	0.95
	3	3.13**	1.02	2.15*
F.D	1	2.08	1.20	4.12**
	2	2.42*	1.67	4.24**
	3	0.24	2.16	2.21

* significant at 5 % level

** significant at 1 % level

7-9-3 **Conclusions**

The findings obtained show that the style of question greatly influences the students performance of students i.e the results support hypothesis two.

1. The results present evidence that students increase their

success in solving physics problems if the question is presented in a more effective way thereby reducing the unknown variables.

2. In general all students found questions in the form A difficult to solve. This form requires more thinking steps and hence can cause overload of the students' working memory.

3. Disembedding ability is also a very important factor in students' success. When a question is presented in a structured form, field dependent students can learn to develop their own strategy to organize their knowledge to select only relevant information.

Chapter eight

Problem solving

Secondary school students

8-1 Introduction

This chapter describes the follow-up investigation of problem solving in physics introduced in chapter 7.

This work was carried out again with secondary school students (terminal mathematics class). A further test of measuring the working memory capacity was done to find out the role of this on student's performance in solving degree type of physics problems. This study was done at Lycée El-Moukrani I & II Ben-Aknoune in Algeria.

The results presented in chapter 7 give support for the validity of both hypotheses. In the first hypothesis, the students performed better in solving physics problems when these are given as "statement plus diagram" form. While in the second hypothesis, the students found the questions much easier when they are given either in the direct form but with one intermediate step given or in the structured form which had explicit steps.

8-2 Digit Span Test

The digit span backward test (DBT) was used to measure the students' working memory space (X-space). To allow the students to become familiar with this type of psychological test a digit forward test was administered to begin with, and only then was the DBT used. As a consequence the sample was classified as follows:

41 students had an X-space =7

32 students had an X-space =6

60 students had an X-space =5

8-3 **Sample**

During the first term in 1989 a total of 133 "terminal mathematics" students from a secondary school at Lycee El-Moukrani 1 & 2 , Ben-Aknon in Algeria participated in this investigation. The sample was divided into three random groups and each group was divided into three sub-groups according to the DBT.

A comparison could then be made between the whole sample and between the sub-groups, for different forms of the same physics problems.

Table 8-1. Timetable for testing the two hypotheses

Hypotheses	Problems	Groups of students		
		1	2	3
1	1	problem form A	problem form B	problem form C
	2	problem form B	problem form C	problem form A
	3	problem form C	problem form A	problem form B
2	1	question fOrm A	question form B	question form C
	2	question form B	question form C	question form A

In order to test each of the three forms of the same problem for both hypotheses, a timetable was drawn up to examine the hypotheses proposed, as shown in table 8-1.

Five problems in different areas of physics were chosen, as can be shown in Appendix 8-1-A and 8-1-B, and each problem was taken by the three separate groups of students.

8-4 Testing hypothesis one

For convenience hypothesis one will be restated:

The performance of students in solving a given problem should depend on the style of presentation. i.e whether the problem is presented in either:

(a) ***Form A*** the original statement form: or

(b) ***Form B*** the diagram form: or

(c) ***Form C*** the statement plus diagram form.

8-4-1 Analyses

Again the data were evaluated in three ways:

I. For the whole sample of students.

II. For each sub-group with different forms.

III. Within each of the three forms separately for each sub-groups of students.

Analysis I

The performance of the whole groups of students was noted for each form of the three problems. Table 8-2 shows the percentage mean scores for every problem. It is seen from these results that the students have a higher mean score in form C than in either form B or form A for all problems. It appears that the Algerian students were less familiar with the physics topic of problem 2 than their counter-parts in Glasgow University (see table 7-2). In problem 3 it is only when the problem is in form C that the students seems to have grasped the meaning and show a marked improvement. This result seems to be very surprising in view of the small changes in the questions. At present we can offer no explanation for this genuine result.

It was again decided to apply t-test (two tailed) to find out whether there is any significant differences in performance of students within these forms. As can be seen from table 8-3 that highly significant differences were found in performance of students between the form A and form C in all three problems. There was also a significant difference found in means of students between form B and C in the third problem, as was also found in the comparison of form A and form B in the second problem.

Table 8-2. Relation between problem forms and success (% score) of whole sample of students in solving different physics problems.

Problem form	% mean score on different problems			
	1	2	3	Average
A	40.5	9.0	17.8	22.4
B	51.7	19.0	16.1	28.9
C	62.7	22.6	64.3	48.9

Table 8-3. The significance of the difference in mean score (whole sample of students) between problem forms in solving different problems.

Problem	Problem forms		
	A and B	B and C	A and C
1	1.44	1.43	3.2**
2	2.40*	0.64	2.92**
3	0.21	6.45**	5.49**

* significant at 5 % level

** significant at 1 % level

Analysis II

Further comparisons were made to investigate whether the working memory capacity (X-space) influenced the students' performance within each problem form. The results are presented in tables 8-4 and as well as figures 8-1, 8-2 and 8-3. Because of the difficulty of assigning X-space parameters, the overall trend is not altogether

Table 8-4. Relation between groups of students and success (% score) of students in different forms of problem

Problem form	Groups	% mean score on different problems			
		1	2	3	Average
A	X=7	67.0	11.2	16.0	31.4
	X=6	22.8	10.0	26.0	19.6
	X=5	31.7	10.0	11.5	17.7
B	X=7	58.6	15.0	30.0	34.5
	X=6	58.5	32.2	10.0	33.6
	X=5	37.5	10.59	8.3	18.3
C	X=7	67.5	27.1	68.4	54.3
	X=6	81.1	25.7	66.6	57.8
	X=5	39.4	14,8	58.0	37.4

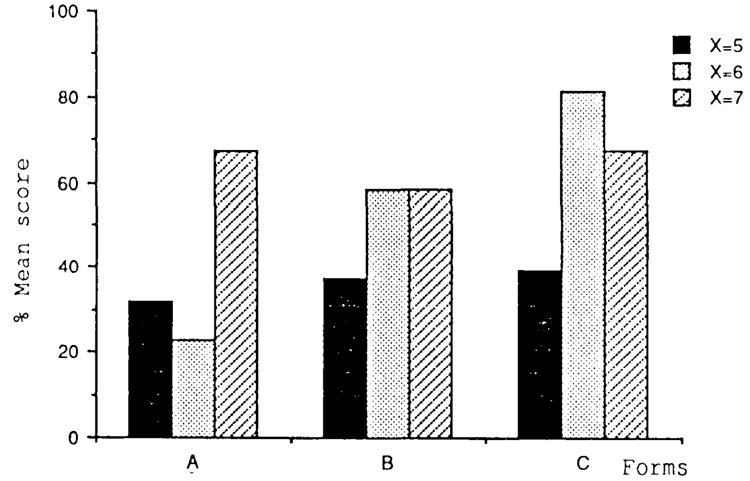


Figure 8-1. Comparison of the results between students' groups of different X-space for *problem* 1.

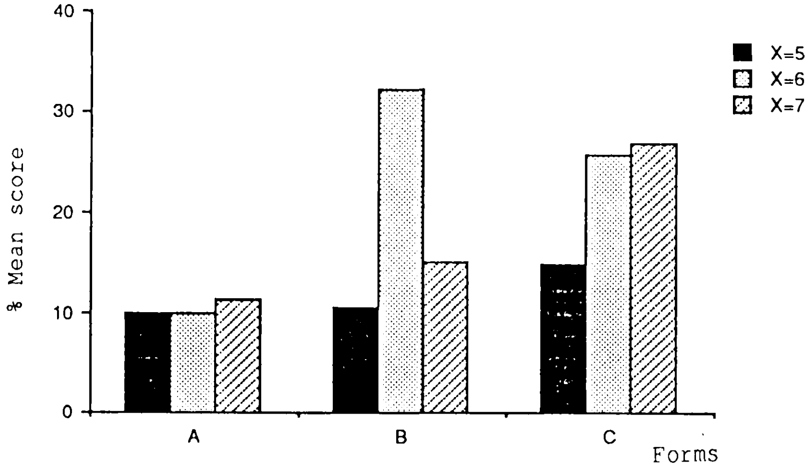


Figure 8-2. Comparison of the results between students' groups of different X-space for *problem 2*

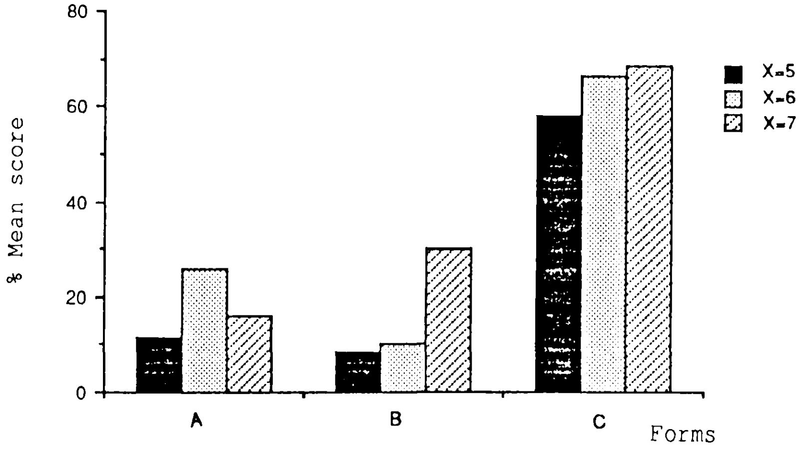


Figure 8-3. Comparison of the results between students' groups of different X-space for *problem 3*

Table 8-5. The significant differences in means between groups of X-space students for each problem form

Problem	Problem form	Groups of(X-space) students		
		X=7 & X=6	X=6 & X=5	X=7 & X=5
1	A	2.66*	0.8	2.31*
	B	0	1.41	1.56
	C	0.98	3.53**	2.01
2	A	0.18	0	0.29
	B	1.56	2.12	0.7
	C	0.1	1.1	1.18
3	A	0.51	1.15	0.27
	B	1.37	0.16	1.87
	C	0.15	0.62	0.64

* significant at 5 % level

** significant at 1 % level

clear from table 8-4 for all data, but it is seen that students with X = 7 always perform better than students with X = 5 (this is also found for hypothesis 2, as seen later in this chapter).

To investigate the effect of the students' X-space on their performance, the mean scores of all groups of students were compared for significant differences between means of the X-space groups in each problem form. Again t-test (two tailed) was used. The results are presented in table 8-5. Significant differences were found in means between X=7 and X=6, as well as between X=7 and X=5 in form A for the first problem., and in the same problem, in the form C a significant difference was found in means between the X=6 and X=5.

Analysis III

The data can also be analysed for each X-space group of students. The results shown in table 8-4 and as well as in figures 8-4, 8-5 and 8-6, indicate that, in general, all three groups of X-space students performed better when they attempted the problem in form C.

Once again t-test (two tailed) was applied to investigate the significance of the differences between the problem forms within each X-space group. The results, in table 8-6, indicate that at 5 % level there was a significant difference between form A and form C for X = 7 group in problem three. For X = 6 group, a significant differences were found between forms A and B in problem one, and also between forms A and C in problem three.

At 1 % level, for X = 6 group there were significant difference in mean scores between forms A and C in problem one, as well as between form B and form C in problem three. For X = 5 group a significant difference was found between forms B and C, and also between forms A and C in problem three,

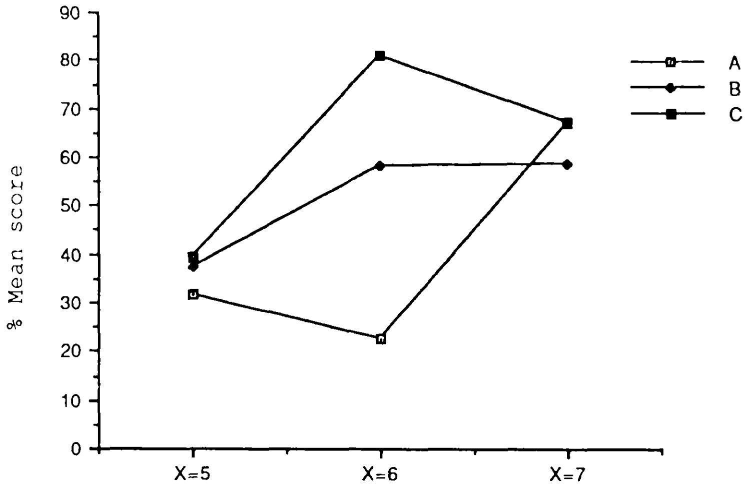


Figure 8-4. A comparison of the results between the three forms in *problem* 1

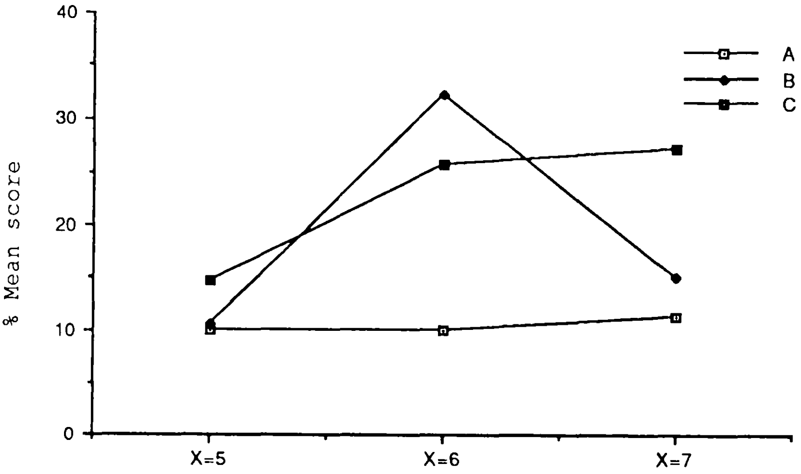


Figure 8-5. A comparison of the results between the three forms in *problem* 2

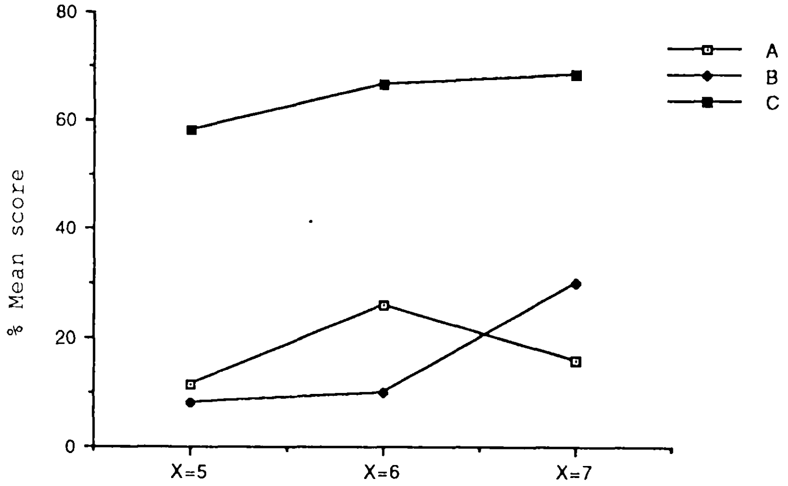


Figure 8-6. A comparison of the results between the three forms in *problem* 3

Table 8-6. The significance of the differences in mean scores between problem forms for each group of students.

Group	Problem	Problem forms		
		A and B	B and C	A and C
X=7	1	0.47	0.54	0.03
	2	0.53	1.04	1.55
	3	0.72	2.49	2.75*
X=6	1	2.32*	1.41	4.38**
	2	2.19	0.51	1.68
	3	1.06	4.84**	3.12*
X=5	1	0.56	0.18	0.83
	2	0.08	0.98	0.69
	3	0.47	3.82**	3.49**

* significant at 5 % level

** significant at 1 % level

8-4-2 **Conclusions**

This investigation was an effort to give us some insight into what variables might be important in solving physics problems. The results obtained here reinforce the findings of our previous study [see chapter 7].

In problem solving, one of the initial steps is to represent the problem in another form. This is adopted in the statement plus diagram form C. The results show that we can increase students' performance by such a method. Not only is the diagram useful as an alternative way of presenting data but it assists by giving a image of the physical situation. This way of presentation of the information to the students can reduce the load on the working memory space of students.

These results lead to the conclusion that we can increase students' performance in solving physics problems when the problem is given in a particular way i.e as a statement plus diagram. It should be noted that this has been shown to be true for X =5 students as well as students with high capacity. This part of the study indicates that the students' capacity is one of the most important factors which influences the ability of students to solve a problem.

8-5 **Testing hypothesis two**

The performance of students in solving a given problem should depend on the style of question. i.e whether the question is presented in either:

(a) ***Form A*** the direct traditional form; or

(b) ***Form B*** the direct form but with answer to an intermediate part of the problem given; or

(c) ***Form C*** the structured form with explicit steps.

It was interesting to test again the validity of the second hypothesis by similar analysis as before.

8-5-1 **Analyses**

Three comparisons were made to interpret the data obtained in this part of investigation:

I. The first analysis to establish whether there is a difference in performance of the whole sample of students between the three question forms of the same problem.

II. The second way was to examine performance of students as a function of their capacity (X-space) for each question form.

III. Finally to find out whether there were any differences in mean scores in these question forms for each group of different X-space students.

Analysis I

The first investigation was to find out if there is any difference in percentage of mean scores between the question forms for the whole sample of students. The results of these comparisons are shown in table 8-7 and indicate that, in the question form C, the students performed better than in the form B, and they did least well in the form A. There is a pattern in these two results (table 8-7) showing form C as the one giving the best performance. However, there is a difference in the intrinsic difficulty of these two problems. The topic in the second problem involves frictional forces, an area which many students find difficult. It is impossible to make any conclusive statement of why this difference should be so.

Table 8-7. Relation between question forms and success (% score) of *whole sample of students* in solving different physics problems

Question form	% mean score on different problems		
	1	2	Average
A	64.8	25.4	45.1
B	79.6	26.5	53.1
C	88.2	42.2	65.2

Table 8-8. The significance of the difference in means (whole sample of students) between question forms for both problems

Problem	Question forms		
	A and B	B and C	A and C
1	2.27* 1	1.98	5.59**
2	0.44	3.4**	3.75**

* significant at 5 % level

** significant at 1 % level

A t-test (two tailed) was applied to all possible differences in responses between these forms of the same problem. These results are presented in table 8-8. As can be seen, a high significant differences in means were found between the form A and form C for both problems, and similar results were obtained for B and C for problem two, and A and B for problem one.

Analysis II

Another comparison was made to find out the effect of question form on student's ability for each X-space group of students for both problems. The results are summarised in table 8-9 which shows that generally the students performed better in the form C than in the form B and they showed the poorest performance in the form A for each X-space group of students on both problems. It is important to note that the students with lowest X-space showed the greatest improvement when the question was in the form C. From a study of their attempts to solve the problems, it could be argued that students with the low capacity could not find a way that led to a solution of the question in form A, and they lacked a strategy to break down the whole problem into small parts. In the form A, there are more stages, hence this needs more working memory space. When the problem was given in either form B or form C there are fewer thinking stages in order to find the correct answer. In form C of both questions the differences in performance between capacity groups almost disappears. It could be that this form is not being affected by psychological factors to the same extend as in 2 A and 1 and 2 B because the demand has now come within the capacity of all students. We cannot however, offer similar explanation for the small range in 1 A.

Table 8-9. Relation between students' groups of different X-space and success (% score) of students in the different forms

Question form	Groups	% mean score on different problems		
		1	2	Average
A	X=7	65.0	26.9	46.0
	X=6	67.5	33.3	50.4
	X=5	61.0	13.3	37.2
B	X=7	93.8	38.1	65.9
	X=6	75.0	21.4	48.2
	X=5	70.0	14.6	42.4
C	X=7	92.5	40.0	66.6
	X=6	90.4	45.0	67.7
	X=5	83.0	41.6	62.3

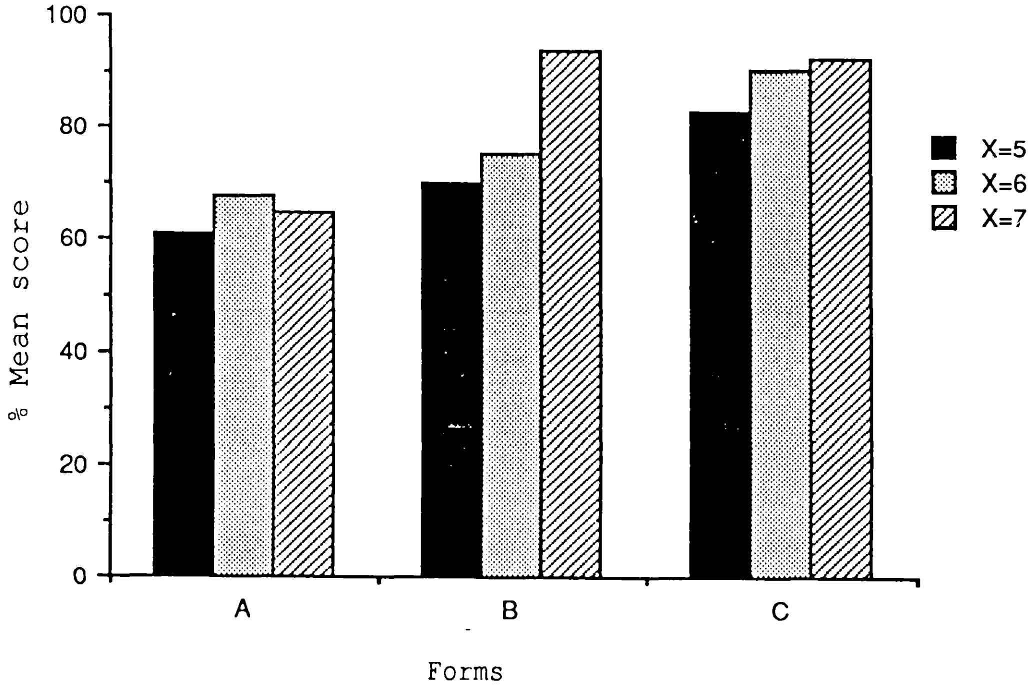


Figure 8-7. Comparison of results between question forms for *problem 1*

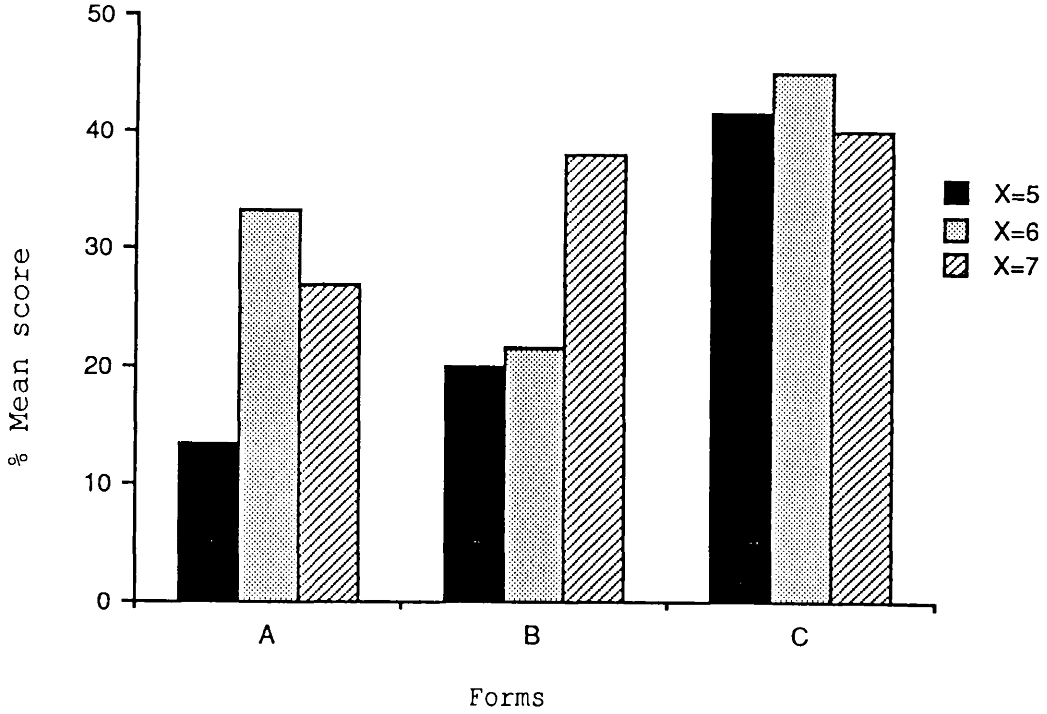


Figure 8-9. Comparison of results between question forms for *problem* 2

Again it was decided to apply t-test (two tailed) to find the significance of the differences between the means of the question forms in each X-space group. The results are shown in table 8-10. It can be seen from this table that for form B, there were significant differences in mean scores between X=7 and X=5 for both problems. While in the form A, there was only one significant difference found in performance between X=6 and X=5 in problem two.

Table 8-10. The significance of the difference in mean scores between groups of X-space students for each question form.

Problem	Question form	Groups of students		
		X=7 & X=6	X=6 & X=5	X=7 & X=5
1	A	0.19	0.54	0.34
	B	1.82	0.44	2.61*
	C	0.50	1.29	1.69
2	A	0.84	2.89*	2.036
	B	2.012	0.33	2.26*
	C	0.52	0.36	0.19

* significant at 5 % level

Analysis III

In order to find the effect of students' working memory capacity on their ability to solve different physics problems, a comparison was made between the three groups of students with different X-space, for each question form for both problems. The results of this comparison appear in table 8-9 and as well as in figures 8-7 and 8-8. It can be seen from these results that the mean score of the X=7 group is higher than that of X =5 students (with one exception, for X = 7 in the form C problem 2).

Once again, a t-test was used to find out the significance of differences between the mean scores within each question form.

These results are given in table 8-11, which indicate that for

Table 8-11. The significance of the difference between the question forms for each group of X-space students

Group	Problem	Question forms		
		A and B	B and C	A and C
X=7	1	2.91*	0.23	3.01**
	2	1.24	0.20	1.63
X=6	1	0.57	1.15	2.36*
	2	1.75	2.81*	1.27
X=5	1	0.82	1.41	2.44*
	2	0.23	3.89**	3.98**

* significant at 5 % level

** significant at 1 % level

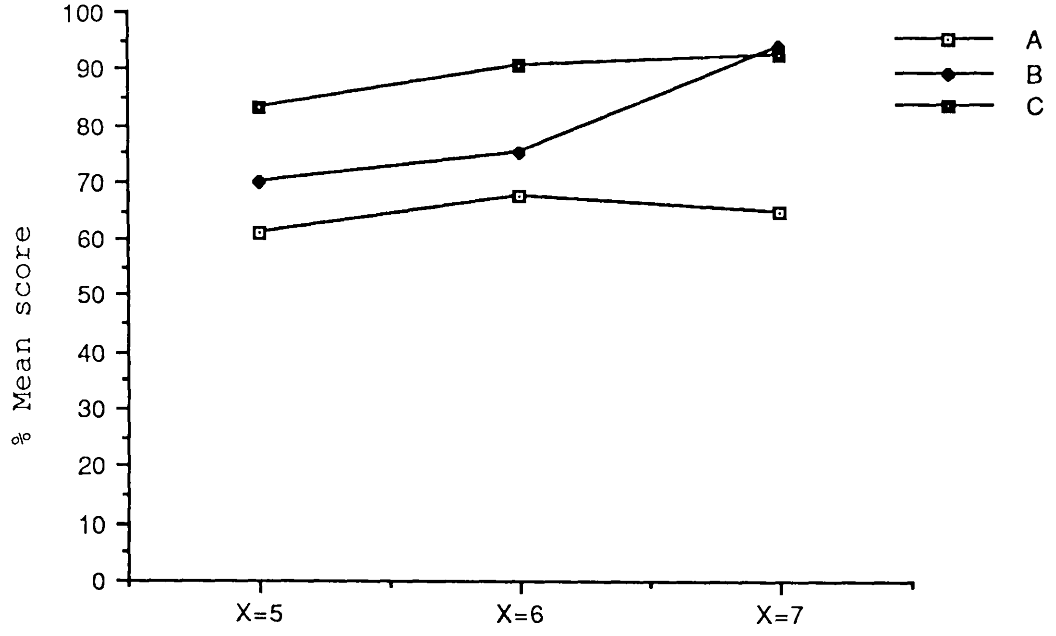


Figure 8-9. A comparison of the results between the three forms in *problem* 1

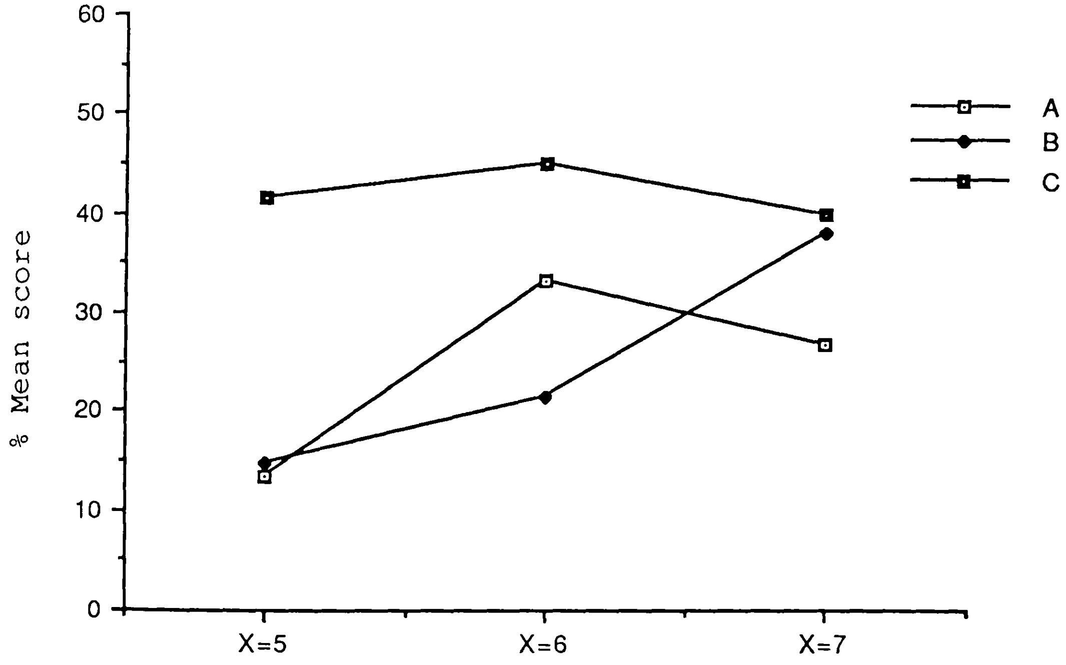


Figure 8-10. A comparison of the results between the three forms in *problem 2*

X = 7 group, in problem 1, there are significant differences in means found between forms A and B, as well as between forms A and C. For X = 6 group, there are significant differences in responses between forms A and C in problem 1, as well as between forms B and C in problem 2. Whereas for X = 5 group, there are significant differences found between form A and form C in problem 1, and also between forms B and C, and forms A and C in problem 2.

8-5-2 **Conclusions**

The performance of students in solving different question forms and their expressed confidence level present evidence for the support of the second hypothesis.

1. There is strong evidence that the form of the question affects the student's performance in general. Significant differences in students' responses were found between the three question forms; in the form C the students performed best, form B second and form A least well.

2. Again there is clear evidence to indicate that students' working memory space is an important factor which has great influence on their ability to solve a physics problem. Generally the X=7 students performed better than X=5 students. Again there was a large improvement in the performance of X =5 students is going from form A to C.

3. Students can more easily and more confidently see a clear way to reach the solution when they are asked a question in form C. Whereas in form A they do not have a clear grasp of the question. This form seems to cause overload to students. The explicit steps can allow students to find a way to devise a plan. By giving a question in an effective way, as style C, the difficulty can be reduced and the students use fewer thinking stages.

Chapter nine

Conclusions and Discussion

9-1 **Class examination**

The findings support the following conclusions:

1. There is clear evidence to indicate that the demand of the question can affect the performance of students.

In support of this we wish to bring together the evidence found for the relationship of F.V against Z in physics examination questions - as in the summary figures 3-21 (Glasgow data) and figure 4-20 (Algerian data).

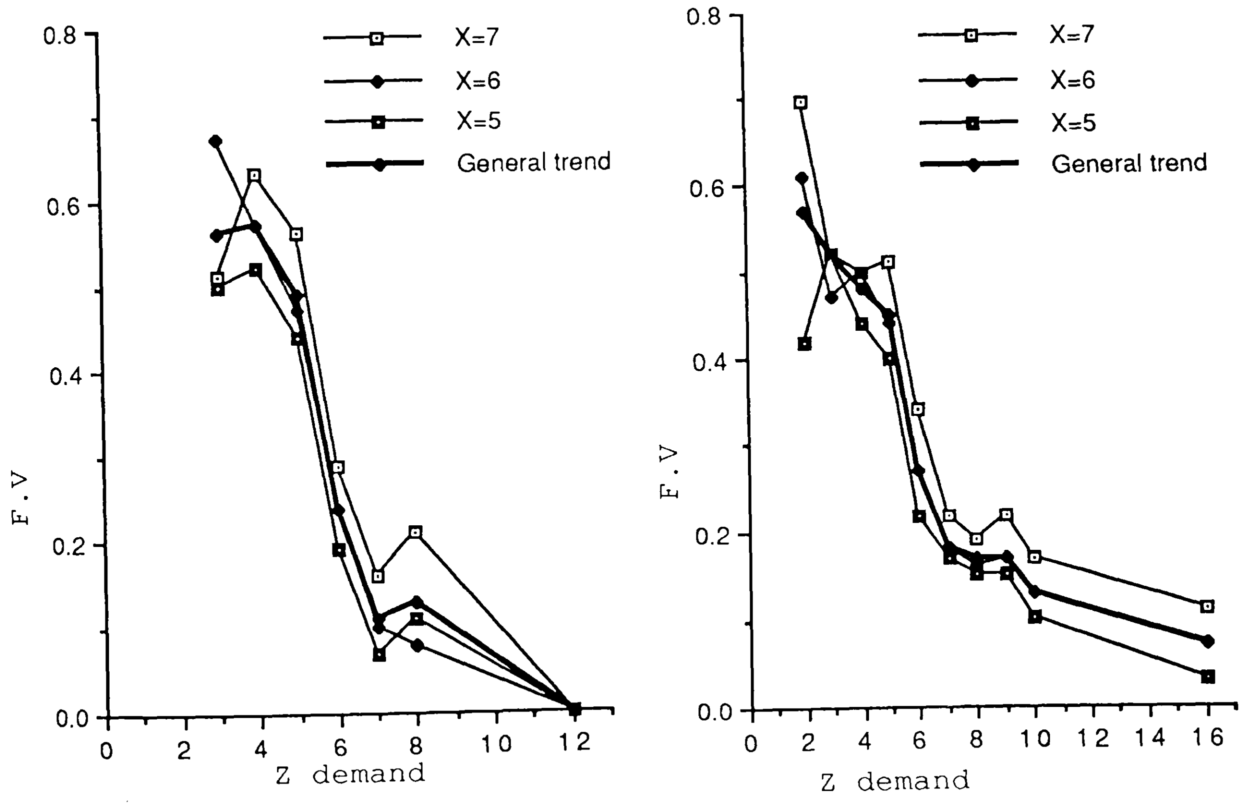


Figure 3-21

Figure 4-20

Comparison of the performance (F.V) for all different X-space students plus general trends.

When compared with the results from chemistry questions[85] (figure 2-5, page 40), it is seen that a similar pattern is exhibited.

(a) The students who have a large X-space in general obtained better results than those with small X-space.

(b) The students' performance was found to decrease as the demand of the problem increased with a sharp fall in the Z = 5/6/7 region.

(c) When the Z-demand of the question is small (from 2 to 4) the X-space value did not enable us to predict reliably any differences in performance of students in solving physics problems, but with high Z-demand discrimination appeared in student problem solving ability. Presumably at low values of Z the tasks were within the X value of all.

2. The Field Dependence/Field Independence factor was found to play an important role in the students' success; Field Independent students achieved higher scores than those who were Field Dependent.

(a) Within each group of students who have the same degree of disembedding skill (FD/FI) the performance decreased as the demand of question increased for each X-space group particularly beyond $Z \geq 5$.

(b) For a given X-space, field independent students generally performed better that field dependent students.

(c) For a given group of FD or FI students, X =7 students perform better than X =5, in most cases.

(d) It is seen that the greatest increase in performance occurs in going from FD, X= 5 to FI, X= 7 groups of students in all activities (e.g Problem solving) investigated.

(e) It is seen that FD, X= 7 students perform nearly the same as FI, X= 5 students. This might suggest that irrelevant material has taken up a significant portion of the working memory of FD students.

3. Literature suggests that the higher the X value for a student, the more likely he is to be FI (AL-Naeme[48]). This is to

some extent supported in this research, for example (Table 3-7).

9-2 **Problem solving in tutorials**

The results obtained present evidence which helps to explain some of the difficulties met by students in problem solving. These results led to the conclusion that we *can* increase student's performance by taking account of psychological factors. This depends on the form of the problem statement(or the question) presented to the students. In the Glasgow sample, performance as a function of disembedding ability was investigated, while in the Algerian sample, it was X-space that was studied. We can make the following overall conclusions:

1. The information in the problem can be presented in an effective way (e.g diagram plus statement) to reduce overload on the working memory of students. This could be related to a temporary visual store (Baddeley[67]). It might also suggest that a picture is a chunking device.

It is also likely that the diagram helps students to understand the physical situation referred to in the problem and hence they can visualize the description in the statement. This could explain why the students found it much easier when the problem was given to them in the form C than in the other forms.

2. There is evidence that the form of the questions affects the student's performance in general. In the questions of form C the students performed best; the form B second and form A least well. Breaking the question into the explicit steps or reducing the number of unknown variables should allow students to find a way of devising a plan and they should use fewer thinking stages in the process.

3. It is possible to reduce the difficulty (demand) of the problem without changing its logical structure, thereby the students can gain more success. In other words it is possible to test the

same physics with less interference from psychological factors.

4. There is clear evidence to show that the predictor factors (i.e X-space and FD/FI) are important and have an influence on students' ability to solve problems in different forms.

Our study showed that it is possible to increase the performance of students with low disembedding ability when they were given the problem in an "effective way" (i.e statement involving a diagram or given explicit steps as in the question form C). We were in fact disembedding and chunking for them.

9-3 **Practical work**

The results obtained in this part of this study give some insight into several variables which are essential for success in practical work.

1. It is important to break down the experimental instruction into several parts, and within each part divide them into procedure and analysis, with explicit steps. This could decrease the number of thinking stages and the load to be processed at any one time. An important factor which caused an increase in the effectiveness of introductory practical work was the reduction in potential overload arising from the improvement of the content and presentation of the laboratory manual, as well as a reduction in the amount of work expected from the students in a typical laboratory period.

2. From demonstrators opinions, the practical work was satisfactorily organized, and the equipment and management were good. Therefore these probably did not contribute to the overload situation.

3. Most students showed an improvement in their understanding of the background theory relevant to the experiment and there was some indication that their overall theory was also improved by giving them the new version of the laboratory manual.

4. By applying the guidelines proposed in chapter 5 (page 167-168) the difficulties met by students during the practical work in physics in general can be reduced.

9-4 Suggestions from this research and from the literature for the teaching and learning of physics

9-4-1 Problem solving

It is important that teachers are aware of the important strategies required to avoid working memory overload in their students by decreasing the Z-demand of a problem without changing its physics content. It is possible to increase the success of students by adding diagrams to the statement, by giving explicit steps or by reducing the number of unknown variables required for processing.

To increase the problem solving abilities of our students and to improve the teaching and learning of this activity, it is suggested that the following steps should be considered:

(a) Students should be taught how to sequence and to select only relevant and to ignore irrelevant information.

(b) Teachers must be informed that there is a limitation to students' working memory space, and that it is necessary to keep the Z-demand of the question below the X-space ($X > Z$) during the early learning stages. As students knowledge and confidence grows they should be able(by chunking) to reduce problems for themselves to keep $Z < X$.

(c) Another way by which teachers can reduce the load is by adding diagrams or graphs to the statement, since these may be an aid for the solver in chunking information or in putting information temporarily into a visual store.

(d) The teacher could assess the tasks involved before giving a problem to their students by asking themselves:

(i) What information should be recalled from long term memory (prior knowledge)?

(ii) What information is provided in the task?

(iii) What processes are necessary for putting these things together?.[99]

All of these demand components which are in the teacher's control and should be balanced in such a way as to avoid overload.

(e). We believe that students can become better problem solvers if teachers were to help students by teaching them explicit strategies; thereby students would build up experience to tackle difficult physics problems. It is worthwhile to make students aware of how often these strategies can help them to develop their ability and encourage them to think more carefully about the physical situation to which a problem refers. This will not necessarily remove all the difficulties, but will go some way towards easing the problem.

9-4-2 **Practical work**

The following suggestions are offered:

(a) The students should be encouraged to prepare the work before coming to the laboratory. This could take the form of a prescribed exercise in which the student has some hand in the design. (Letton[88])

(b) The lecture instruction of the topic should precede its application in practical work (Letton[88]).

(c) The experimental instruction, and procedure should be broken down into small manageable parts.

(d) Unnecessary information (noise) should be removed from the experimental instruction and thereby reduce the potential information overload on the students. "Noise" may not be evident to the teacher, who is familiar with the equipment. The manual may have to be "shredded" with the help of students.

(e) A clear statement of the background physics should be made in the notes, (perhaps in an Appendix if it is particularly mathematical, in which case, reference should be made to this in the main section of the notes).

(f) Clear diagrams should be added where necessary in the experimental notes. This helps students to grasp the physical situation and visualize the description stated in the experimental instruction.

(g) The objective of the experiment should be clearly identified and the main steps necessary in the procedure should be defined, possibly as an outline map or flow chart (Letton[88]).

(h) Manipulative skills should be mastered at the start of experimental work if students are faced with unfamiliar equipment. This then eases the burden on working memory, leaving space for thought and planing later.

(i) Sufficient time should be allowed for the average students to carry out the work (Wham[89]).

(j) Written material and the instructions for a given experiment should be presented in such a way that relevant information from previous knowledge is grouped together, and students should be strongly encouraged to read such material before attempting the experiment. In this way relevant linking material can be activated in working memory in readiness for connection with new input from the experiment (Ausubel[21]).

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Appendix 3-1

Digits Backward Test (DBT)

Directions- Start by saying:

Now I'm going to give another set of number, but this time there's a complication. When I have finished saying each set of number, I want you write them down in reverse order. For example, if I say, "719", you would write down "917".

Now, no cheating. Do not write from right to left. You listen carefully, turn the number over in your mind and write from left to right. Have you got that? Then let's began.

SERIES:

2	2 4
	5 8
3	6 2 9
	4 1 5
4	3 2 7 9
	4 9 6 8
5	1 5 2 8 6
	6 1 8 4 3
6	5 3 9 4 1 8
	7 2 4 8 5 6
7	8 1 2 9 3 6 5
	4 7 3 9 1 2 8
8	9 4 3 7 6 2 5 8
	7 2 8 1 9 6 5 3

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Appendix 3-2

NAME:.......................................SEX:......
(capital letters)

Matriculation No.

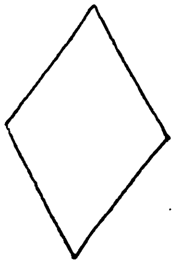
This is a test of your ability to find a simple shape when it is hidden within a complex pattern.

The results will not affect your University work in any way.

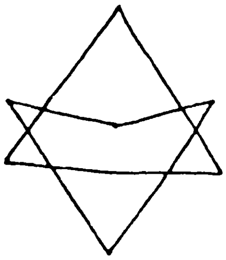
EXAMPLE (1)

Here is a simple shape which we have labelled (X):

(X)



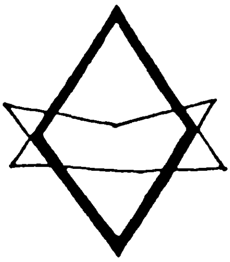
This simple shape is hidden within the more complex figure below:



Try to find the simple shape in the complex figure and trace it in pen directly over the lines of the complex figure. It is **the same size**, in **the same proportions**, and **faces** in the same direction within the complex figures as when it appeared alone.

(When you finish, turn the page to check your answer.)

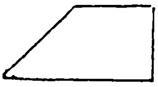
The answer is:

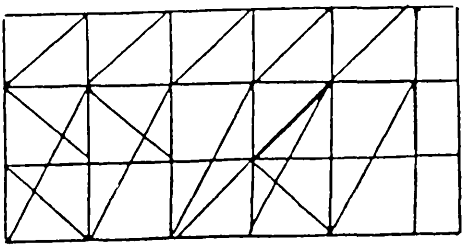


EXAMPLE (2)

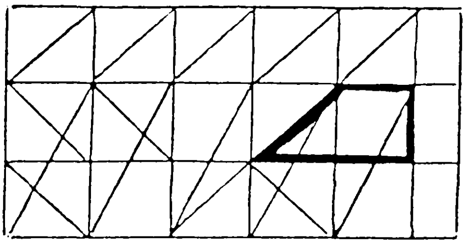
Find and trace the simple shape (Y) in the complex figure beside it.

(Y)

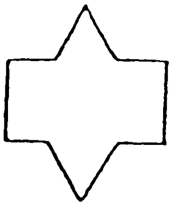




The answer is:

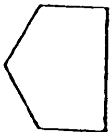


SIMPLE FORMS

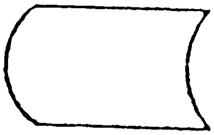


A

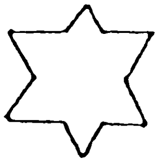
B



C



D



E

G

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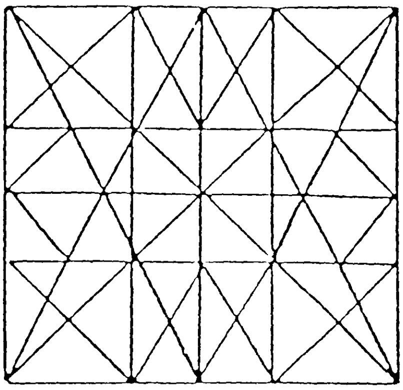

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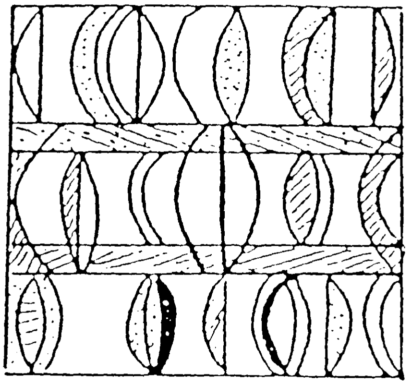

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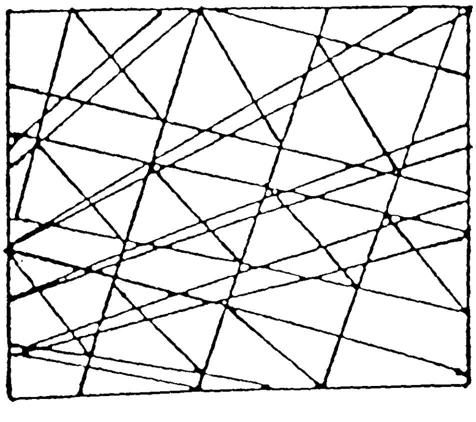

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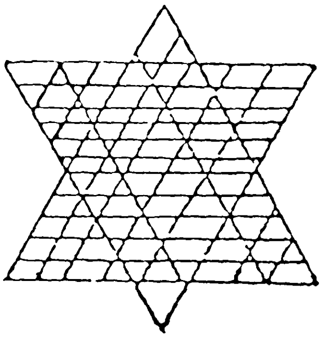

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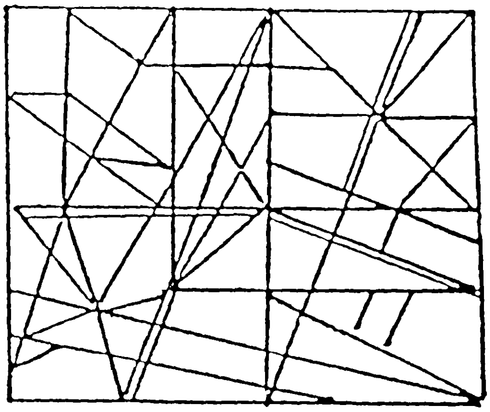

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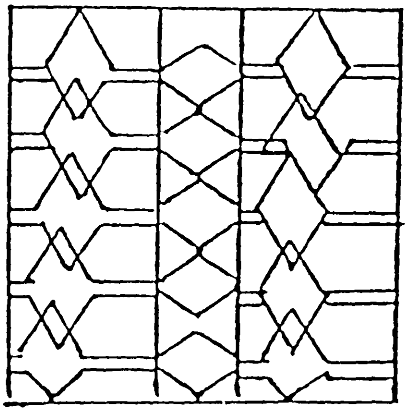

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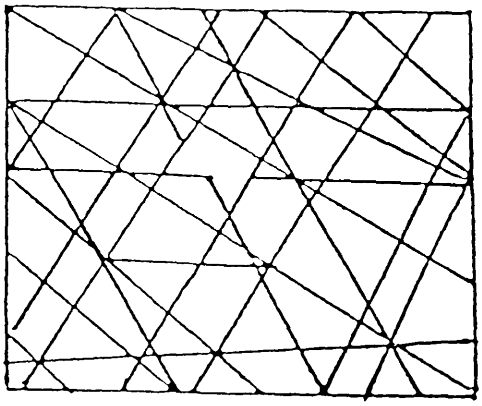

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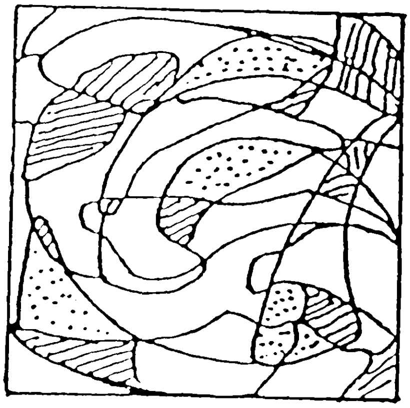

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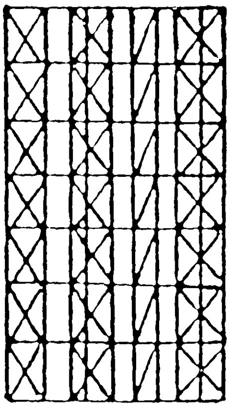

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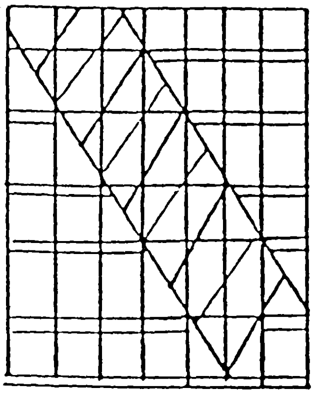

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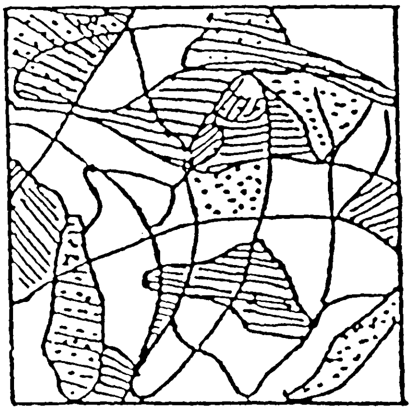

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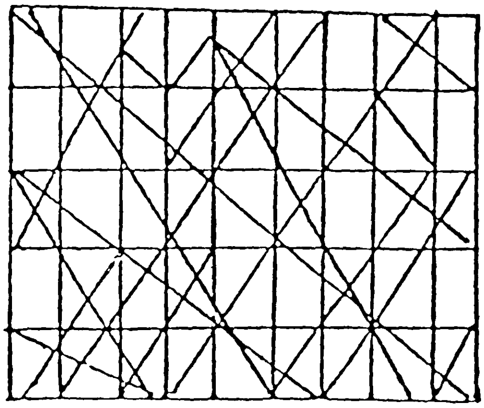

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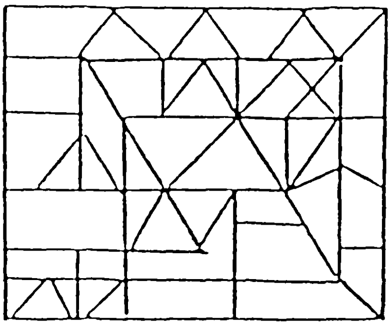

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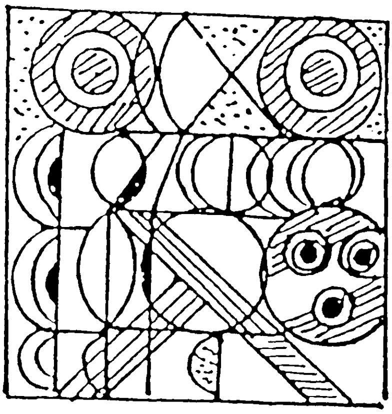

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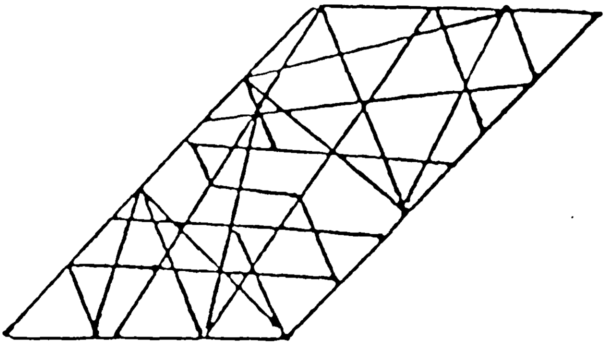

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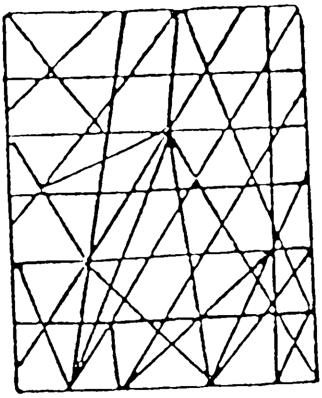

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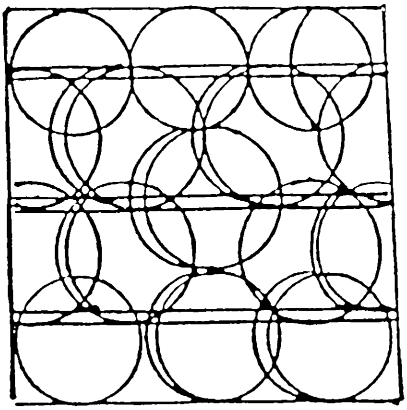

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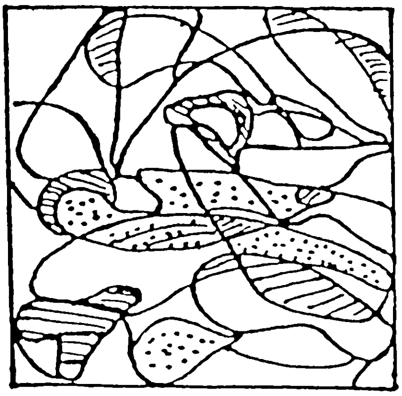


Appendix 3-3.

Problem 1: A sprinter runs 100 m in 10 s. He starts from rest, runs with uniform acceleration, reaches full speed after 10 m and then maintains that speed. Calculate the value of his acceleration.

Z=6 steps

Problem 2:

(a) Show from first principles that the horizontal range of a body projected with speed v at angle ß to the horizontal is given by

$$R = \frac{V^2 \sin 2ß}{g}$$

Z= 5 steps

(b) A footballer kicks a ball and it lands 40 m away. If the ball was projected at an angle of 30° to the horizontal what was its initial speed?

Z=3 steps

Problem 3: A particle, moving with simple harmonic motion, takes 1.0 s to travel from a extremity Q of its path to the point P half way between Q and its mean position. Its speed at P is 0.54 ms^{-1}. What is its amplitude?.

Z=7 steps

Problem 4 : A long light string passes over a smooth light pulley. To one end of the string is attached a mass of 1.5 kg, and to the other end two masses of 1.9 kg each. The system is released from rest. After 5.0 s one of the 1.0 kg masses becomes detached from the string. Calculate the further time which elapses before the system comes instantaneously to rest.

Z-6 steps

Problem 5: (a) A lorry of mass 5000kg skids on an icy road and strikes a stationary at 15 km per hour. The mass of the car is 1000 kg. State the circumstance in which the car moves off with minimum possible velocity after impact, and calculate this velocity.

Z=3 steps

(b) A cyclist and her bicycle together have a mass of 100 kg. When the cyclist travels on the level the force resisting the motion is 20 N. If the cyclist works at 200 W what is the acceleration when her velocity is 8.0 ms^{-1} on the level?.

Z=5 steps

Problem 6 :A spherical concave mirror has a radius of curvature of 0.30 m. A real object is placed 0.10 m from the mirror. Find the magnification.

Z=4 steps

Problem 7: Diamond has an index of refraction of 2.42. What the smallest angle that a ray of light inside a diamond can make with the surface and still pass from the interior to air?

Z=3 steps

Problem 8: A compound microscope has an eyepiece with a focal length of 0.05 m. The spacing of the lenses is 0.25 m, and the final virtual image is formed at 0.30 m from the eyepiece. If the original object distance to the objective is 0.05 m, calculate the overall magnification.

Z=6 steps

Problem 9: Show that in a Young's double slit experiment the distance from the central fringe to the m th bright fringe is

$$Y_m = \frac{m D}{d}$$

Where d is the slit separation, D is the slit to screen distance, and λ is the wavelength of light.

Light containing two wavelengths of 567 nm and 486 nm illuminates such a double slit arrangement in which d=1.50 m. At what distance from the central bright fringes on the screen will a bright fringes from one interference pattern first coincide with a bright fringe from the other?

Z=6 steps

Problem 10: A brass wire AB, 2.0 m long, and a steel wire BC, also 2.0 m long, are jointed in series. A is fixed to a rigid support and the wire hangs vertically. The diameter of each wire is 0.7 mm. A mass of 4.0 kg is attached to C. Calculate the energy stored in the system. For brass Young's modulus = 11 x 10^{10} P_a

For steel Young's modulus = 22 x 10^{10} P_a

Z=7 steps

Appendix 3-4

Problem 1: (a) There stationary point charges -2μC, +3μC are situated at the corners, S and T respectively of an equilateral triangle of side 0.6 m. A fourth charge of +6μC is placed at the midpoint of side ST.

(a) Calculate the magnitude and direction of the force on the +6μC charge.

Z=5 steps

(b) What is the electric field E at the midpoint of ST due to the charge at R, S and T?

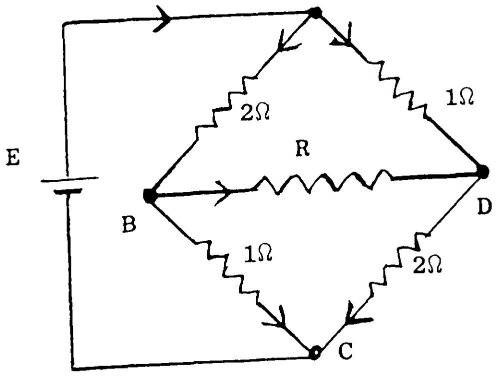
Z=6 steps

Problem 2: A parallel plate capacitor stores 125 J of electrical energy when charged to 5000 volts. It is filled with oil of dielectric constant 2.5. If the electric field between the plates must not exceed 10^7 V m^{-1}, calculate the minimum plate area required.

Z-6 steps

Problem 3: Calculate the value of R to be inserted in the network shown so that 1/4 of the current from the battery will pass through R.

Z-12 steps



Problem 4: Electrons and protons are injected perpendicularly into a uniform magnetic field with equal (non-relativistic) velocitie' s kinesics. In terms of the masses of the electron, m_e, and the proton, m_p, calculate the ration of the periods of their orbits T_e/T_p

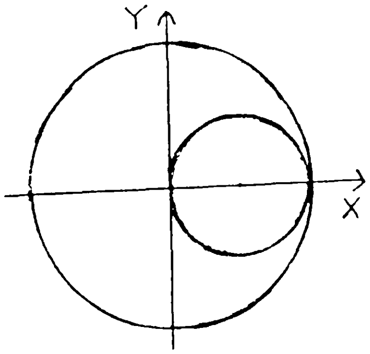
$m_e/m_p = 5.45 \times 10^{-4}$

Z=8 steps

Problem 5: A 1 mV rms signal is generated by a source whose output resistance if 100 Ω. This signal is fed into an amplifier of input resistance 900 Ω and output resistance 20 Ω. If the open circuit voltage amplification factor is 1000, calculate the power dissipated in a load resistance of 180 Ω.

Z=6 steps

Problem 6B: A uniform circular disk of radius R has a circular hole cut from it, as shown the diameter of the hole is R. Calculate the position of the center of mass of the remainder.



Z=6 steps

Problem 7 A uniform ladder of length 3.25 m rests at an angle ß with the horizontal against a smooth vertical wall. (a) What is the minimum value of ß possible if the coefficient of static friction between the ladder and the ground is 0.30?

Z=5 steps

(b) The base of the ladder is now moved so that it is 1.25 m from the wall. How far up the ladder can a man, whose mass is four times that of the ladder, climb before the ladder begins to slip?

Z=7 steps

Problem 8 :A uniform circular disk of radius 0.20 m and mass 2.5 kg is mounted on a horizontal axle supported by bearings considered frictionless. A light inelastic cord is warped around the rim of the disk.

(a) A steady vertically downward pull of 5 N is exerted on cord. Calculate the angular acceleration of the disk.

Z=3 steps

(b) If now instead of exerting a pull on the cord a mass of weight 5 N is suspended from the free end of the cord. Calculate the tension in the cord.

Z=7 steps

Appendix 3-5

The distribution of F.V , M.S and Z demand for each question

March examination

	Q1-a	Q1-b	Q2-b	Q-3	Q-4	Q-5	Q-6	Q7-a	Q7-b	Q8-a	Q8-b
% F.V	68	24	20	0	13	14	37	20	10	63	10
Mean score	4.3	2.8	3.8	2.0	3.1	3.1	3.2	2.1	2.4	2.2	2.1
% M.S	86	56	63	21	39	39	53	42	34	73	42
Max mark	5	5	6	10	8	8	6	5	7	3	7
Z-demand	5	6	6	12	8	6	6	5	7	3	7

Appendix 4-1

FIGURE INTERSECTION TEST

NAME: SEX:

School: CLASS:

This a test of your ability to find the overlap of a number of simple shapes.

There are tow sets of simple geometric shapes, one on the right and the other on the left. The set on the left contains the same shapes (as on the right) but overlapping, so that there exists a common area which is inside all of the shapes.

Look for and ***shape*** in the common ***area of overlap***.

Note these points:

(1) The shapes on the left may differ in size or position from those on the right, *but*, they match in ***shape*** and ***proportions***.

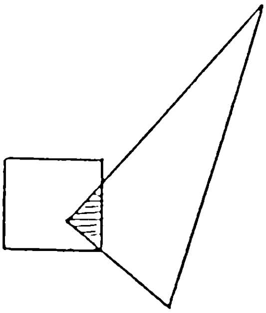
(2) In some items on the left some extra shapes appear which are not present in the right hand set, and which do not form a common area of intersection with all of the other shapes. These are present to mislead you but to ignore them.

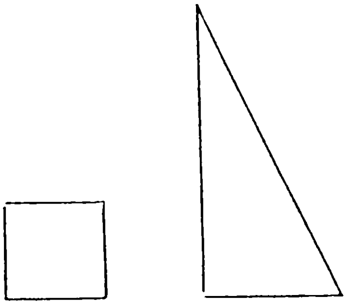
(3) The overlap should be shaded clearly by using a pen.

(4) The results of this test will not affect your schoolwork (University work) in any way.

Here are some example to get you started.

EXAMPLE (1):





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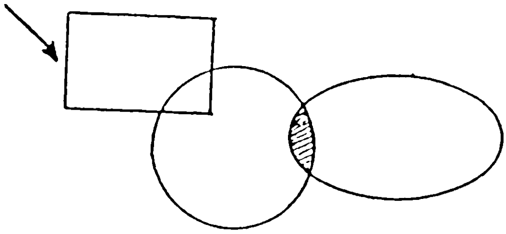
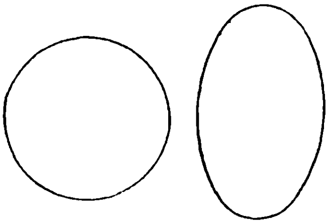


irrelevant shape
put in to confuse
you



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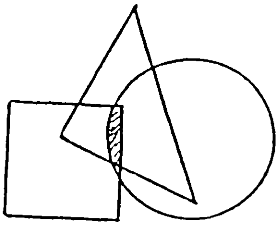
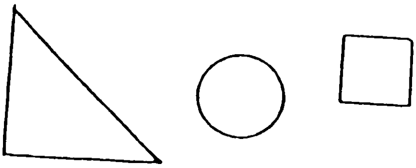
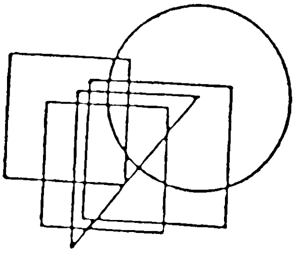
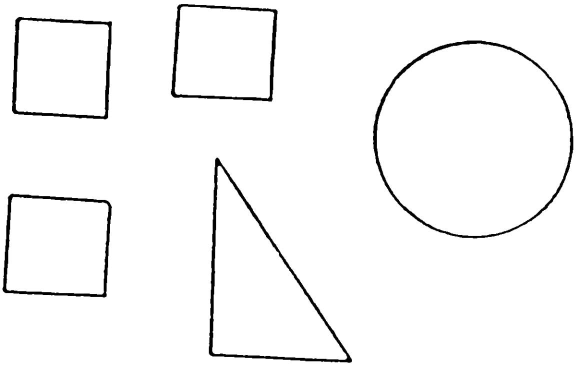
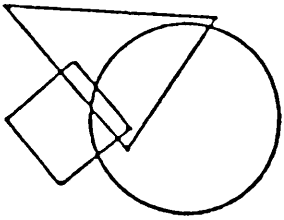


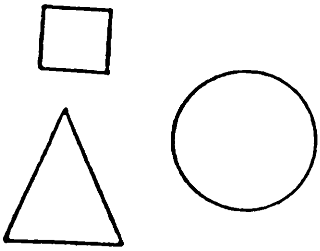


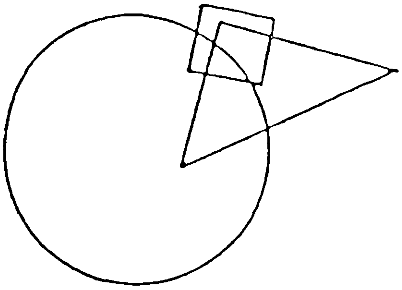
Now attempt each of the items on the following sheets:

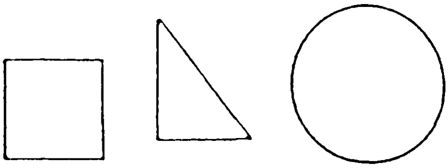


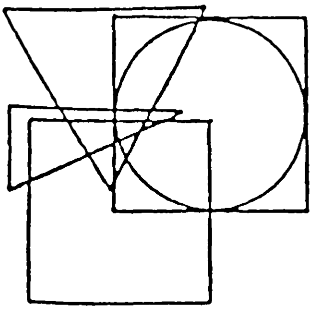


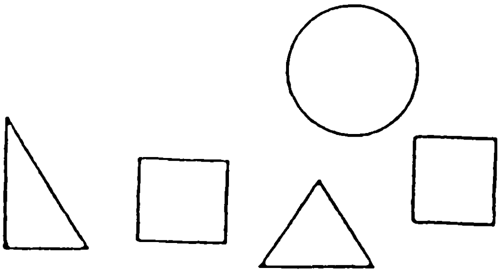


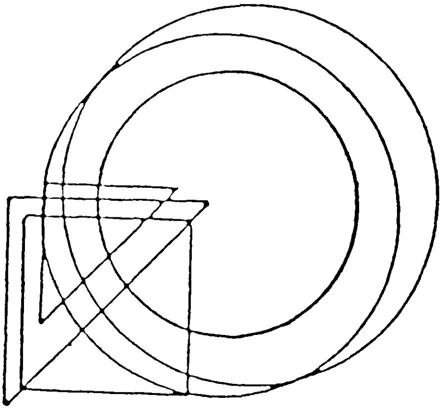


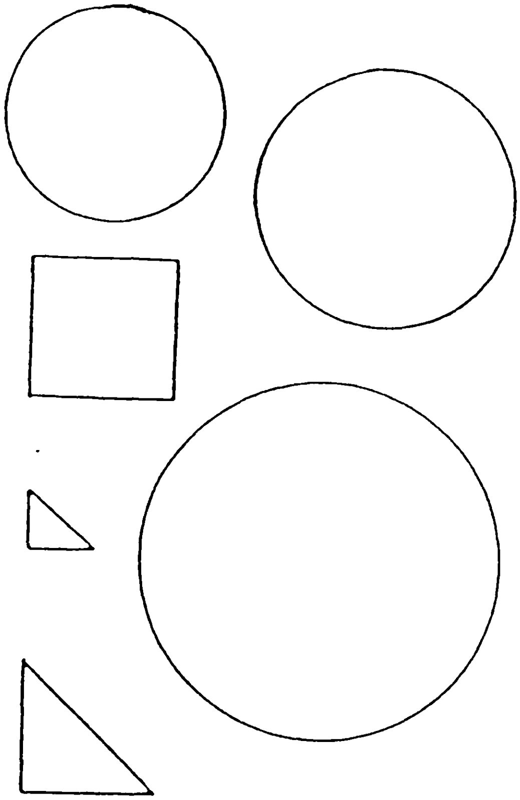


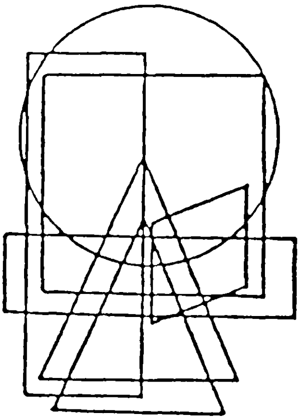


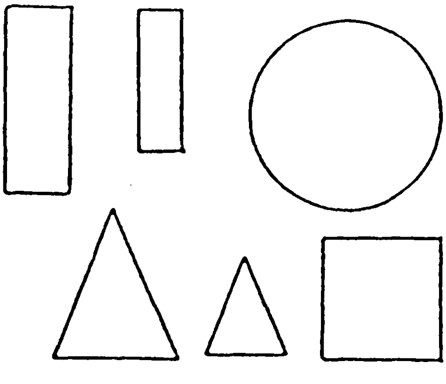


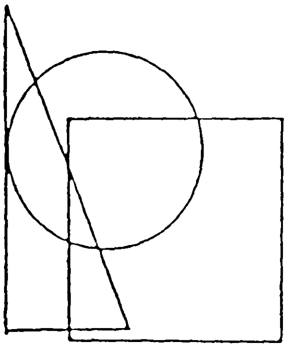


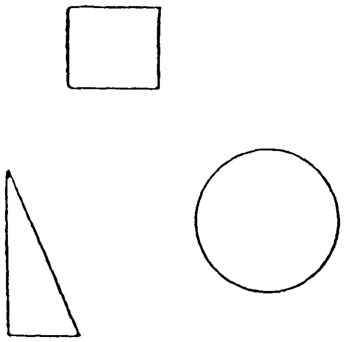


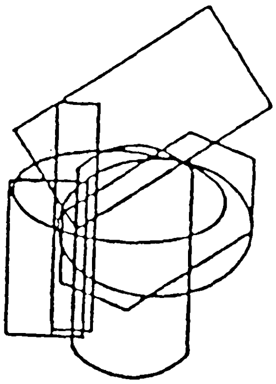


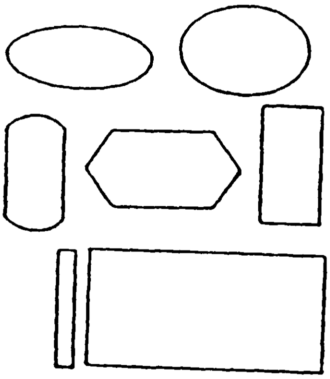


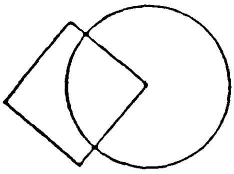


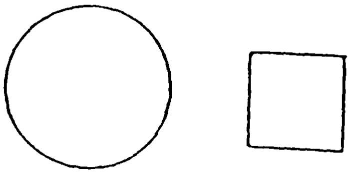


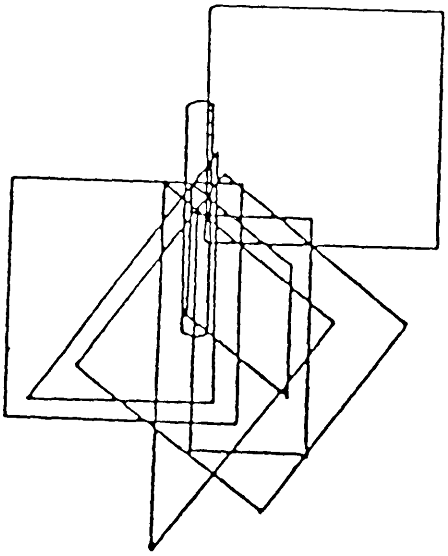


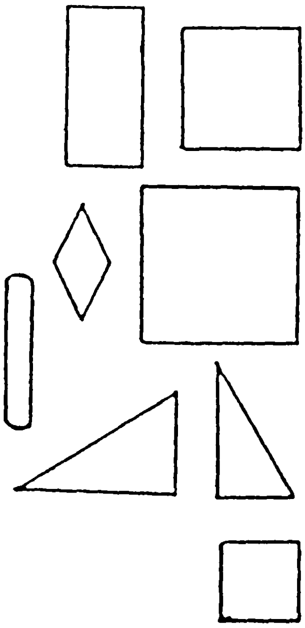


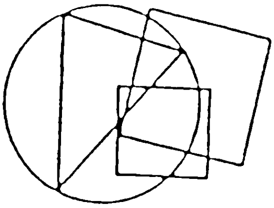


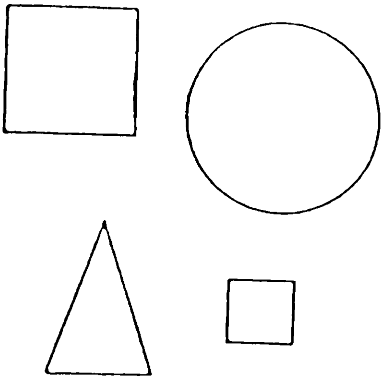


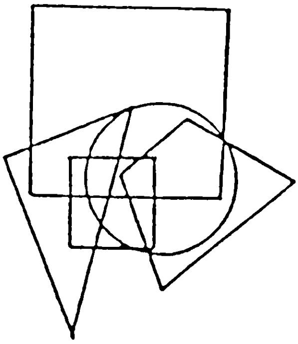


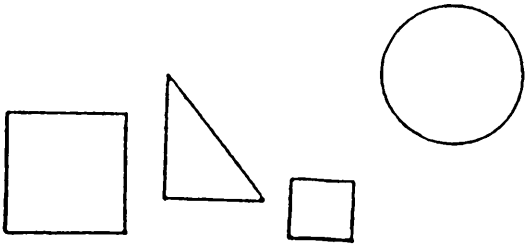


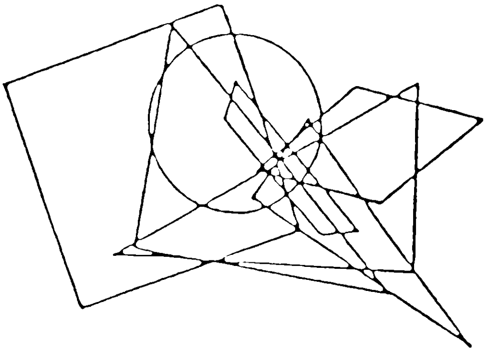


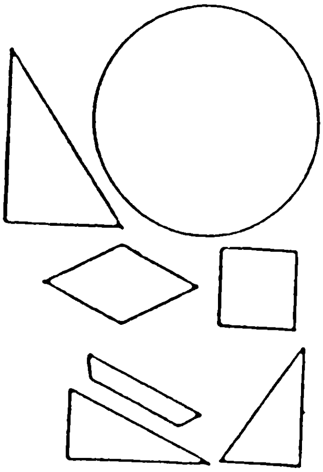


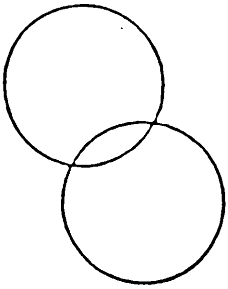


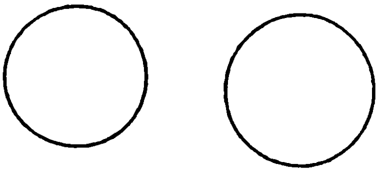


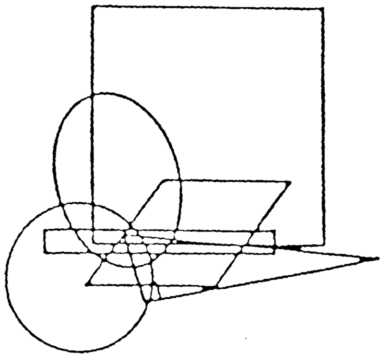


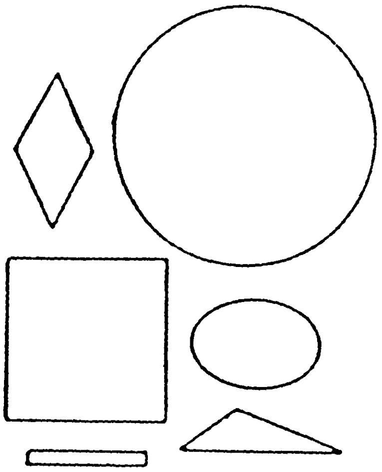


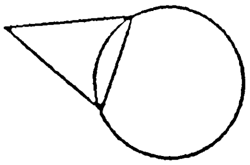


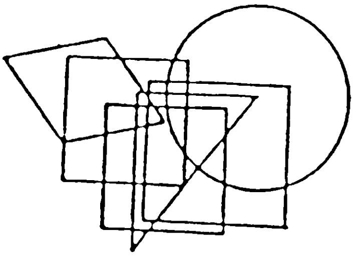


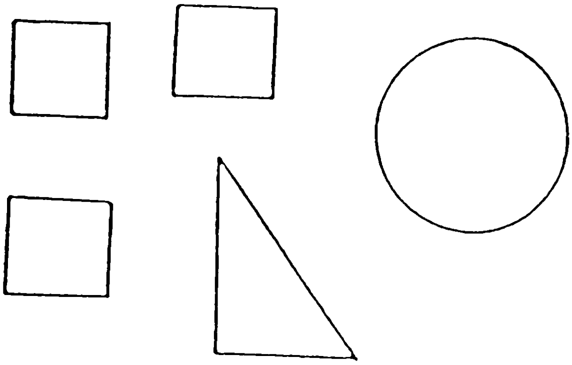


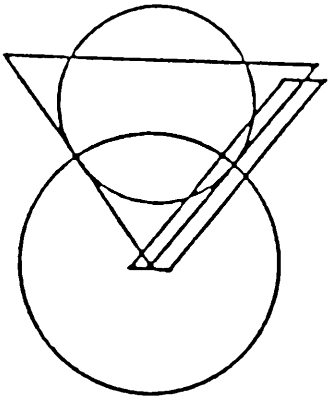


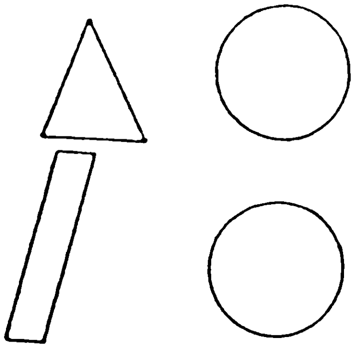


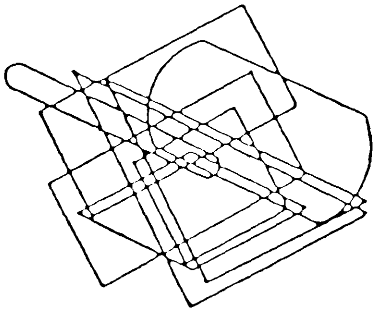


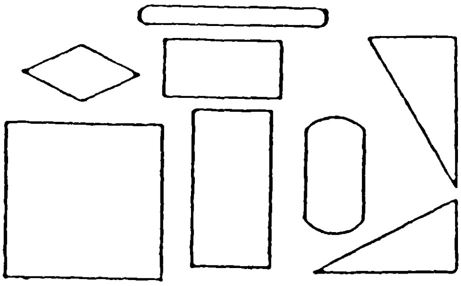


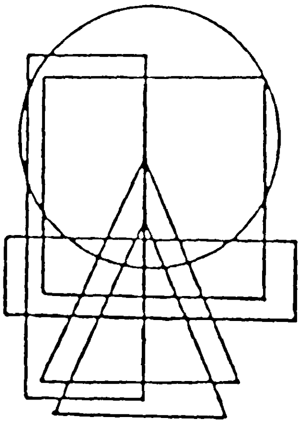


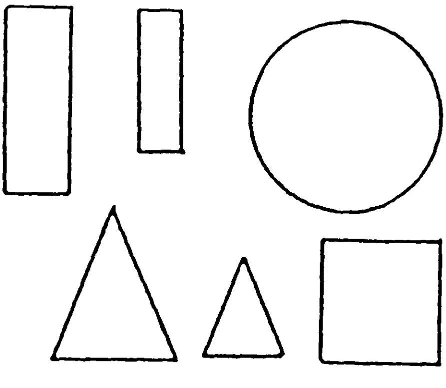


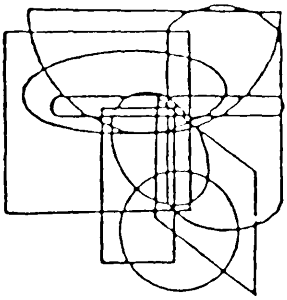


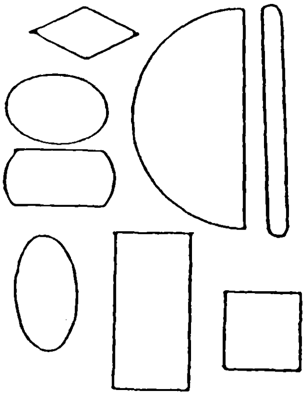


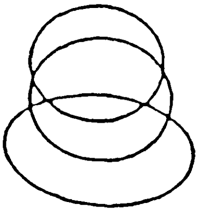


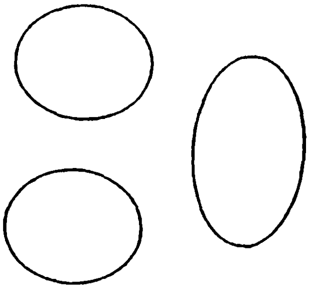


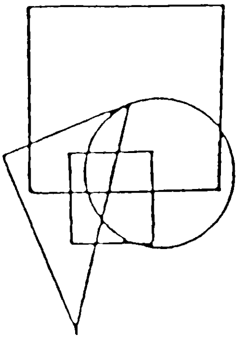


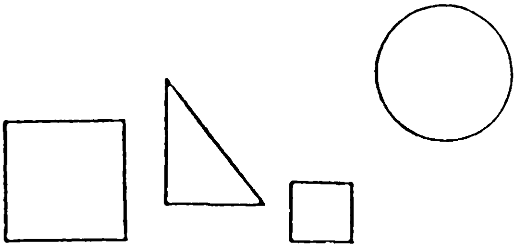


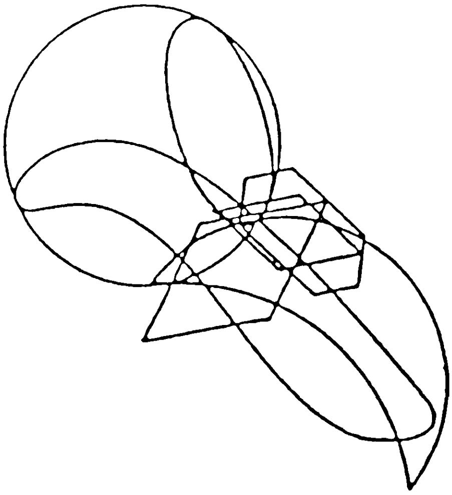


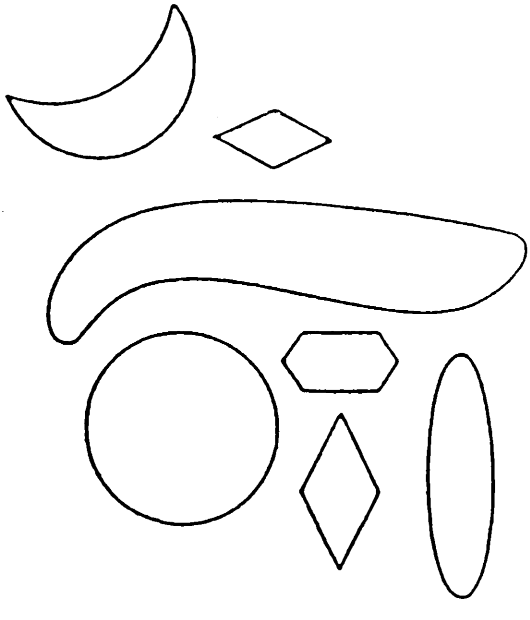


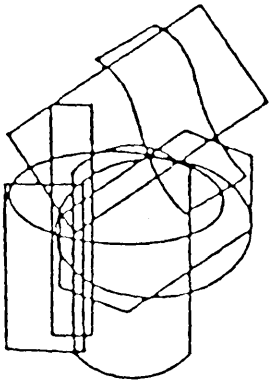


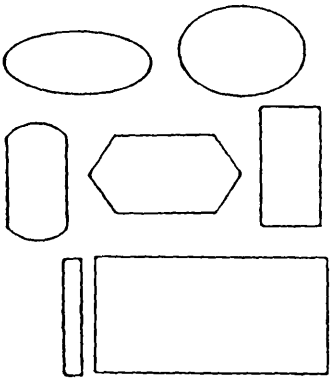


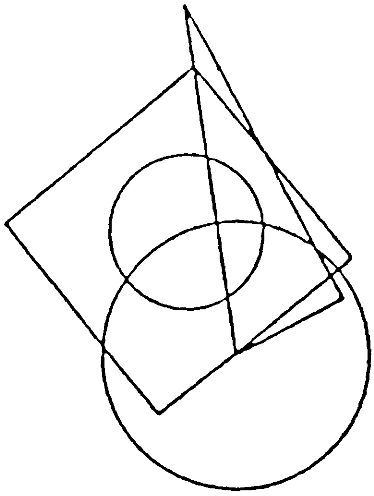


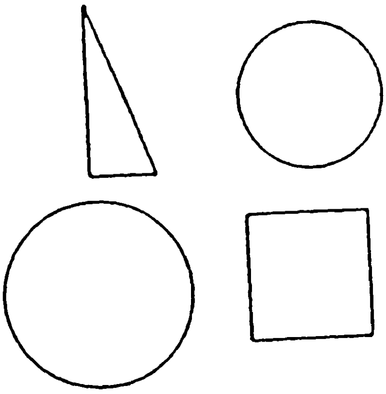


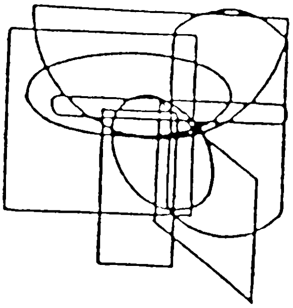


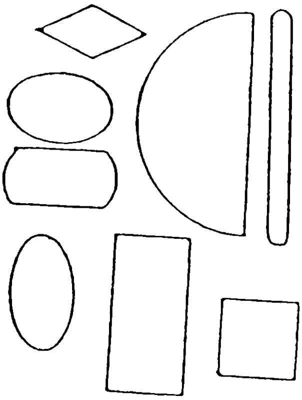


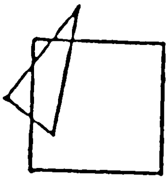


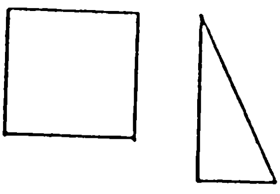


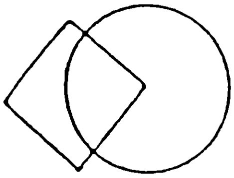


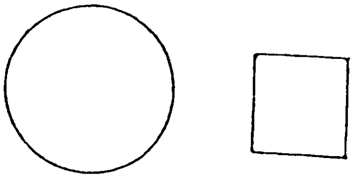


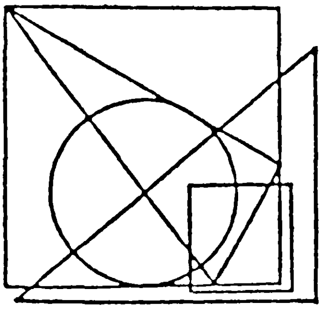


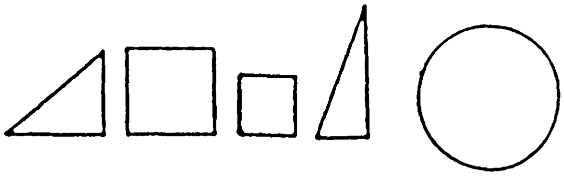


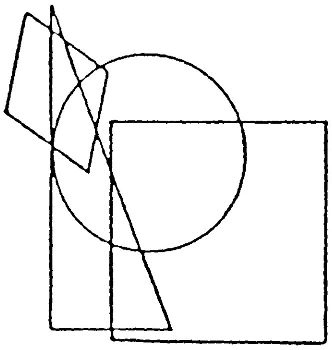


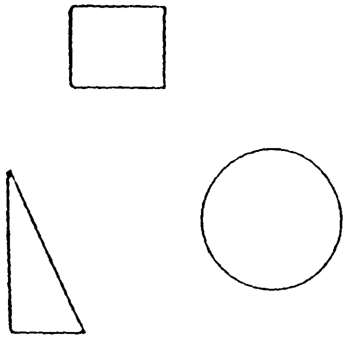


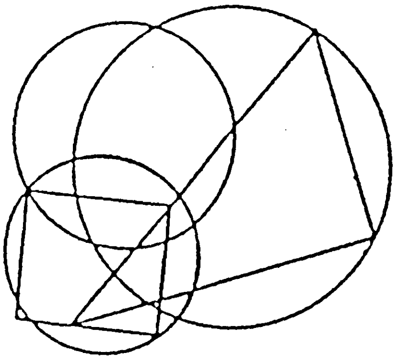


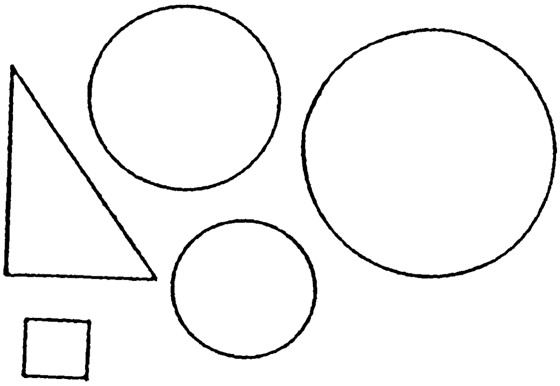


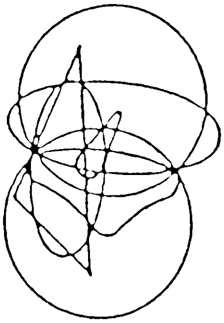


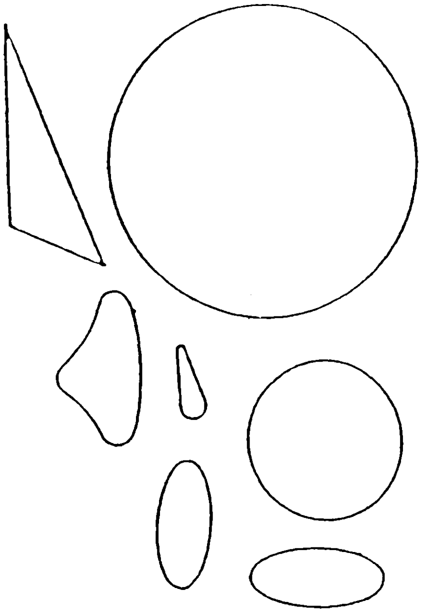


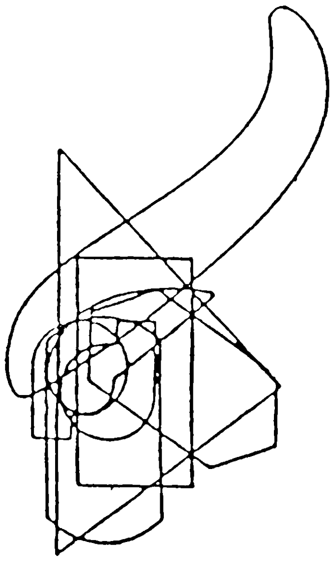


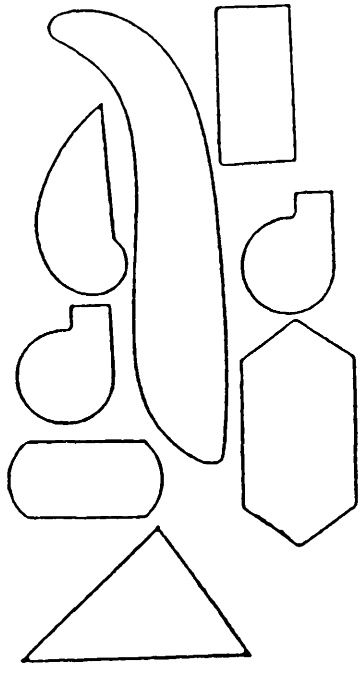


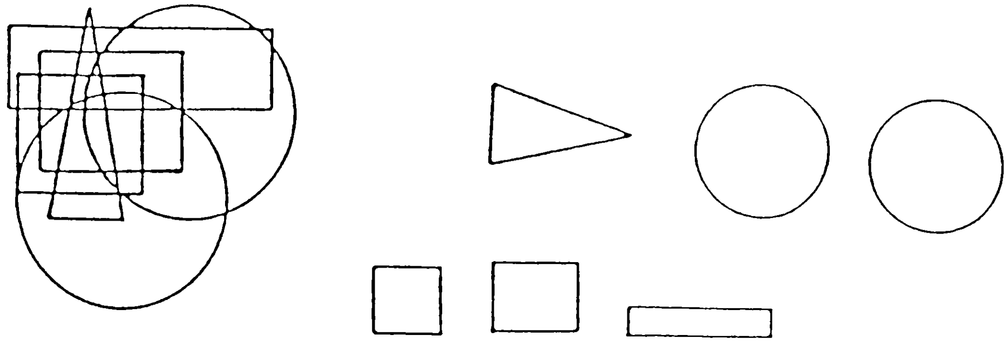


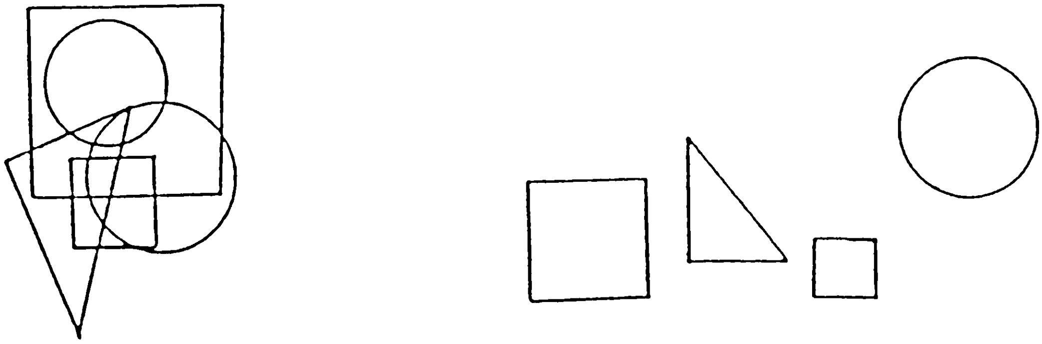












Appendix 4-2

The distribution of F.V, M.S and Z-demand for each question

March examination

	Q1-1	Q1-2	Q1-3	Q2-a	Q2-b	Q3	Q4	Q5-a	Q5-b	Q5-c	Q6-a	Q6-b	Q6-c	Q7-a	Q7-b
% F.V	47	57	48	47	30	25	8	61	60	28	43	34	35	9	18
M.S	0.5	0.31	0.12	0.89	0.62	0.44	0.15	0.36	0.63	0.15	0.52	0.34	0.18	0.25	0.07
% M.S	67	62	48	65	42	35	8	72	63	30	52	34	36	25	14
Max mark	0.75	0.5	0.25	1.25	1.5	1.25	2	0.5	1	0.5	1	1	0.5	1	0.5
Z-demand	5	2	6	4	6	7	8	5	3	5	5	8	6	6	9

Appendix 4-3

The distribution of F.V , M.S and Z demand for each question

December examination

	Question 1						Question 2					Question 3					Question 4		Question 5	
	1-a	1-b	2-a	2-b	2-c	3	1-b	1-c	2-a	2-b	2-c	1-a	1-b	2-b	3-b	4-b	a	b	a	b
% F.V	14	33	32	19	19	13	73	40	7	32	23	33	49	28	50	20	19	10	59	45
M.S	0.47	0.19	0.08	0.10	0.05	0.07	0.18	0.38	0.16	0.08	0.15	0.24	0.26	0.23	0.25	0.12	0.46	0.12	0.35	0.22
% M.S	41	39	33	21	18	14	72	50	20	32	29	47	55	42	50	25	36	17	69	50
Max mark	1.25	0.5	0.25	0.5	0.25	0.5	0.25	0.75	0.75	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1.25	1	0.5	0.5
Z-demand	6	8	3	7	8	10	3	6	3	8	6	4	5	3	4	6	7	8	3	3

Appendix 5-1-A

UNIVERSITY OF GLASGOW

(Science Education Research)

A Survey of the O.P.A Laboratory Work- Session 1988/89

Please fill in your Matriculation Number in the box opposite ☐☐☐☐☐☐

In no way will your response to this questionnaire affect your progress in this subject.

what was will your highest qualification in physics on entering University?

"O" GRADE (LEVEL)   "S" GRADE   "H" GRADE

"A" LEVEL   CSYS   OTHER

1) Have you personally (hands on) carried out experiments in physics before coming to University?

2) How to complete the questionnaire: in the grid below,

If you have found previous lab. Work **fairly** interesting you would tick the box as follows: interesting ☐ ☑ ☐ ☐ ☐ ☐ boring

If you found previous lab. Work **extremely** boring you would tick the box as follows: interesting ☐ ☐ ☐ ☐ ☐ ☑ boring

Please tick one of the boxes in each line, according to your opinion of of any previous physics lab. work you have experienced .

	A	B	C	D	E	
interesting						boring
enjoyable						unenjoyable
difficult						easy
worthwhile						waste of time
satisfying						frustrating
confusing						understandable
well organised						disorganised
adequate written instruction						inadequate written instruction
enough help from teacher						not enough help from teacher
exciting						dull

Appendix 5-1-B

UNIVERSITY OF GLASGOW

(Science Education Research)

A Survey of the O.P.A Laboratory Work- Session 1988/89

Please fill in your Matriculation Number in the box opposite ☐☐☐☐☐☐

In no way will your response to this questionnaire affect your progress in this subject.

We would like you to complete the following questionnaire, to indicate what you think of physics lab. work you have experienced during the first term.

How to complete the questionnaire: in the grid below,

f you have found previous lab. Work **fairly** interesting you would tickthe box as follows: interesting ☐ ☑ ☐ ☐ ☐ boring

If you found previous lab. Work **extremely** boring you would tick the box as follows: interesting ☐ ☐ ☐ ☐ ☑ boring

Please tick one of the boxes in each line, according to your opinion of physics lab. work you have experienced during this term.

	A	B	C	D	E	
interesting						boring
enjoyable						unenjoyable
difficult						easy
worthwhile						waste of time
satisfying						frustrating
confusing						understandable
well organised						disorganised
adequate written instruction						inadequate written instruction
enough help from demonstrator						not enough help from demonstrator
exciting						dull

Appendix 5-3

UNIVERSITY OF GLASGOW

(Science Education Research)

A Survey of the O.P.A Laboratory Work- Session 1988/89

Please fill in:

Name of experiment:..................Matriculation No. ☐☐☐☐☐☐

In no way will your response to this questionnaire affect your progress in this subject.

The following questions about the experiment can be answered by "YES" or "NO".

please delete as a appropriate, to indicate what you thought of the experiment.

SECTION A

1. Did you find it interesting? YES/NO
2. Did you find it difficult? YES/NO
3. Was the laboratory session well organised? YES/NO
4. Did you enjoy doing this experiment? YES/NO
5. Did you think it was a waste of time? YES/NO
6. Did you have enough time to complete the experiment? YES/NO
7. Did you get all the help you need from the:
   Demonstrator? YES/NO books? YES/NO notes? YES/NO

SECTION B

8. Before you began this experiment did you understand the background theory? YES/NO
9. Was your understanding of theory improved by doing the experiment? YES/NO
10. when did the objective of today's experiment become clear to you?
    at the beginning YES/NO part way through YES/NO
    at the end YES/NO or not at all YES/NO
11. Did you have enough time to write up your record? YES/NO
12. Were you given sufficient instructions to carry up the experiment? YES/NO
13. Did you encounter any new equipment today? YES/NO
    If so, specify...
14. Was all the equipment for this experiment available when you needed it YES/NO
15. Did you learn any practical techniques (e.g.timing, length, or angular measurement etc.) that were completely new to you? YES/NO
    If so, what techniqe...

Appendix 5-4

The relationship between students' responses

No Students	Number of expt attempted	Total number of negative responses	No of negative res / No of experiments	Average of exam paper	Average of report mark	Average Of record book mark
1	13	69	5.3	68	8	7.7
2	10	39	3.9	78	8	7.5
3	11	48	4.4	69	7.1	7.7
4	8	25	3.1	44	7.8	8.2
5	10	57	5.7	69	7.6	7
6	13	67	5.2	57.5	8	8.4
7	13	59	4.5	42.5	8	7.5
8	14	63	4.5	70	7.8	8.5
9	12	54	4.5	93	8.7	8.2
10	14	60	4.3	39	6.8	7.1
11	12	55	4.5	72.5	8	8.1
12	11	55	5.5	86.5	7.5	7.4
13	12	68	5.6	65.5	8	8
14	10	47	4.7	79.5	7	7.7

Appendix 5-4. Contiund

15	15	53	3.5	40	7.6	7.3
16	11	38	3.5	19	6.5	6
17	13	91	7	32.5	7	7.1
18	16	76	4.7	55.5	7.2	7.2
19	16	64	4	47	7.5	8
20	14	78	5.6	49	8.5	7.5
21	11	60	5.5	33.5	8	6.7
22	9	54	6	61	7.5	7
23	14	62	4.4	36	7.2	6
24	7	24	3.5	33.5	6.7	7.5
25	12	70	5.8	29	6.6	6.2
26	13	43	3.3	46	7	6
27	14	60	4.3	37.5	6.8	6.3
28	14	45	3.2	56	7.3	8.8
29	14	66	4.7	51	8	8
30	14	35	2.5	38	8	7.5
31	16	72	4.5	47.5	7.5	7.5
32	14	62	4.4	56.5	8	7.8
33	13	61	4.7	55	8	7.8
34	11	36	3.3	75.5	8.3	8.3
35	15	55	3.7	43	8	8.2
36	10	54	5.4	58.5	6.5	7.6
37	16	90	5.6	41.5	7	6
38	11	39	3.5	24	5.7	5.2

Appendix 5-4. Contiund

39	12	59	4.9	63	7.8	8
40	10	39	3.9	48	8.2	6.3
41	16	86	5.3	41	7.5	7.4
42	10	48	4.8	30	7	7.4
43	11	66	6	70	7	8
44	11	61	5.5	55	7	7.7
45	12	57	4.7	30	7.2	6.5
46	11	70	6.4	28.5	6.4	6
47	11	56	5.1	42.5	7.3	7.3
48	11	33	3	41	6	5
49	13	45	3.5	47	7.2	7
50	9	31	3.4	92.5	8	8.3
51	14	48	3.5	27	6	6.4
52	13	52	4	34.5	6	6.8
53	10	46	4.6	37	8	8.2
54	12	27	2.3	90	8.2	8.2
55	12	60	5	63.5	7	6
56	15	42	3	34.5	6.5	6
57	11	40	3.6	77	8	8
58	12	62	5.2	32	7.8	7.2

Appendix 5-4. Contiund

59	9	26	2.9	75	8.6	7.3
60	7	26	3.7	74	6.8	7.4
61	8	26	3.5	58.5	7.6	8
62	11	41	3.7	29	7.2	7
63	8	28	3.5	54	7.5	8
64	12	71	6	25.5	6.5	6.2
65	12	67	5.6	48	7	7.4
66	9	67	7.4	23.5	6.7	6.7
67	6	24	4.5	19	6.6	6
68	11	53	4.8	43.5	7	7.2
69	7	25	3.6	75	8	7
70	6	32	5.3	57	6.6	6
71	10	57	5.7	37.5	6.2	6.2
72	7	31	4.4	52.5	7	7.5
73	10	54	5.4	43.5	7	6.5

Appendix 5-5-A

Frequency with value> 0.39

Category	Unenjoyable	Not understood the theory	Uninteresting	Difficulty	No help from notes	No help from books	Not improved theory	Not enough time	Insufficient instructions	Waste of time	No help from demonstrator	Disorganized	Equipment not available
Unenjoyable		1	2	1	2	1	0	0	0	0	0	0	0
Not understood theory			2	2	3	2	0	0	0	0	0	0	0
Uninteresting				1	1	1	0	0	0	0	0	0	0
Difficulty					2	2	1	0	0	0	0	0	0
No help from notes						2	0	0	0	0	0	0	0
No help from books							0	0	0	0	0	0	0
Not improved theory								0	0	0	0	0	0
Not enough time									0	0	0	0	0
Insufficient instructions										0	0	0	0
Waste of time											0	0	0
No help from demonstrator												0	0
Disorganzied													0
Equipment not available													

Appendix 5-5-B

Frequence with value >0.35

Catigory	Unenjyyable	Not understood theory	uninteresting	Difficulty	Not help from notes	No help from books	Not improved theory	Not enough time	Unsufficient instructions	Waste of time	No help from demonstrator	Not well organized	Not available the equipment
Unenjoyable		6	3	3	3	2	0	0	0	0	0	0	0
Not understood theory			2	4	3	2	0	0	0	0	0	0	0
Uninteresting				1	1	1	0	0	0	0	0	0	0
Difficulty					2	2	1	0	0	0	0	0	0
Not help from notes						2	0	1	0	0	0	0	0
No help from books							0	0	0	0	0	0	0
Not improved theory								0	0	0	0	0	0
Not enough time									0	0	0	0	0
Unsufficient instructions										0	0	0	0
waste of time											0	0	0
No enough help from demonst												0	0
Desorganized													0
Equipment not available													

Appendix 3-5-C

Frequency with value >0.20

Category	Unenjoyable	Not understood the theory	Uninteresting	Difficulty	No help from notes	No help from books	Not improved theory	Not enough time	Insufficient instructions	Waste of time	No help from demonstrator	Disorganized	Equipment not available
Unenjoyable		13	9	14	16	10	8	2	1	0	0	0	0
Not understood theory			8	11	13	12	8	5	5	1	0	0	0
Uninteresting				7	9	8	7	3	0	1	0	0	0
Difficulty					13	13	9	7	2	1	0	0	0
No help from notes						14	9	7	1	0	0	0	0
No help from books							8	8	1	0	0	0	0
Not improved theory								6	0	0	0	0	0
Not enough time									2	0	0	0	0
Insufficient instructions										0	0	0	0
Waste of time											0	0	0
No help from demonstrator												0	0
Disorganzied													0
Equipment not available													

Appendix 5-5-D

frequncey with >0.10

Category	Unenjoyable	Not understood the theory	Uninteresting	Difficulty	No help from notes	No help from books	Not improved theory	Not enough time	Insufficient instructions	Waste of time	No help from demonstrator	Disorganized	Equipment not available
Unenjoyable		14	15	17	17	17	15	14	8	11	1	0	0
Not understood theory			14	14	14	14	14	12	5	9	0	0	0
Uninteresting				15	15	15	14	12	7	10	1	0	0
Difficulty					17	17	15	14	8	11	1	0	0
No help from notes						17	15	14	8	11	1	0	0
No help from books							15	14	8	11	1	0	0
Not improved theory								12	7	11	1	0	0
Not enough time									8	8	1	0	0
Insufficient instructions										5	1	0	0
Waste of time											1	0	0
No help from demonstrator												0	0
Disorganzied													0
Equipment not available													

Appendix 5-6

Demonstrator's diary

Name of experiment:..............................

1) What questions did the students ask most frequently about this experiment?	Frequency
1.1) About the written instructions	
1.2) About the actual doing of the experiments	
1.3) About the use of apparatus, e.g. Vernier scales	
1.4) About analysis of data, e.g.graphs	
1.5) About use of record books	
2) What "stupid" things were they doing without asking you?	

Appendix 5-7

demonstrators

during the physics lab sessions, you demonstrated experiments on:

First term

1 Air track:..

2 SHM:..

3 Refraction:..

4 Lenses:..

5 Spectrometer:....................................

6 Melde's expt:....................................

7 Newton's Rings:................................

8 Vibrating blade:................................

Second term

9 Compound pendulum:.........................

10 Thermal condactivity:......................

11 Force and potential:........................

12 Growth and decay:...........................

13 Sound:...

14 Current electricity:..........................

15 Solenoid:..

16 Radioactivity:...................................

17:e/m of electron:...............................

Looking back over these experiments, can you pick out any one (or more than one) that the students found particularly:

1- boring
2- interesting
3- easy
4- confusing
5- enjoyable
6- adequate explained (written instruction)
7- understandable
8- difficult
10-not enough time.

Thank you for your help

Appendix 5-8. General Notes for Students

Introduction

1. Physical science relies on a fine balance between experiment and theory. Experimental work provides the facts on which theories are based and the theories provide predictions which can then be confirmed or refuted experimentally.

   Thus it is important that you - as a student of physics - obtain a firm grasp both of the theoretical principles of physics and of the fundamentals of experimental method.

2. *The Objectives* of this laboratory course are to give you a grounding in the methods of experimental physics and to help you to a better understanding of physics.

3. *Attendance*

   Laboratory timetable: the laboratory will be open from **09.00 to 17.00** from Monday to Friday, inclusive.

   Practical classes are held on

   Monday 13.00 to 16.00; *Tuesday, Thursday and Friday* **10.00 to 13.00;** *Tuesday and Friday* 14.00 to 17.00; *Thursday* **13.30 to 16.30.**

   Attendance at the laboratory is obligatory for one period of ***three hours each week.*** Allocation to sessions is largely dependent on the timetable restrictions of individual students.

   Students are expected to attend the laboratory with regularity. Your attention is drawn to the requirement that you must complete a ***Certificate of Absence*** for ***all*** absences lasting up to and including five days. (Beyond five days a Medical Certificate is required). Certificate of Absence forms can be obtained from the laboratory office and should be returned to Dr Knights' office on the first floor of the Boyd Orr Building.

   When these certificates cover absences from lectures, tutorials or laboratories in Physics, you are requested to inform the technician-in-charge of the dates involved.

4. *Class Certificate and Practical Examination*

   Satisfactory performance in practical classes is a requirement for the award of a Class Ticket. A ***practical examination*** may be held at the end of the session. However, students who show an acceptable standard in attendance records, in performance of normal laboratory work (including Record book), and in Reports may be exempted from this examination. It is to the advantage of students to complete the work of the Practical Class (i.e. until the end of the Third term) even if a Class Ticket is not being awarded for other reasons.

5. ***Extra working*** can be arranged with the laboratory technicians (Room 209) but availability of a demonstrator can only be guaranteed during the practical class times detailed above.

6. All breakages must be reported to the laboratory technician; students may be charged cost or part of damaged or broken equipment.

7. *Procedure*

   To obtain the greatest benefit from your laboratory work you should

   a) prepare yourself by doing some background reading of the physics involved in your next experiment;

b) carry out experiments ***thoroughly***. It is better to perform one part of an experiment well and fully understand it than to do the whole experiment badly. Have each part of an experiment checked by a demonstrator before you move on to the next part. Any unfinished analysis of data should be completed before your next laboratory period;

c) be sure of the following before starting any experiment:

   i) what is the objective of the experiment,
   ii) what measurements will be needed,
   iii) what instruments and/or techniques will be involved,
   iv) what is my plan of action to achieve the objective(s);

d) keep careful records of *ALL* measurements (raw data rather than average values) - this is recommended good practice. The measurements should be noted as soon as they are taken, more often as not in *TABULAR FORM,* in a *LABORATORY NOTEBOOK* (as specified below) and *NEVER* on loose paper. See the use of tables in the example of a Laboratory Record of the simple pendulum experiment.

8. *Sections*

All students follow a common laboratory course during Term I; thereafter there will be two sections, I and II. Allocation to sections depends on the past practical experience of a student, on his stated choice of section, on availability of places, and on the type of course pursued (single or combined Honours physics).

Section I: for students with wide previous practical experience in physics. Students work singly with little formal instruction and some of the experiments are more advanced. The progress of a student depends greatly on himself; the student works at his own pace, but a minimum amount of work is expected.

Section II: for students with less practical experience. Students work mainly by themselves but more assistance is given by demonstrators. In Section II, most experiments are arranged so that each one has a basic part and a supplementary part. The demonstrator will outline the technique and use of the apparatus. It is the responsibility of each student to be familiar with the background and theory of the basic experiment. The demonstrator should be shown results as soon as these are obtained. If the results are acceptable the basic experiment may be followed by the supplementary part, or by further measurements suggested by the student or demonstrator.

9. *Notebooks*

Two laboratory ***notebooks*** are needed; the type with mm graph paper, A4 size is recommended. One of these notebooks, the ***RECORD*** book, is used to record all data as an experiment is performed, i.e. a daily log book. ***All*** notes, readings etc. are entered in the Record book. Loose paper is *NOT* allowed. The Record book will be inspected by the demonstrator at the end of each experiment or each laboratory period.

In the second, the ***REPORT*** book, students will write a full account of an experiment carried out previously. This work will be required only ***five*** times in the year, as requested by the laboratory supervisor.

BOTH notebooks should be clearly identified with your name, term address, laboratory day and time. You should also show a table of contents with page references as shown:

a) RECORD and REPORT Books

First Left Hand Page:

Name

Term Address

Lecture Sections (from Term II)

Laboratory day and time

Laboratory section (from Term II)

First Right Hand Page

Index

Date : Title of Experiment : Page : Mark

b) RECORD Book *(Daily Log Book)*

Left Pages	***Right Pages***	
READINGS *(tables)*	DATE	TITLE
DIAGRAMS *(apparatus, ray diagrams)*	OBJECT	
	THEORY*	
GRAPHS	NOTES*	
	RESULTS	
	CONCLUSIONS	
	DISCUSSION	

* The **THEORY** and **NOTES** sections must *NOT* be a copy of the experimental notes provided - instead quote relevant formulae, make reference to experimental notes and *BRIEFLY* describe any particular features of *YOUR* experiment not mentioned elsewhere.

10. HELP

If you are having any difficulties or are concerned about your experimental work consult your demonstrator, or the Laboratory Head.

Time

Time for 50 swings = (55.5 ± 0.7) s

Time for 50 swings (s)

55.5 ± 0.7	53.9 ± 0.7
55.0 ± 0.7	54.7 ± 0.7
54.2 ± 0.7	

.˙. Mean time = 54.7 s

$$S^2 = \frac{1}{4}\left[(0.8)^2 + (o.3)^2 + (0.5)^2 + (0.8)^2 + 0\right]$$

$$= \frac{1}{4}\left[0.64 + 0.09 + 0.25 + 0.64\right]$$

$$= \frac{1.62}{4} = 0.41$$

.˙. Standard deviation S = 0.64

.˙. Standard deviation of mean = $\frac{0.64}{\sqrt{5}}$ = 0.3

.˙. Mean time = (54.7 ± 0.3) s

Variation of period with length

Length (cm)	Time for 50 Swings		Period (s)	$(\text{Period})^2$ $(s)^2$
	Readings (s)	Mean Time (s)		
30.1 ± 0.2		54.7 ± 0.3	1.094 ± 0.006	1.196 ± 0.013
97.1 ± 0.2	98.5 ± 0.7 99.5 ± 0.7 98.4 ± 0.7	98.8 ± 0.4	1.976 ± 0.008	3.904 ± 0.032
68.3 ± 0.2	82.1 ± 0.7 83.0 ± 0.7 83.0 ± 0.7	82.7 ± 0.4	1.654 ± 0.008	2.736 ± 0.026
10.7 ± 0.2	33.5 ± 0.7 32.6 ± 0.7 32.9 ± 0.7	33.0 ± 0.4	0.660 ± 0.008	0.436 ± 0.011
42.8 ± 0.2	66.9 ± 0.7 67.3 ± 0.7 66.2 ± 0.7	66.8 ± 0.4	1.336 ± 0.008	1.785 ± 0.021
21.4 ± 0.2	45.1 ± 0.7 46.1 ± 0.7 46.5 ± 0.7	45.9 ± 0.4	0.918 ± 0.008	0.843 ± 0.015

L cm	30.1	97.1	68.3	10.7	42.8	21.4
$\log_{10}L$	1.48	1.99	1.83	1.03	1.63	1.33
$\log_{10}T$	0.037	0.196	0.019	-0.180	0.126	-0.037

EXAMPLE OF A LABORATORY RECORD

DATE

MEASUREMENT OF g - SIMPLE PENDULUM

OBJECT: To verify the theory of the Simple Pendulum and hence to evaluate the acceleration due to gravity, g.

DEFINITION: The Simple Pendulum is a massive dimensionless bob suspended at the end of a weightless string which has no rigidity.

The period of a pendulum is the time taken for one complete cycle of its motion.

THEORY: The period of a simple pendulum is given by

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T is the period (s),
L is the length of the pendulum (m),
g is the acceleration due to gravity (ms^{-2})

1. Variation of period with amplitude

Method Period measured with stopclock. Angles measured with protractor.

Conclusion Up to angles of 30^o (where $\sin\theta \sim \theta$) there is no evidence of a variation of period with amplitude.

2. Variation of period with mass

Method Masses measured with spring balance. Two pendulums with different masses but the same lengths were set swinging in phase and with the same amplitude. The small difference observed in the periods was explicable in terms of a small difference in lengths (assuming here

$$T = 2\pi\sqrt{\frac{L}{g}}\ ).$$

Conclusion Any possible variation of period between the two pendulums used was less than 1%.

3. Variation of period with length

Method Pendulum length measured with metre stick.

Conclusion T^2 is proportional to L.

Result Evaluation of g :

$$T = 2\pi\sqrt{\frac{L}{g}}$$

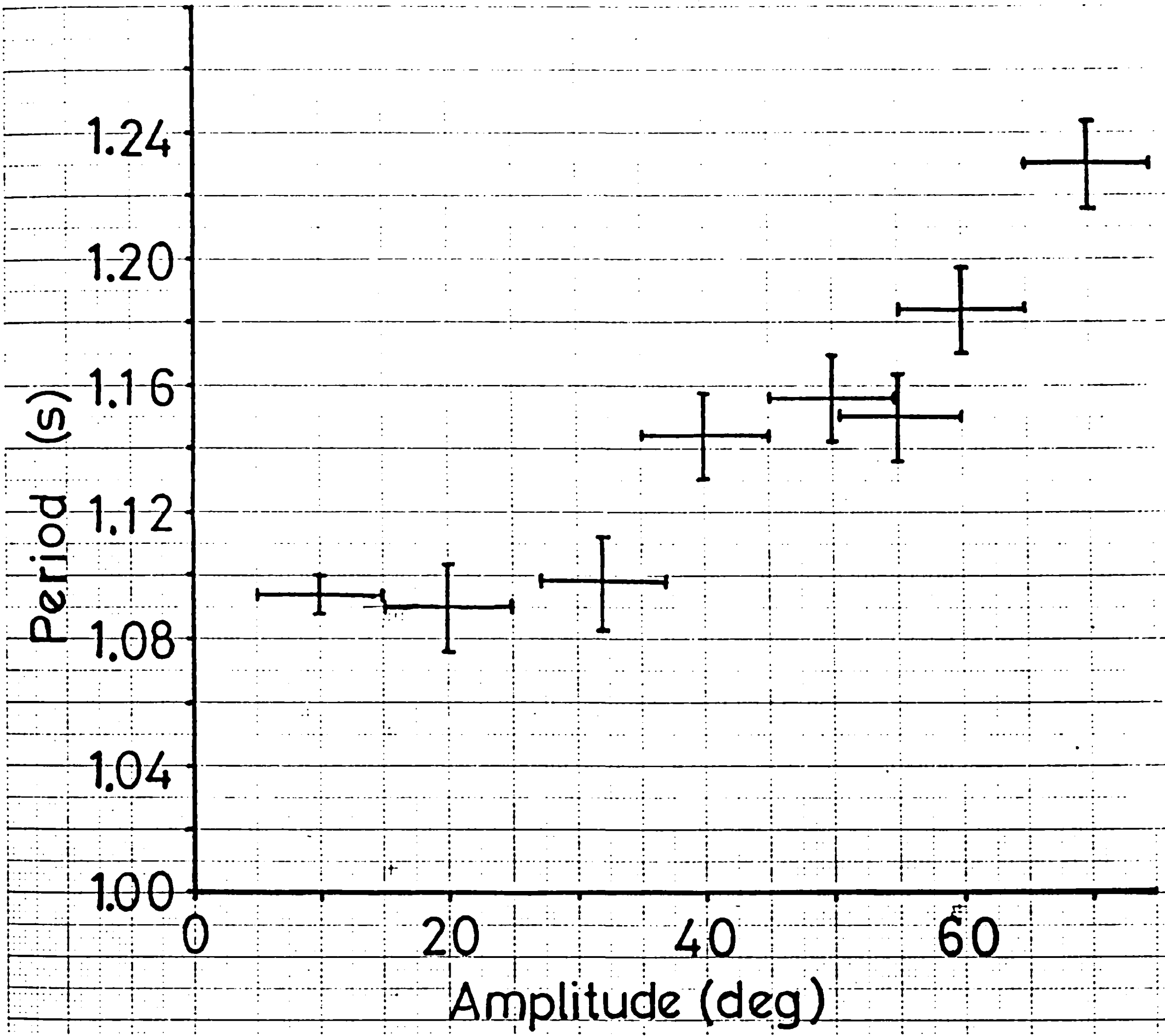
$$\text{i.e. } T^2 = 4\pi^2\,\frac{L}{g}$$

$$\text{i.e. } g = \frac{4\pi^2}{\text{gradient}} = \frac{4\pi^2}{\frac{4.0}{1.0}} = 9.873\ ms^{-2}$$

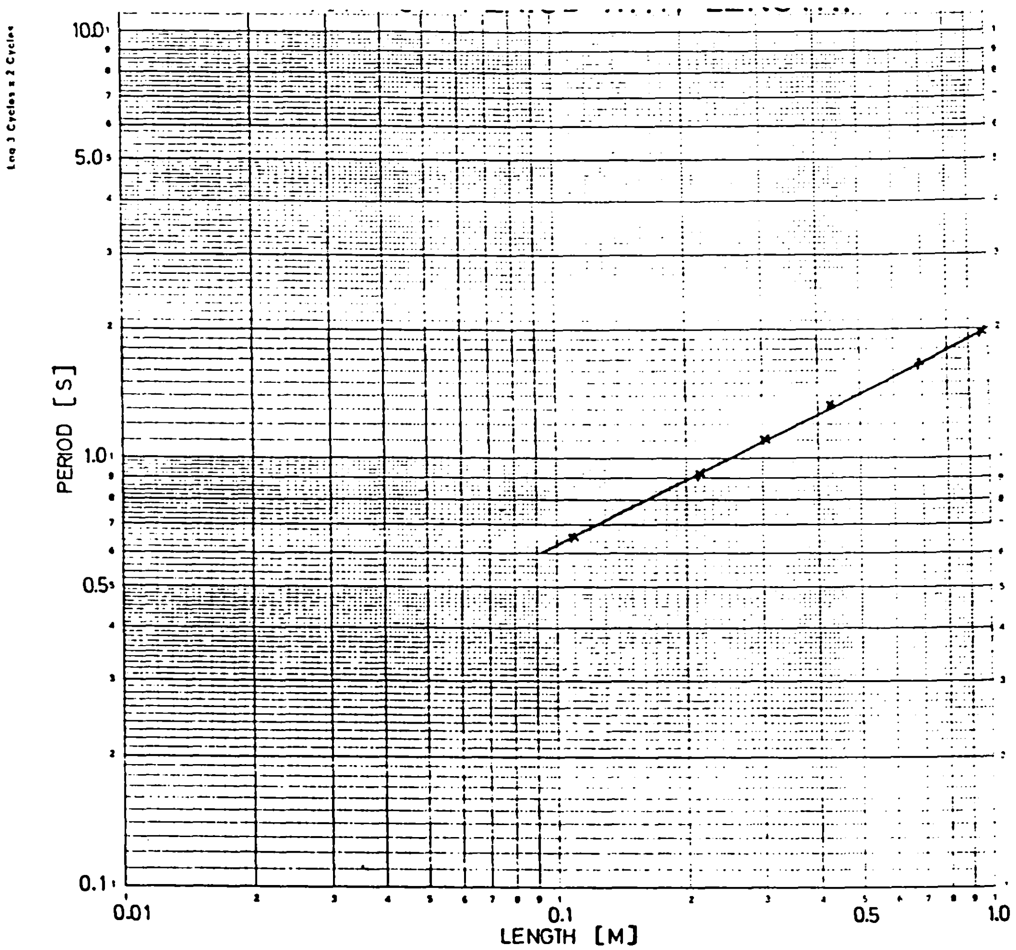
$$\text{Error in gradient} = \frac{2}{160} = 1.25\%$$

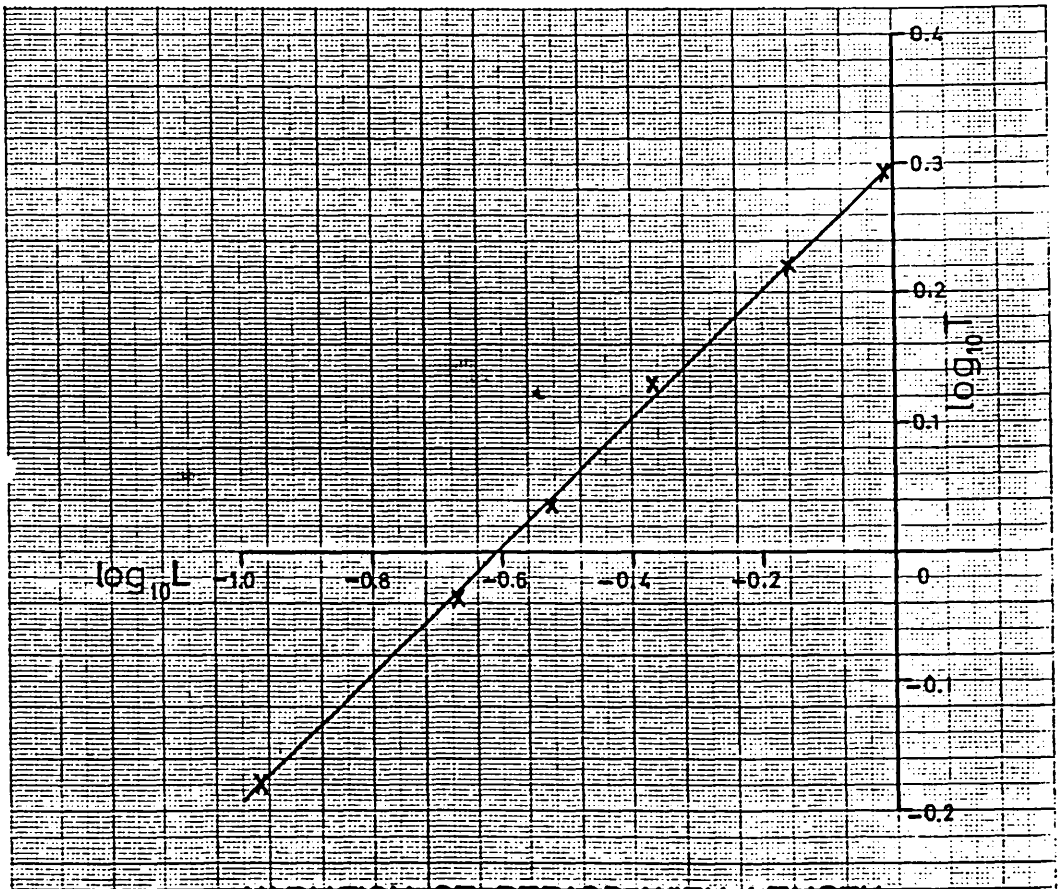
$$\therefore \text{Error in g} = \frac{1.25}{100} \times 9.873 = 0.12\ ms^{-2}$$

$$\therefore g = (9.87 \pm 0.12)\ ms^{-2}.$$



Variation of period with amplitude





VARIATION OF PERIOD WITH LENGTH.

7

EXAMPLE OF A LABORATORY REPORT

MEASUREMENT OF g - SIMPLE PENDULUM

DATE

INTRODUCTION

The object of the experiment was to investigate whether or not the behaviour of a practical simple pendulum could be described by the theory of the Simple Pendulum based on Newton's Laws of Motion; and if so, to use the theory to determine a value of the acceleration due to gravity - "g".

THEORY

The period of a simple pendulum is given by

$$T = 2\pi\sqrt{L/g}$$

where T is the period (s)
L is the length of the pendulum (m)
g is the acceleration due to gravity ($m\ s^{-2}$).

EXPERIMENTAL METHOD

The pendulum bobs were brass spheres with a hole drilled through the centre, through which was passed a light string. At the suspension the string went through a hole in a support rod.

The timing was done with a stop clock and lengths were measured with a metre stick.

It was noted that timings of one swing of the pendulum gave values of about 1 second, with an error of 0.7 s (personal estimate). This 70% error was unacceptable. A study of the distribution of the results of five timings of 50 swings under identical conditions showed that the standard deviation of each measurement was 0.6 s in about 55 s, i.e. about 1% accuracy. It was decided that a measurement of the time of 50 swings would lead to a fair compromise between the time taken to do the experiment and the desired accuracy.

(i) Variation of period with amplitude

The time for 50 swings was determined for a range of angles up to 90°. At large angles of swing, the amplitude decreased considerably during the time of the 50 swings, and an average value was estimated.

(ii) Variation of period with mass

Two pendulums with masses of 0.072 and 0.028 kg and with the same lengths were set swinging in phase and with the same amplitude. The two pendulums went slowly out of phase and returned in phase after 300 swings, the one pendulum having swing once less than the other.

Since it may be shown from the above theory

$$\frac{dT}{dL} = \frac{T}{2L}$$

it follows that

$$dL = 2L\frac{dT}{T} = 2 \times 0.30 \times \frac{1}{300} = 2 \times 10^{-3} m$$

i.e. the small difference in the periods could be explained in terms of a 2×10^{-3} m difference in the lengths of the pendulums, and this is within the estimated error of these lengths.

(iii) Variation of period with length

The length of the pendulum was taken as the distance from the point where the string left the supporting rod, to the centre of the bob.

A series of readings were taken of the time for 50 swings for different lengths of the pendulum. For a given length, the measurements were repeated to determine the errors. The resulting variation of T^2 against L is shown in graph 2.

RESULTS AND CONCLUSIONS

It is seen from graph 1 that the results are consistent with the prediction of the theory (valid for $\sin\theta \simeq \theta$) that there is no variation of period with amplitude of swing for small amplitudes.

The small observed difference in period of the two pendulums of different masses could be explained in terms of a small difference in the two lengths. There is, therefore, no evidence of a genuine variation of period with mass within the accuracy and scope of the measurements.

The graph 2 of T^2 against L was a straight line, in agreement with

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Hence the predictions of the theory have been shown to be correct in the experimental situation, within the accuracy of the measurements, and the theory could be used to evaluate g. From the gradient of graph 2 it was found that

$$g = (9.87 \pm 0.12)\text{m s}^{-2}$$

(Graph 1 (variation of period with amplitude) and graph 2 (variation of period with length) should be reproduced from the Record on the left hand side pages of the Report.)

i.e. the small difference in the periods could be explained in terms of a 2×10^{-3} m difference in the lengths of the pendulums, and this is within the estimated error of these lengths.

(iii) Variation of period with length

The length of the pendulum was taken as the distance from the point where the string left the supporting rod, to the centre of the bob.

A series of readings were taken of the time for 50 swings for different lengths of the pendulum. For a given length, the measurements were repeated to determine the errors. The resulting variation of T^2 against L is shown in graph 2.

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$$g = (9.87 \pm 0.12)\text{m s}^{-2}$$

(Graph 1 (variation of period with amplitude) and graph 2 (variation of period with length) should be reproduced from the Record on the left hand side pages of the Report.)

Graphical Analysis

Introduction

This section is designed to acquaint you with graphing techniques and how to extract the maximum amount of information from a graph. A graph will reveal not only the existence of a relationship between two variables, but also the constant of proportionality and many other relationships of physical interest.

Suppose an experiment gives you sets of data connecting two variables s and t, all other variables in the experiment having been held constant. Suppose we want to find the dependence of s on t. A powerful technique is graphical analysis.

In general we can derive more information from a linear rather than a non-linear graph. The problem therefore is to determine those powers of the variables which give rise to a linear graph, from which the gradient and intercept can yield physical information.

1. The Linear Graph

If the dependence of s on t is known (e.g. between the period T and the mass m in the oscillating spiral spring), a sensible choice will give the required linear graph (e.g. graph of T^2 against m in this example).

The Linear Equation. A linear equation is one whose form is

$$y = mx + c \qquad (1)$$

If this equation is plotted, a straight line results. For two points P_1 and P_2 on the straight line, the slope m is defined as Δy, the change in y, divided by Δx, the change in x.

$$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$$

The value of y when x = 0 is C. Since the line "intercepts" or crosses the y axis at x = 0, C is called the y intercept.

2. The Semi-Log Graph

The Exponential Equation. Certain physical quantities are related by an equation of the form

$$s = ae^{bt} \text{ where a(>o) and b are constant} \qquad (2)$$

We see that

$$\log_e s = bt + \log_e a \qquad (3)$$

Compare this with $y = mx + c$.

Thus, if the natural logarithm of s is plotted *versus* the quantity t, a straight line will result on linear graph paper, from which a and b can be obtained.

However it is sometimes more convenient to use graph paper with one set of scale divisions corresponding to the natural logarithms, and with linear divisions in the other direction. What is actually available is paper with divisions corresponding to base 10 logarithms. Such paper is called semi-log paper; one scale is linear, the other is logarithmic.

Defining the Slope of a Semi-Log Plot. To find the slope of a line plotted on this paper, you must calculate the ratio of the change in the logarithm of s to the change in t:

$$\text{slope} = \frac{\ln s_2 - \ln s_1}{t_2 - t_1} = b$$

From the slope you can evaluate b. The units of b are governed by the units of t, since the exponent must be unitless.

To find the value of a, graphically determine the value of s when t = 0.

Computing the Slope of a Semi-Log Graph. The procedure for a s *versus* t semi-log plot is straightforward. First, find the line that best fits the data points. Then select two arbitrary points on this line (not your data points). Your arbitrary points P_1 and P_2 yield 2 sets of values (s_1,t_1) and (s_2,t_2) which are read off the scales. You *must calculate the natural log of both* s_1 *and* s_2. The graph does *not* do this for you.

3. The Log-Log Graph

The General Equation. Consider an equation of the form

$$s = ct^d \text{ where } c\ (> o) \text{ and } d \text{ are constants}$$

a log/log graph can give the unknowns.

Then $\log s = d \log t + \log c.$

A graph of log s against log t is a straight line and will give the index d from the gradient. Note that

$$d = \frac{\log s_2 - \log s_1}{\log t_2 - \log t_1}$$

To obtain c observe that where t = 1, log t = 0, i.e. at t = 1 (units), s = c. Remember that the magnitude of c must depend on the units of s and t. Here one can use linear graph paper and convert s to log s, etc. Alternatively log/log paper can be used. In this case take care to interpret the gradient correctly.

As an example study the log/log graph of period and length in the Record of the simple pendulum.

4. Suppose $s = at^2$ where a (> o) is a constant, but suppose we cannot measure t. We can, however, easily measure s and x where

$$t = x + \Delta$$

Here Δ is a small constant, not conveniently measurable.

Then

$$s = a(x + \Delta)^2$$

i.e. $$s^{1/2} = a^{1/2}x + a^{1/2}\Delta$$

this is of the form

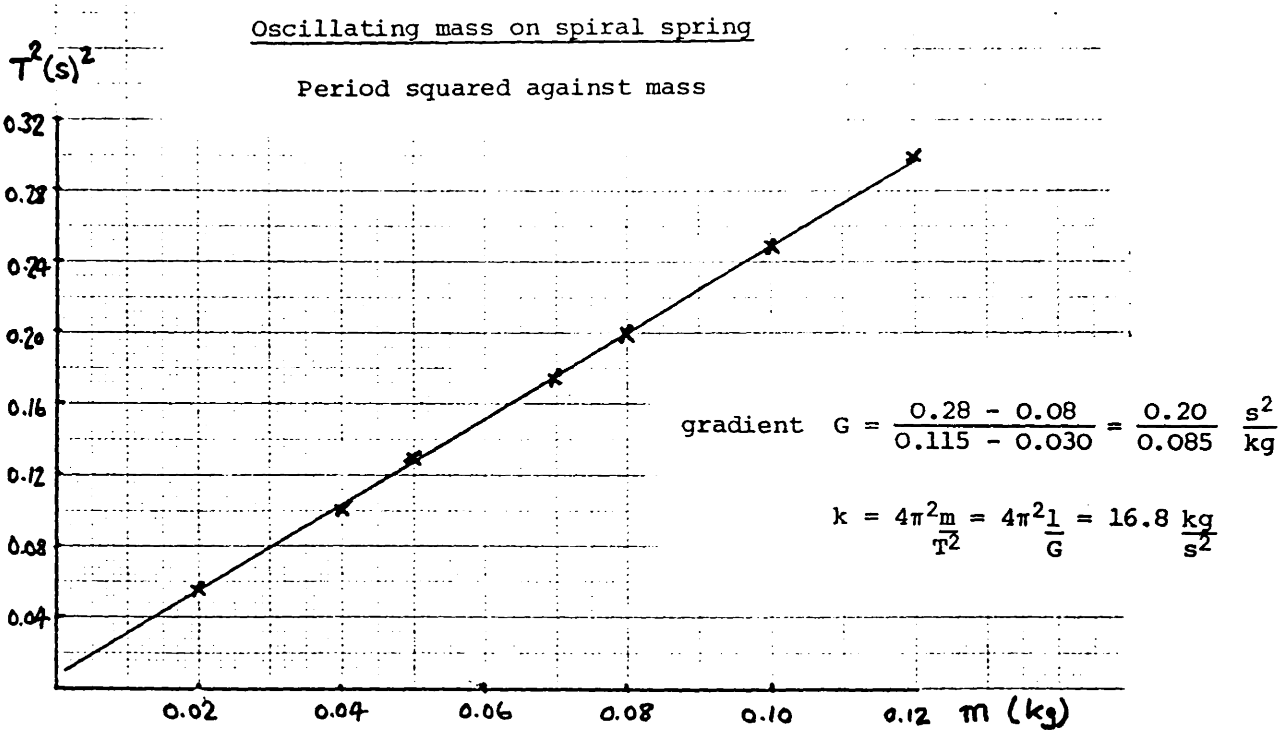
$$y = mx + c$$

i.e. the quantity Δ, inaccessible to measurement, appears as part of the intercept on a graph of $s^{1/2}$ against x. Obviously a can be calculated from the gradient of this graph.

This is a useful technique in graphical analysis and you can take advantage of it in the experiment on the Absorption of Light, for example.

5. General

All graphs should have axes labelled, with units, and should have titles giving meaning to the data displayed. Study the examples which follow.

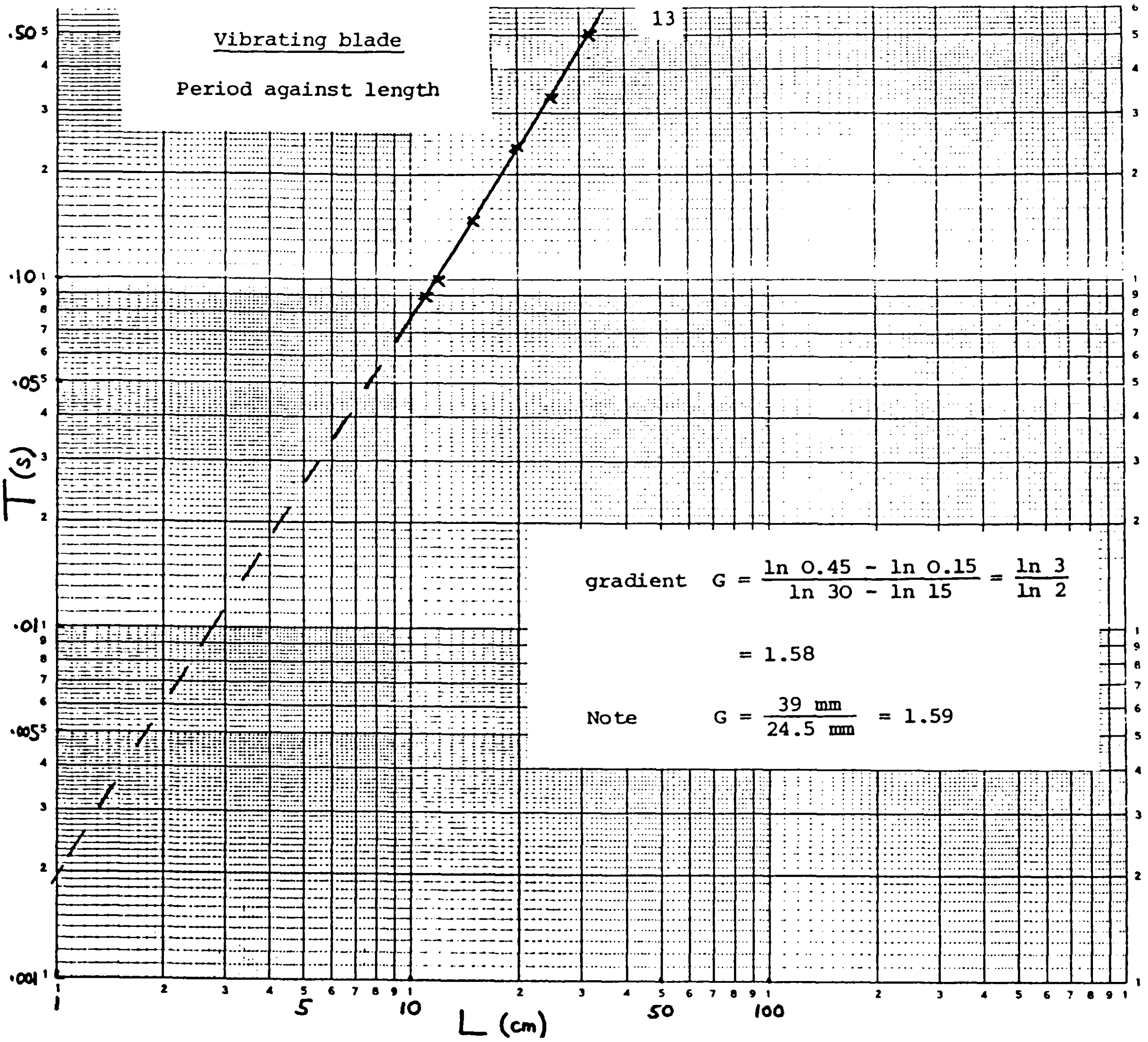


Oscillating mass on spiral spring

Period squared against mass

$$\text{gradient} \quad G = \frac{0.28 - 0.08}{0.115 - 0.030} = \frac{0.20}{0.085} \quad \frac{s^2}{kg}$$

$$k = \frac{4\pi^2 m}{T^2} = \frac{4\pi^2 1}{G} = 16.8 \ \frac{kg}{s^2}$$



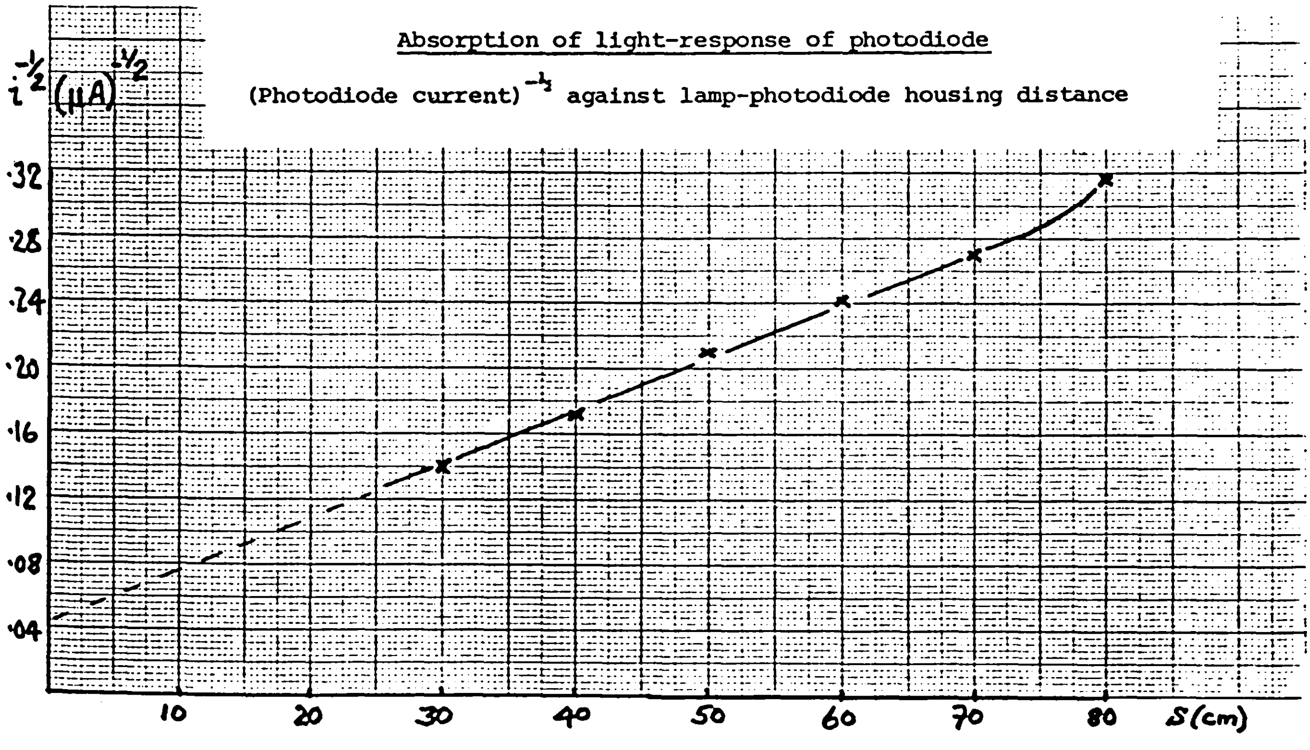
Vibrating blade

Period against length

gradient $G = \frac{\ln 0.45 - \ln 0.15}{\ln 30 - \ln 15} = \frac{\ln 3}{\ln 2}$

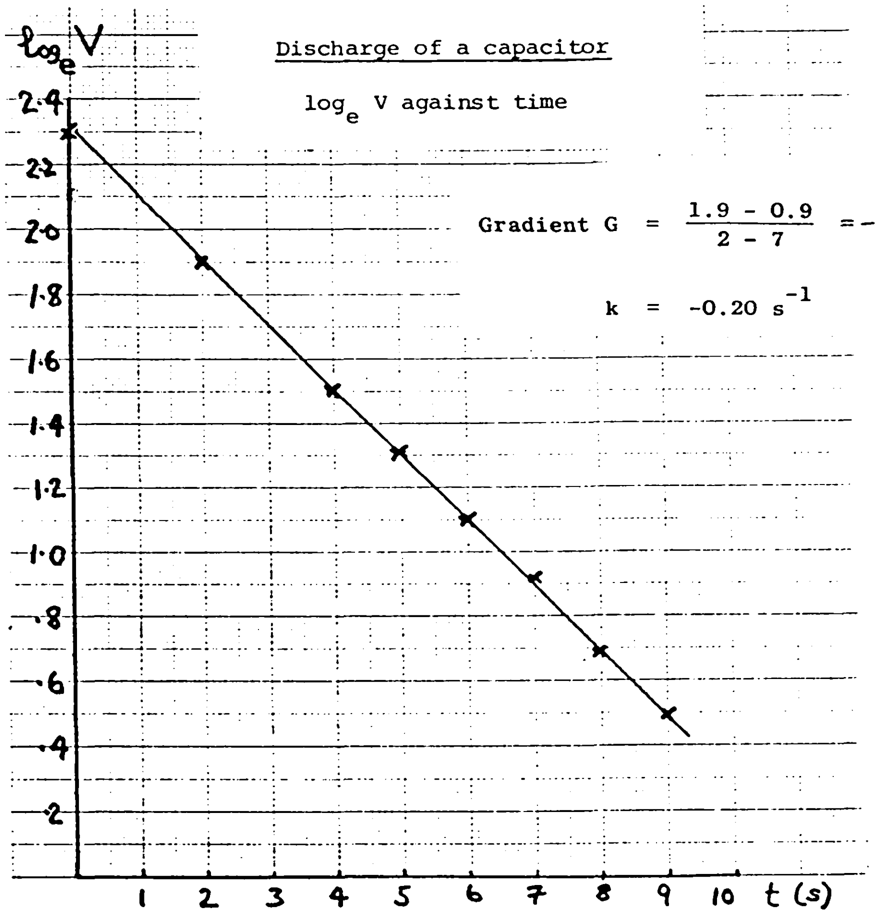
$= 1.58$

Note $G = \frac{39 \text{ mm}}{24.5 \text{ mm}} = 1.59$



Absorption of light-response of photodiode

(Photodiode current)$^{-\frac{1}{2}}$ against lamp-photodiode housing distance

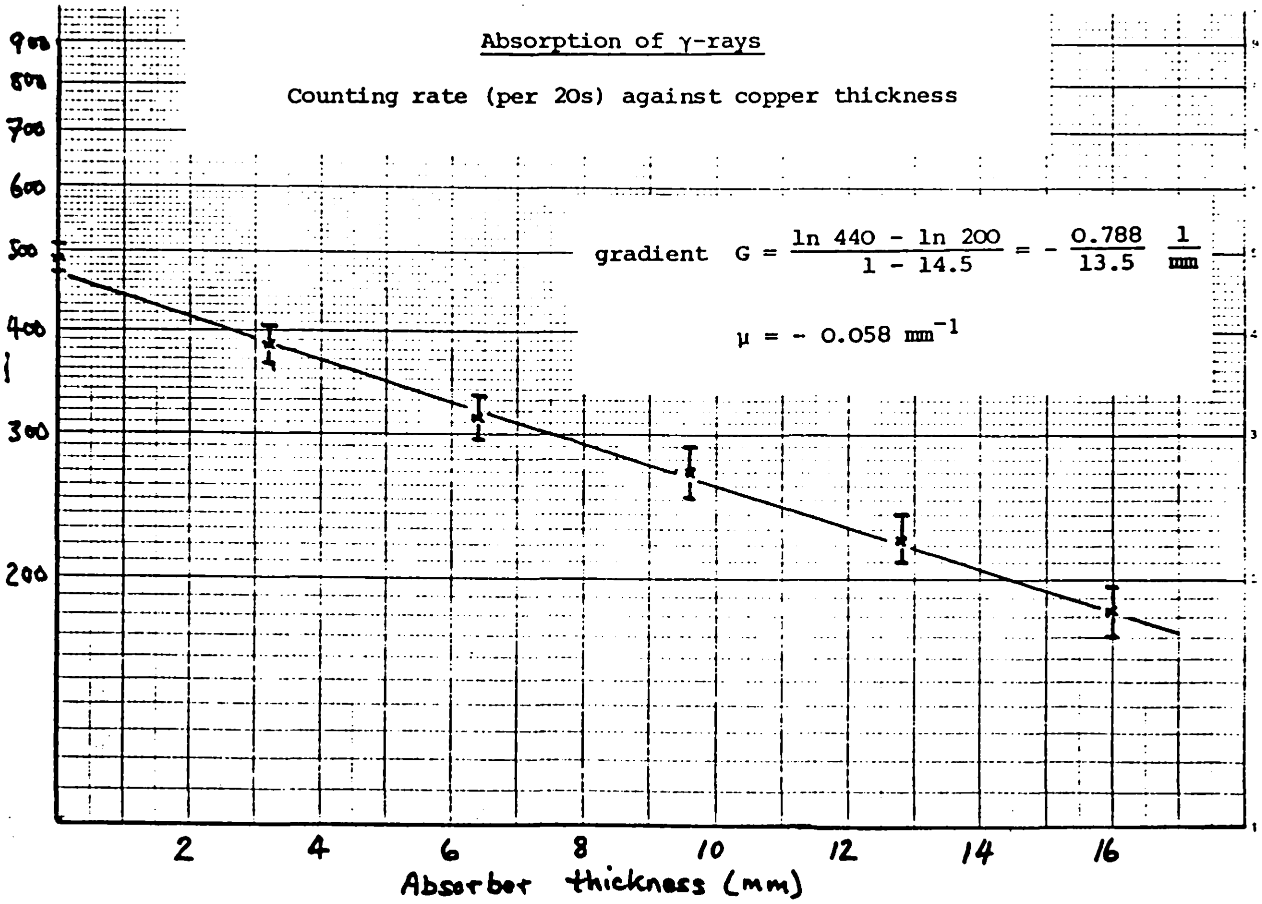


Discharge of a capacitor

$\log_e V$ against time

$$\text{Gradient } G = \frac{1.9 - 0.9}{2 - 7} = -\frac{1.0}{5}\ \frac{1}{s}$$

$$k = -0.20\ s^{-1}$$



Absorption of γ-rays

Counting rate (per 20s) against copper thickness

$$\text{gradient } G = \frac{\ln 440 - \ln 200}{1 - 14.5} = -\frac{0.788}{13.5}\ \frac{1}{mm}$$

$$\mu = -0.058\ mm^{-1}$$

Treatment of Observational Errors

1. a) If a quantity b is measured only once, a ***personal estimate*** δb of the precision of the measurement should be made, by allowing for the method and the judgment of the observer.

   b) If a quantity is measured many times, the ***adjusted deviation*** should be calculated, as shown below.

   If a quantity is measured n times, a_1, a_2, a_3 ....a_n the best value to be taken is the mean $\bar{a}$ where:

$$\bar{a} = \frac{1}{n}\sum_{i=1}^{n} a_i$$

The ***standard deviation*** σ is a measure of the spread in the measurements of the quantity a about the mean.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i} (a_i - \bar{a})^2} \qquad \text{for large n.}$$

For small n (e.g. n < 10) it is better to use the ***adjusted standard deviation s***

$$s = \sqrt{\frac{\sum (a_i - \bar{a})^2}{(n - 1)}}$$

If we calculate $\bar{a}$, as above, from n measured numbers a_i, this measured mean $\bar{a}$ will still differ from the *true* mean. The standard deviation of $\bar{a}_{(\text{measured})}$ about the true mean value is:

$$\delta a = \frac{\sigma}{\sqrt{n}} \quad \text{or} \quad \frac{s}{\sqrt{n}}$$

and is called the standard error in the measurement of a, ie $\bar{a} \pm \delta d$.

NB The number of ***significant figures*** quoted in the result should be consistent with the stated accuracy (see following example).

2. This section is intended to set out rules and procedures which should be adopted in determining the error in a quantity which is derived from other quantities subject to experimental error.

   (Notation: measured quantities will be denoted by letters from the beginning of the alphabet, and derived quantities by X, Y, Z. The error in any quantity will be denoted by prefixing the name of the quantity by δ, e.g. δa, δX).

i) *Error in a Sum or Difference*

If $x = a + b$

then $\delta X = \surd (\delta a)^2 + (\delta b)^2$

Similarly, if $X = a - b$

then $\delta X = \surd (\delta a)^2 + (\delta b)^2$

This can obviously be extended to the sum or difference of any number of quantities. The general rule is -

> *The error in a sum or difference of quantities is the square root of the sum of the squares of the errors in the quantities.*

e.g. if $X = a + b - c$

where $a = (34.1 \pm 0.1)m$

$b = (17.31 \pm 0.05)m$

$c = (21.0 \pm 0.2)m$

then $X = (30.41 \pm 0.229)m$

which we would round off to $X = (30.4 \pm 0.2)m$

ii) *Error in a Product or Quotient*

If $X = ab$ or $X = \frac{a}{b}$

then $$\frac{\delta X}{X} = \sqrt{\left(\frac{\delta a}{a}\right)^2 + \left(\frac{\delta b}{b}\right)^2}$$

Again this can be extended to products and quotients of any number of quantities. To state the rule in words we must define a new term 'fractional error'. The fractional error in a quantity is the error in that quantity divided by the magnitude of the quantity.

(e.g. if $a = 25 \pm 3$, the fractional error in a is $\frac{\delta a}{a} = \frac{3}{25} = 0.12$).

We can now state the rule as follows:

> *The fractional error in a product or quotient of quantities is the square root of the sum of the squares of the fractional errors in those quantities.*

iii) Error in a Quantity Raised to a Power

If $x = a^n$ where n is any number

then $\frac{\delta X}{X} = n\frac{\delta a}{a}$

*i.e. **the fractional error** in a quantity raised to the power n is n times the fractional error in the quantity.*

e.g. $X = \sqrt{a}$ where $a = (9.0 \pm 0.1)s$

then $\frac{\delta X}{X} = \frac{1}{2} \times \frac{\delta a}{a} = \frac{0.05}{9.0}$

$\therefore \quad \delta X = 3 \times \frac{0.05}{9.0} = 0.017$

$X = (3.00 \pm 0.02)s^{1/2}$ rounded off to two places.

iv) Error in a Function

If $X = f(a)$ where $f(a)$ is some function of a, then

$\delta X = \delta a \frac{df}{da}$

i.e. the error in a function of a quantity is the error in the quantity times the derivative of the function a.

e.g. $X = \sin a$ where $a = 60° \pm 1°$

we have $\delta X = \delta a \frac{d}{da}(\sin a)$

$= a \cos a$

$= 0.018 \times {}^1/_2$ *(Note that we have expressed* a *in **radians**)*

$= 0.009$

$\therefore \quad X = 0.866 \pm 0.009$

These are all the rules which you will require for error calculations in the Ordinary Laboratory. To assist you in applying these rules some examples follow. Of course the demonstrators exist to help with just this sort of problem - ***if in doubt ask.***

3. Applications

The calculation of the error in a quantity like $X = a + b$ is straightforward, but how do you approach an expression like

$$X = \frac{1}{2a}\sqrt{\frac{b}{c}}\ ?$$

The best technique is to perform the error calculations in the same order as the arithmetical calculation:

Here the order of calculation is,

i) $Y = \frac{b}{c}$

ii) $Z = \sqrt{Y}$

iii) $X = \frac{Z}{2a}$

So the error calculation proceeds:

i) $\frac{\delta Y}{Y} = \sqrt{\left(\frac{\delta b}{b}\right)^2 + \left(\frac{\delta c}{c}\right)^2}$

ii) $\frac{\delta Z}{Z} = \frac{1}{2}\frac{\delta Y}{Y}$

iii) $\frac{\delta X}{X} = \sqrt{\left(\frac{\delta a}{a}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2}.$

Hence

$$\delta X = X\left[\left(\frac{\delta a}{a}\right)^2 + \frac{1}{4}\left\{\left(\frac{\delta b}{b}\right)^2 + \left(\frac{\delta c}{c}\right)^2\right\}\right]^{1/2}.$$

As another example, consider

$$\frac{1}{X} = \frac{1}{a} + \frac{1}{b}$$

Show that the error in X is δX given by:

$$\delta X = X^2\left[\left(\frac{\delta a}{a^2}\right)^2 + \left(\frac{\delta b}{b^2}\right)^2\right]^{1/2}.$$

4. Graphical Presentation

Suppose an experiment involves measurements of two quantities x and y, which are related by:

$$y = k f(x)$$

where **k** is a physical constant to be determined by the experiment.

On a graph of y against f(x) let the gradient be G. Generally a range of gradients δG (minimum to maximum slopes) can be drawn through the error bars.

$$\frac{\delta k}{k} = \frac{\delta G}{G}$$

hence k ± δk.

Examples of Calculations of Observational Errors

Remember the two simple starting points:

i) If you measure a quantity only once or twice, make a ***personal estimate*** of the observational error.

ii) If you repeat the measurement of a quantity at least five times, calculate the mean value and its ***adjusted standard deviation.***

Then follow the rules and examples on the notes on ***"Treatment of Observational Errors".***

1. For example, consider Newton's rings experiment to determine the wavelength of sodium light.

We have $\frac{r_m^2}{R} = m\lambda$.

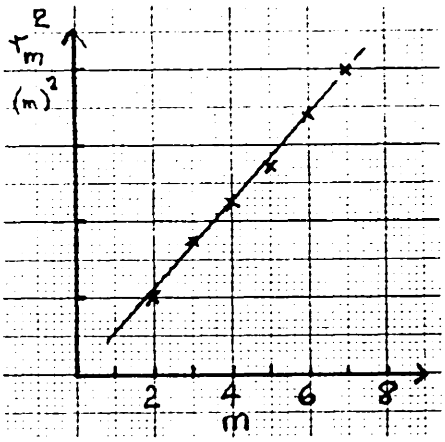
In your experiment λ and R are constant.

Let $r_m^2 = mK$ where K is a constant.

The graph of r_m^2 against m should be linear.

The gradient of this graph

$$G = \frac{r_{m_2}^2 - r_{m_1}^2}{m_2 - m_1}$$



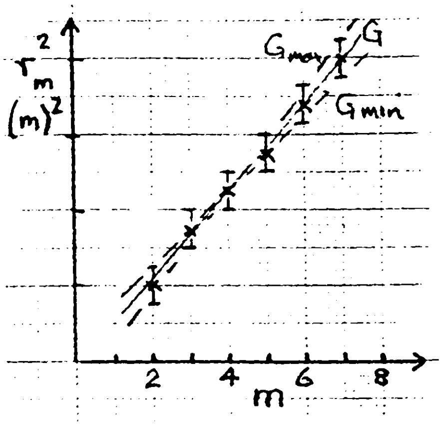
Now m is a number, the order of the interference ring. From doing the experiment you can make a personal estimate of the error in each value of r.

We recall that

$$\frac{\delta(r_m^2)}{r_m^2} = \frac{2\delta(r_m)}{r_m}$$

You can then mark the errors in r_m^2 by bars on the points in your graph.

You can therefore determine the minimum gradient G_{min} and the maximum gradient G_{max}, as well as the mean gradient G.



From $\frac{r_m^2}{R} = m\lambda$

$$\lambda = \frac{1}{R} \cdot \frac{r_m^2}{m} = \frac{G}{R}$$

and hence $\frac{\delta\lambda}{\lambda} = \sqrt{\left(\frac{\delta G}{G}\right)^2 + \left(\frac{\delta R}{R}\right)^2}$

where δR can be found by the method discussed in the following example.

2. Take as another example the calculation of the power of a lens, and its error, from data obtained on an optical bench.

We have

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad \text{or} \qquad \frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

Rewrite this as

$$U + V = F$$

From optical bench measurements we have values of u and v.

We make personal estimates of the observational errors of u and v

$u \pm \delta u$ and $v \pm \delta v$.

The objective of the measurements is to obtain $F \pm \delta F$.

Now $\frac{\delta U}{U} = \frac{\delta u}{u}$

or $\delta U = U\frac{\delta u}{u} = \frac{\delta u}{u^2}$.

For the error in a sum

$$\delta F = \sqrt{(\delta U)^2 + (\delta V)^2}$$

$$= \sqrt{\left(\frac{\delta u}{u^2}\right)^2 + \left(\frac{\delta v}{v^2}\right)^2}$$

Suppose $u \pm \delta u = (0.600 \pm 0.002)$m and $v \pm \delta v = (0.350 \pm 0.002)\text{m}$

Hence $F = U + V = \frac{1}{0.60} + \frac{1}{0.35} = 4.53$ dioptres

and $$\delta F = \sqrt{\left(\frac{0.002}{0.60^2}\right)^2 + \left(\frac{0.002}{0.35^2}\right)^2} = 1.7 \times 10^{-2}$$

Finally $F \pm \delta F = (4.53 \pm 0.02)\text{D}$.

Appendix 6-1.

MELDE'S EXPERIMENT

The objective of this experiment is to measure the frequency of the a.c. mains supply by Melde's method.

The EXPERIMENTAL ARRANGEMENT is shown schematically in figure 1; a steel wire fixed at one end, passes over a pulley so that a tension F may be applied at the other end of the wire. There is an alternating current in the wire, supplied by the step-down transformer T. The wire passes between the poles of a permanent magnet M.

Standing waves can be generated in the system of the wire which can be considered to be fixed (approximately) at both ends. Only certain forms of oscillation can take place - the normal modes of the wire. Remember in this experiment the (unknown) frequency is constant. Different normal modes can be excited by altering the tension of the fixed length of wire. The energy to generate the oscillations of these normal modes is obtained from the forced oscillation of the wire, carrying an alternating current in the magnetic field. This is described by the Lorentz force (refer to your textbook).

The essential PROCEDURE is to generate different standing wave patterns in the wire by changing the tension F. The system is tuned, by varying F, to give the maximum amplitude of oscillation for a given mode m - see figure 2. Let the best value of F which corresponds to a given m be F_m . You are exploring a resonance phenomenon here, and the general shape of the curve showing the relationship between the tension and the amplitude of oscillation is illustrated in figure 3.

The various steps you will need to follow are :
- (i) select 12 volts, say, in the step-down transformer T and switch on
- (ii) add about 10 grams to the scale pan (the mass of which is given)
- (iii) see if you can detect any vibration of the wire:
  - (a) if so, tune the tension to obtain F_m for that mode.
  - (b) if not, vary the tension by a few grams - repeat
- (iv) now reduce the voltage from T and see if you can obtain a better value of F_m(see question b)
- (v) note that $m\sqrt{F_m}$ is a constant (see equation [1] below). Use this to help you to seek your next resonance.

Obtain a set of values of m and F_m over as large a range of m as the apparatus allows. Caution : small m means large F - take care to avoid stretching or breaking the wire.

ANALYSIS

The frequency f of vibration of the wire is given by [refer to Appendix]

$$f = \frac{m}{2L}\sqrt{\frac{F_m}{d}} \qquad [1]$$

where m is the mode (a number - the number of antinodes of the vibrating wire)
L is the length of wire between the fixed point and the pulley contact
F is the tension at resonance for the m'th mode
d is the linear density of the wire (ie mass per unit length) which is a given quantity.

From your knowledge of equation [1] choose functions of the measured quantities m and F_m to give a linear plot. Why might m against $F_m^{-\frac{1}{2}}$ be a good choice? From the gradient of this graph calculate a value of f, the mains frequency.

Estimate how well you have obtained the tensions F_m , and show these uncertainties as error bars on your graph. Evaluate the gradient error, and hence calculate the error δf in f.[Refer to the worked example of an error calculation in General Notes.]

Questions:

(a) does the equation $f = \frac{m}{2L}\sqrt{\frac{F_m}{d}}$ have the correct dimensions ?

(b) what is the significance of changing the current in the wire ?

(c) does it matter where the magnet M is positioned ? Why ?

(d) how sharp is the resonance curve (figure 3)? Obtain data of the amplitude of oscillation as a function of F_m for a given mode m.

APPENDIX

The velocity of a transverse travelling wave on a stretched wire is given by

$$v = \sqrt{\frac{F}{d}}$$

For a harmonic wave $v = f\lambda$

The length L of vibrating wire is given by

$$L = m\frac{\lambda}{2} \qquad \text{(see figure 2)}$$

Hence equation [1] follows

$$f = \frac{m}{2L}\sqrt{\frac{F_m}{d}}$$

FURTHER EXERCISE

Measure the linear density of the sample piece of wire provided.

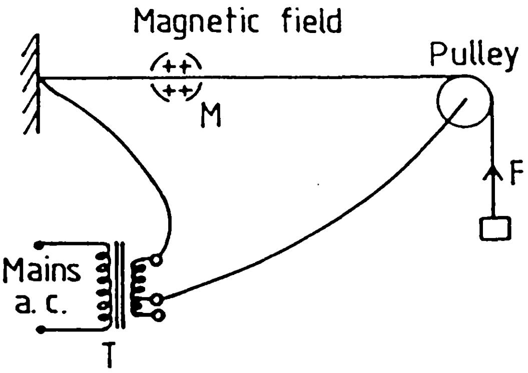


Figure 1

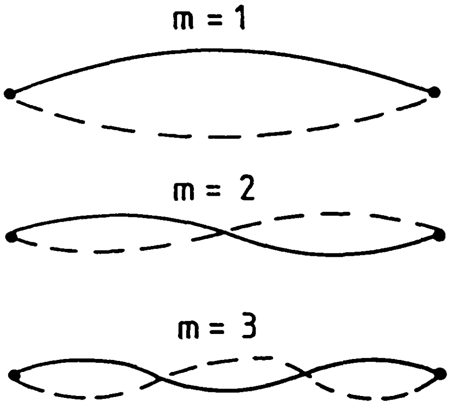
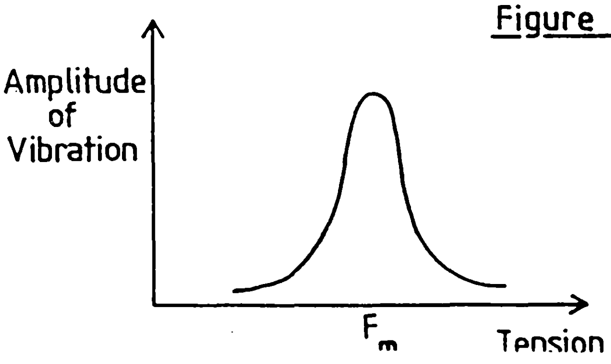


Figure 2



OPTICS

The OPTICS experiments are carried out over two consecutive weeks in a continuous scheme of work.

I REFRACTION

The objective of this part of the experiment is to measure the index of refraction of a solid and of a liquid, by a method using total internal reflection of light.

SEMI- CIRCULAR SLAB METHOD

PROCEDURE

(a) A semi-circular slab of glass or perspex is placed centrally and parallel to the protractors on the stand. Its position is adjusted until the line between the black and the white parts of the plastic base appears unbroken when viewed near vertically through the slab and through air,outside the slab.

(b) Next scan your eye down from a vertical position and observe that this line is not visible through the slab when viewed at large angles with respect to the vertical i.e. the slab appears dark.

(c) Measure the angle (from the vertical) at that position where the image of the line is not visible. For this situation, figure 1 shows the limiting ray from A. One way to measure this angle accurately is to place a card horizontally across the edges of the protractors and move the card and your eye down and then read the angles (left and right scales) when you think the line is just no longer visible. This special angle is the **CRITICAL ANGLE C** for glass (or perspex) and air. You should want to repeat this measurement a few times and calculate the average value of C. Also estimate the observational error in C.

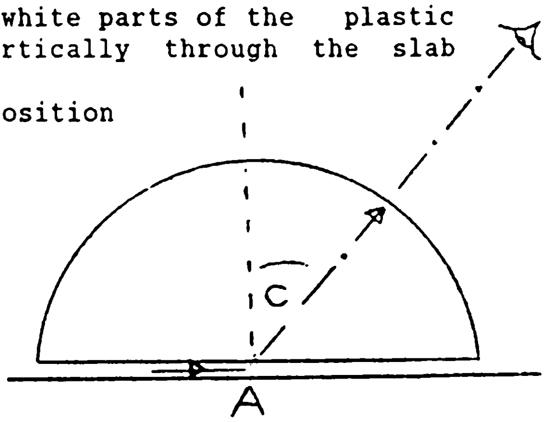


fig 1

ANALYSIS

Snell's law can be stated

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \qquad [1]$$

for the rays in figure 2.
Use this relation to calculate the index of refraction of the glass (or perspex) of the slab when $\theta_1 = C$ (in which case $\theta_2 = \pi/2$), for air below the slab.

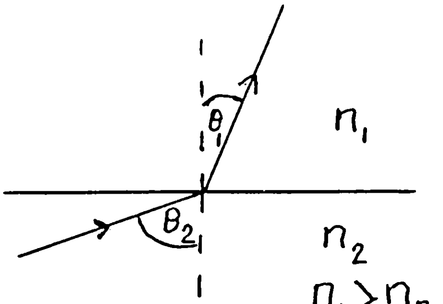


fig 2

Repeat the measurement with a thin film of water between the base of the stand and the slab. Measure the new critical angle C' for glass (or perspex) and water.
Remember when you use [1] this time that the lower material is no longer air. Calculate the index of refraction of water.

II SPHERICAL MIRRORS and LENSES

The objectives of this experiment

- (i) to set up and use correctly an optical bench
- (ii) to study how images are formed by simple spherical mirrors and lenses
- (iii) to make measurements of object distances, image distances and focal lengths of these mirrors and lenses
- (iv) to use the relationship

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

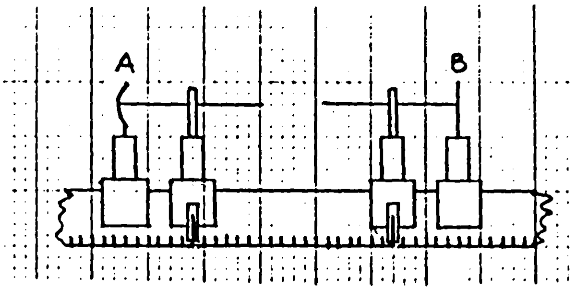
- (v) to draw ray diagrams to correspond to the experimental situations.

INTRODUCTION

Recall that the focal length of a spherical mirror [or lens] is defined as the distance from the mirror [or lens] to the image of an infinitely distant object.

It is a good routine to TABULATE readings.

To measure distances accurately on an optical bench you should use a VERTEX POINTER. To measure the distance between A and B on an optical bench follow the steps:



- (i) place the pointer with its left point touching A. Read the position of the pointer holder by using the scribe mark on the perspex tab against the metre scale on the optical bench.
- (ii) place the pointer with its right hand point touching B. Read the position of the holder as above.
- (iii) The distance required is equal to the displacement of the pointer holder plus the length of the vertex pointer.

(A) MIRRORS

View the video programme on spherical mirrors.

Select the CONCAVE mirror.

PROCEDURE

1

- (a) Use a distant source of light [distant means that 1/s is negligibly small - greater than 5 m] to form an image in the focal plane of the mirror.
- (b) Measure f directly.
- (c) Draw the corresponding ray diagram.

2

- (a) Use the illuminated triangle in the screen of the lamp as an object.
- (b) Form an image in the object plane.
- (c) Draw a ray diagram of this situation.
- (d) Measure the radius of curvature directly, and hence calculate f.

3

(a) With the same object, use a screen with a large aperture and form an image on this screen by reflection off the mirror, as shown in the ray diagram.

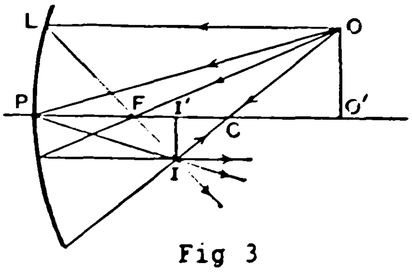


Fig 3

(b) Measure the object and the image distances , and hence calculate f.
(c) Repeat for a different object distance.

View the video programme on the parallax method.

Select the CONVEX mirror.

4

(a) Use an illuminated vertical pin as an object placed near the mirror. A VIRTUAL image will be formed behind the mirror.
(b) Use a second vertical pin, an image marker, behind the mirror so that while viewing the image of the object pin in the mirror you can also see the top of the image marker above the mirror, aligned parallel to the axis. Use the method of no parallax to set the image marker at the position where the image appears to be.
(c) Measure the distance from the mirror to this image marker pin - this gives a VIRTUAL image distance. Also measure the REAL object distance.
(d) Calculate the focal length of the convex mirror.
(e) Repeat for a larger object distance.
(f) Draw a ray diagram.

(B) LENSES

In the following measurements the focal lengths of various lenses are obtained by different methods. Express the focal lengths f in metres and the powers P in dioptres, where P = 1/f(m) .

Select a CONVERGING lens.

PROCEDURE

1

(a) Use the illuminated triangle in the screen of the lamp as an object
(b) Form an image on the object plane by reflection from a plane mirror on the side of the lens opposite to the object.
(c) Study the ray diagram and be convinced that it describes the experimental situation.

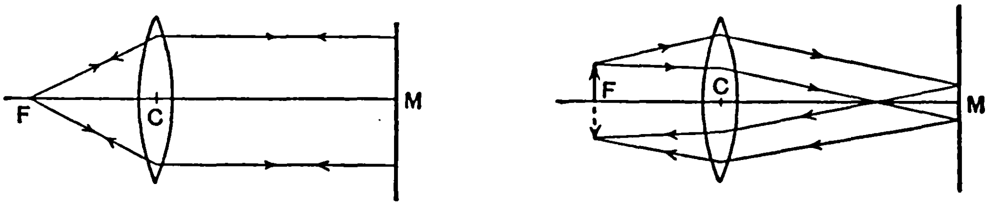


Fig 4 **Lens and plane mirror. Object at principal focus.**

(d) Find the focal length and the power of the converging lens.
(e) Repeat for all converging lenses (of 50 mm diameter) provided.

2

(a) Select the converging lens with the shortest focal length.
(b) With the same object as above form a real image of the illuminated aperture on a screen.
(c) Measure the object distance and the image distance, and hence calculate the focal length and power of the converging lens.
(d) Repeat for a different object distance.

3

(a) Place two converging lenses in contact, in the special holder.
(b) Measure the power of the combination P_c by one of the above methods.
(c) Compare P_c with the algebraic sum of the separate powers, P_1 and P_2 of the individual lenses. Does $P_c = P_1 + P_2$ hold ?

4

(a) Select the converging lens with the shortest focal length and put it in contact with the diverging lens.
(b) Use method 1 to obtain the power of the combined lenses, and hence the power of the diverging lens, using

$$P_c = P_1 + P_2$$

5

(a) With the same converging lens, form a real image on a screen at a short distance from the lens. Note the position of the image plane.
(b) Place the diverging lens on the original image side of the converging lens (but NOT in contact), and form a new real image on the screen.
(c) The first image is a VIRTUAL OBJECT for the diverging lens [and this distance must be measured from the diverging lens] and the final image is clearly real.
(d) Calculate the focal length and power of the diverging lens. Compare this with the result from 4.
(e) Be satisfied that you understand the ray diagram for this case.

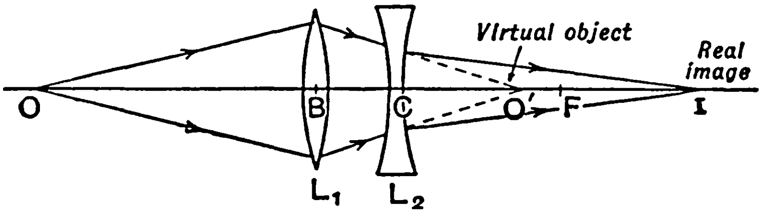
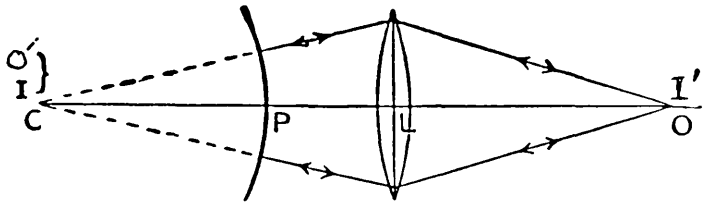


Fig 5 —Converging lens *not in contact* with diverging lens.

III LENS and MIRROR COMBINATIONS

1 Converging lens and convex mirror

On the optical bench set up the following arrangement; use a converging lens of known and long focal length. Hence measure the radius of curvature of the convex mirror.

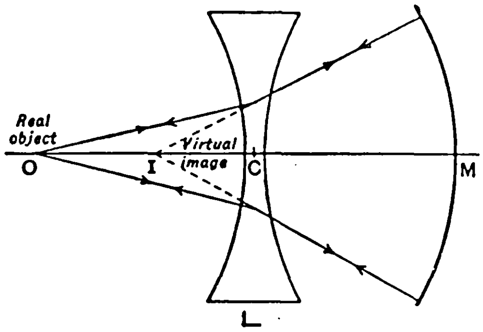


Locating centre of curvature of convex mirror.

Fig 6

2 Diverging lens and concave mirror.

On the optical bench set up the arrangement shown in figure 7; use a concave mirror of known radius of curvature, and hence take measurements to obtain the focal length of the diverging lens.



The virtual image *I* formed by the lens *L* is thus at the centre of curvature of the mirror.

Fig 7

IV DEFECTS OF THIN LENSES

1 Chromatic aberration

This is an effect which arises because the refractive index of glass is a function of the wavelength of light transmitted through it.

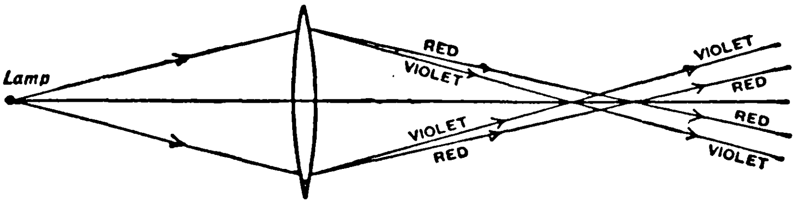


Fig 8 —Demonstration of chromatic aberration.

Use the triangular screen as object O, and use the screen B with the 10 mm central hole in front of the lens. Place a blue (or green) filter at O and find the position of the image. Repeat for the red filter.

What are your conclusions?

Is your result consistent with the fact that a prism deviates red light least?

2 Spherical aberration

In this part you will investigate the effect of rays passing through a lens at different distances from the principal axis.

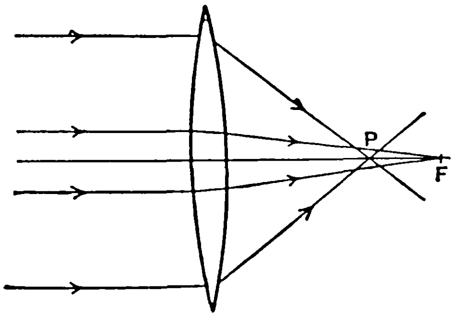


Fig 9 —Spherical aberration.

Use the illuminated triangle as object O. Cover the central portion of the 63 mm diameter biconvex lens L with the cardboard disc D and form a sharp image on the screen or ground glass S. Ensure that O lies on the principal axis. Measure object and image distances. Leave O and L untouched, readjust S and repeat the measurement.

Remove the disc and use the screen with the 10 mm central hole, B. Repeat the above measurements, the object distance remaining unchanged.

What are your conclusions?

3 Astigmatism

This is a lens defect which appears when a narrow beam of incident light falls obliquely on the lens.

Replace the triangle with the small cross as object with one line vertical. Cover the lens with screen B and turn the lens through an angle of about 30° about a vertical axis.

Examine the positions where an image is formed, (a) of the vertical line of the cross and (b) of the horizontal line. Can you find a position where the whole cross is in focus?

VIBRATING BLADE

GENERAL AIM :

(i) to plan an experiment - e.g. which measurements to take?
(ii) to analyse data using log-log graphs
(iii) and hence to investigate whether the data can be fitted by a power law.

SPECIFIC OBJECTIVES

You will investigate experimentally the variables which affect the period of vibration T of an oscillating uniform steel blade. For example

the length L of the blade
the total load M at the free end
the amplitude of oscillation θ, etc

INTRODUCTION

Plan your investigation.

You should realise that in an experiment which has many variables the simplest way to proceed is to measure how two of them behave, when all the rest are kept constant e.g.

for a constant unloaded blade (M = 0) and a constant amplitude θ (which should be noted), how does T depend on L?

In the planning of the experiment, decide how many different values of a given variable (eg L) you want to measure and whether these should be evenly spaced. Also remember you are going to analyse the data graphically - this usually implies that you will need at least six values of a given variable.

Power law.

Think of the oscillating systems with which you are familiar e.g. simple pendulum, or oscillating mass at the end of a spring. Recognise that in these cases the behaviour of the period can be described by a mathematical model which is a power law

$$T = k P^n$$

where k is a constant, P is a variable (length of the pendulum or mass on end of the spring), and n is a numerical constant.

In the vibrating blade experiment we want to find an expression relating T and L for a given M, for example. On the basis of our knowledge of other oscillating systems, suppose we suggest

$$T = k_1 L^a \qquad \{1\}$$

where k_1 and a are constants to be found from the measured data.

From {1} it follows that

$$\log_{10} T = a \log_{10} L + \log_{10} k_1 \qquad \{2\}$$

PART I : TO INVESTIGATE HOW T DEPENDS ON L FOR AN UNLOADED BLADE

PROCEDURE

Find out how to measure the period T of vibration of the blade.
Decide what is meant by the length L of the vibrating blade - discuss with your demonstrator if necessary.
Make measurements of T as a function of the variable L, noting the values of all parameters you are holding constant.

ANALYSIS

To test if {1} fits your experimental data, plot $\log_{10}T$ against $\log_{10}L$. If this is a straight line graph, then {1} is a valid description of your data. In which case you can determine both k and a. Here

$$a = \frac{\log_{10}T_2 - \log_{10}T_1}{\log_{10}L_2 - \log_{10}L_1}$$

When log/log paper is used a is the geometrical gradient of the graph. [Refer to General Notes - Graphical Analysis].

You can then calculate a value of k_1 from one set of values of T and L. Alternatively from {2} you can see that when L = 1 (units),

$$[\log T]_{L=1} = [\log k_1]_{L=1}$$

Hence from your log/log graph read the value of T when L=1. This value of T must be equal to k_1. Check that your calculated value of k_1 agrees with this. Derive the units in which k_1 is expressed - see equation {1}.

PART II : TO INVESTIGATE HOW T DEPENDS ON L FOR ANOTHER M

The same treatment can be applied to data of T and L for a different choice of M.

PART III : TO INVESTIGATE HOW T DEPENDS ON M FOR A CONSTANT L

Likewise you can investigate how T varies with M for a constant L. Use

$$T = k_2 M^b$$

Hence obtain values of b and k_2.

Note

It is useful to compare the use of both linear graph paper (as in your notebook) and log/log graph paper in the graphical analysis of this experiment. Again refer to the Graphical Analysis in General Notes.

OBSERVATIONAL ERRORS

Estimate how accurately you have measured the various quantities in the experiment. See if you can plot these as error bars on your graphs, and hence attempt to evaluate the observational errors in a, k_1, b and k_2. Discuss with your demonstrator.

FURTHER EXERCISE

Does it matter whether the vibrations of the blade take place in the horizontal or in the vertical plane ?

MAGNETIC FIELD OF A SOLENOID

GENERAL AIM : (i) to investigate the variation of magnetic field along the axis of a long solenoid.
(ii) to compare values of the magnetic field B on the axis of the solenoid obtained experimentally, from Faraday's law and from Ampere's law.

INTRODUCTION : from your textbooks find out what is meant by a solenoid, and how to calculate the magnetic field along its axis by using Ampere's law.

PROCEDURE

(a) Set up the circuits shown in figure 1; the *primary* circuit consists of the solenoid, a variable power supply and a current meter. The separate *secondary* circuit includes a search coil, and a ballistic galvanometer G with its damping resistor R. G is a Scalamp galvanometer used in the DIRECT switched position.

(b) Devise a means of being able to measure exactly where the centre of the search coil is positioned. Choose a coordinate x to describe the position of the search coil.

(c) Establish a current of a few hundred mA in the solenoid (primary circuit) by adjusting the variable power supply.

(d) Slide the search coil inside the former of the solenoid to a position approximately in the middle of the length of the solenoid. Investigate the response of the ballistic galvanometer G in the secondary circuit when the current is *made and broken* in the solenoid. Note the magnitude and direction of these throws.

(e) Now measure the throw d of the galvanometer as a function of position of the search coil along the axis of the solenoid, for *a constant* solenoid current I (which should be noted). Decide how many positions you need to measure, and whether these should be evenly spaced or not. From symmetry you should expect that measurements in one half of the length of the solenoid would give you information about the other half of the solenoid. Also take readings outside the limit of the windings of the solenoid.

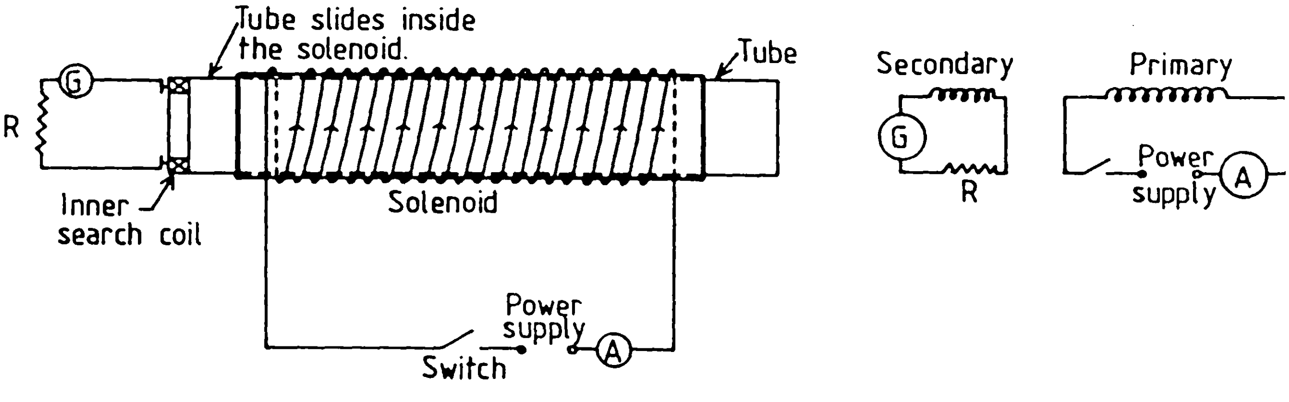


Figure 1

ANALYSIS

The deflection d of the galvanometer reading is related to the magnetic field B by (see Appendix 1)

$$B = \alpha\ d \qquad [1]$$

where the constant $$\alpha = \frac{k\ R_2}{A\ N}$$

Here k is the *quantity sensitivity* of the galvanometer (expressed in ''C per mm when d is in mm). k is marked on top of the instrument.

A is the cross sectional area of the search coil (see figure 2)

N is the number of turns of this coil (marked on coil)

R_2 is the *total* resistance of the secondary circuit

$$R_2 = R + R_G + r \qquad [2]$$

where R_G is the galvanometer resistance (marked on the face plate of the instrument).

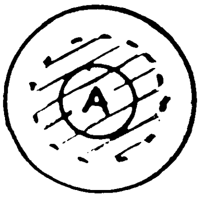


Figure 2

(a) Plot a graph of B against x.

(b) Calculate from Ampere's law the value of B on the axis at two positions, at the centre and at the limit of the windings of the solenoid, using the expression (see Appendix 2) for B for a solenoid of finite length.

$$B = B_\infty \{ \cos\theta_1 - \cos\theta_2 \}/2 \qquad [3]$$

where $B_\infty = \mu_o n I$.

Here $\mu_o = 4\pi \times 10^{-7}$ Wb $A^{-1}m^{-1}$, a constant called the permeability of free space,

n is the *number of turns per unit length* of the solenoid

I is the current in the solenoid.

You will need to measure n, for example, by counting the number of turns in 50 mm and scaling it to a metre.

At the *two* positions on the axis obtain values of $\cos\theta_1$ and $\cos\theta_2$ from the geometry of the solenoid.

Plot these values of B from [3] on the same graph as (a) above.

(c) What conclusions can you make ?

APPENDIX 1

Faraday's law of electromagnetic induction can be stated:

$$\mathcal{E} = -\ d\Phi/dt \qquad [4]$$

This relates the induced emf $\mathcal{E}$ and the time rate of change of magnetic flux $d\Phi/dt$.

Also $$\mathcal{E} = R_2\ i = R_2\ dQ/dt \qquad [5]$$

where i and Q are the induced current and induced charge respectively.

In your experiment ϕ goes from 0 to BAN on making the circuit, and the charge goes from 0 to Q_T, where Q_T= kd and d is what is measured.

Hence equating the right sides of relations [4] and [5], and integrating we find that in *magnitude*

$$BAN = R_2 Q_T$$

Hence

$$B = \frac{(kd)}{AN} R_2 \qquad [6]$$

APPENDIX 2

For an infinitely long solenoid Ampere's law gives

$$B_\infty = \mu_o n I$$

When corrections are made to account for a finite length of a practical solenoid, we obtain

$$B = B_\infty \{ \cos \theta_1 - \cos \theta_2 \}/2$$

where θ_1 and θ_2 shown in figure 3 . Check that B goes to B_∞ when the length of the solenoid becomes large.

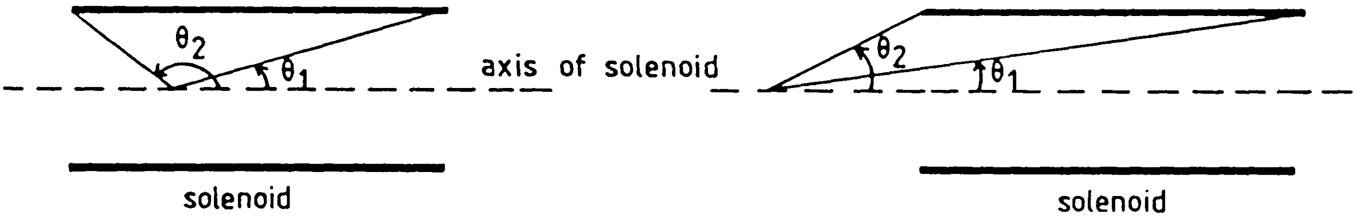


Figure 3

COMPOUND PENDULUM

GENERAL AIM

To study small oscillations of a compound pendulum and hence determine the acceleration due to gravity.

OBJECTIVES

(1) To measure the period T of small oscillations of a compound pendulum, using a photodiode gate.
(2) To plan the measurements i.e. to decide what range of variables to measure and their frequency.
(3) To establish graphically the relation between T^2 and h, the distance from the centre of gravity of the pendulum to the axis of suspension
(4) To calculate a value for g, the acceleration due to gravity.
(5) To estimate the observational error in g.

PROCEDURE

In the following procedure we are neglecting the change in the position of the centre of gravity and the moment of inertia of the pendulum due to the movable support brackets.

(a) Balance the pendulum on the knife edge (see figure 1) to determine the position of the centre of gravity
(b) Suspend the pendulum in one of the movable supports (figure 2). Measure h.
(c) Use the photodiode gate to measure the period T of *small oscillations.* Repeat the measurement a few times (up to five), note all data, and calculate the mean value.
(d) Repeat for different values of h. Consider how many different values of h you should take and their distribution along the axis of the pendulum (evenly spread or not ?).

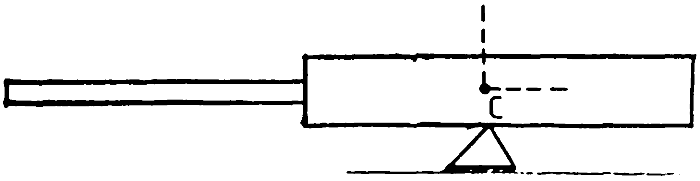


Figure 1

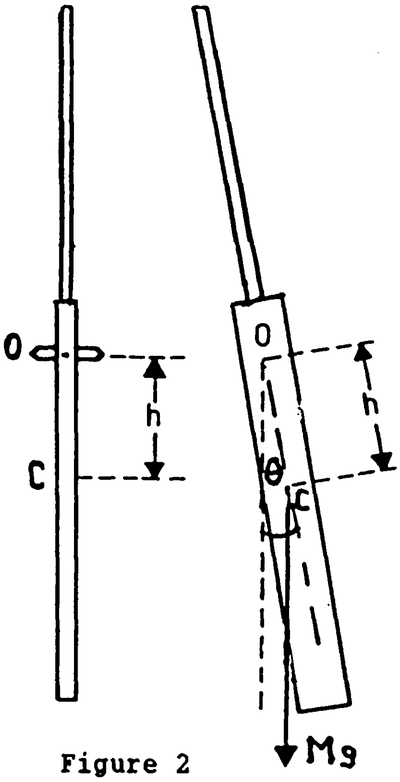


Figure 2

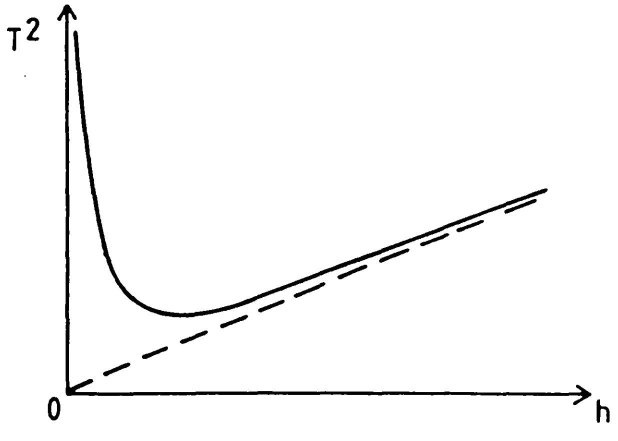


Figure 3

ANALYSIS

(a) Plot the mean values of T^2 against h. Call this graph 1. Does your graph look like figure 3, predicted from the mathematical model?

(b) If the model applies, select at least six values of T^2 and find the corresponding values of the intercept on the curve, giving h_1 and h_2.

(c) Plot a graph of T^2 against $(h_1 + h_2)$. Call this graph 2.

(d) From the gradient of this graph deduce a value of g.

(e) From the coordinates of the turning value $\{k_c, 8\pi^2 k_c/g\}$, determine a value of g. Here k_c is the radius of gyration of the rigid body about the centre of gravity C .

(f) Choose the Glasgow value for $g = 9.81$ m s^{-2} in the equation for the asymptote

$$T^2 = \frac{4\pi^2}{g} h$$

and select a value of T^2 within the range of your measurements to give h. Plot these coordinates $\{h, T^2\}$ and draw the asymptote from $\{0,0\}$ to this point. Is this a reasonable asymptote to the curve of your data ? Discuss with your demonstrator.

THEORY

For the rigid body shown, apply Newton's II law

$$- Mgh \sin\theta = I_o \alpha \qquad [1]$$

Here M is the mass of the body, θ is the angle which OC makes with the vertical, I_o is the moment of inertia of the pendulum about the point O, and α is the *angular* acceleration of the body. There is a minus sign because it is a *restoring* torque and positive θ is measured from the equilibrium position of the pendulum.

When θ is small we can take $\sin\theta = \theta$

In which case

$$\alpha = - \frac{M gh}{I_o} \qquad [2]$$

Now

$$\alpha = \frac{d^2\theta}{d^2t} \qquad [3]$$

Hence the motion is simple harmonic and the period is given by

$$T = 2\pi \sqrt{\frac{I_o}{M g h}} \qquad [4]$$

Now use the parallel axis theorem

$$T = 2\pi \sqrt{\frac{k_c^2 + h^2}{g h}} \qquad [5]$$

Here k_c is the radius of gyration of the rigid body about an axis through C.

We can rewrite this as

$$T^2 = \frac{4\pi^2}{g} \left\{ \frac{k_c^2 + h^2}{h} \right\} \qquad [6]$$

Note that as $h \to 0$, $T^2 \to \infty$ and as $h \to \infty$, $T^2 \to \infty$. Hence a graph of T^2 against h should be asymptotic to the T^2 axis and to the line

$$T^2 = \frac{4\pi^2}{g} h$$

as shown in figure 3. It can be shown that the curve has a turning value (a minimum) at the coordinates

$$\left\{ k_c , \frac{8\pi^2 k_c}{g} \right\}$$

We can rewrite [6] as

$$h^2 - \frac{T^2}{4\pi^2} gh + k_c^2 = 0 \qquad [7]$$

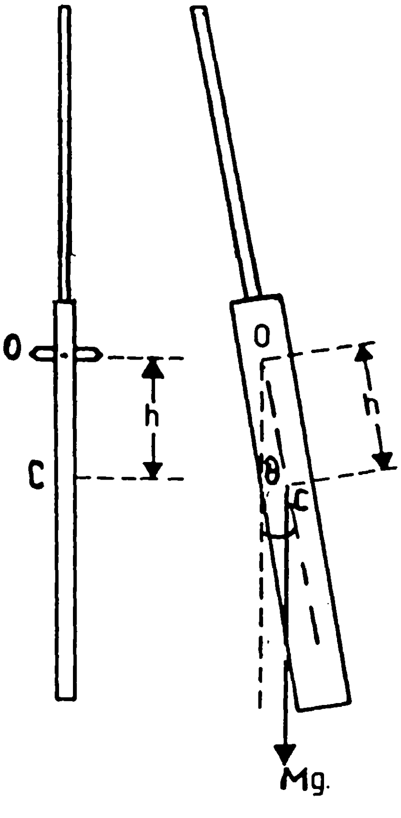
This is a quadratic in h, which can be written as

$$(h - h_1)(h - h_2) = 0$$

where h_1 and h_2 are the two roots.

Hence $\qquad (h_1 + h_2) = T^2 g / 4\pi^2$

This shows that a graph of T^2 against $(h_1 + h_2)$ will give a value of g from the gradient.



LAW of EXPONENTIAL GROWTH and DECAY

INTRODUCTION

There are many systems in nature for which the rate of change of the size of a quantity varies directly as the size of the quantity at that time e.g. population growth, radioactive decay. This is the law of exponential growth or decay.

OBJECTIVES

(i) to study a few physical systems which exhibit growth or decay behaviour

(ii) to enquire experimentally whether such systems can be described by the law

$$N = N_o \exp (kt)$$

and if so to evaluate the constant k. Here N is the value of a quantity after a time t when it had a value N_0 initially (time zero).

(iii) to take experimental data of a time-varying quantity

(iv) to analyse experimental data graphically, using log-linear graphs (which show exponential behaviour as a straight line).

EXPERIMENTS

(a) COOLING of a WARM BODY

Procedure

In this simple experiment you will investigate the cooling of warm water as a function of time.

Warm water (about 20 degrees above room temperature) should be put in the container, fitted with a lid and placed on its thermally insulated stand. Measure the temperature of the water as a function of time, taking room temperature at the same time. Keep the water gently stirred. Take data until the fall in temperature is about 10 degrees. Decide the frequency of taking data i.e. every 1/2, or 1 or 2 minutes or .... What determines this decision ?

Analysis

Let D = ($\theta - \theta'$) where θ is the temperature of the water, and θ' is room temperature.

Can your experimental data be described by the form

$$\frac{dD}{dt} = - k \ D$$

i.e.is a graph of ln D against time linear? [Refer to Appendix (I),below]. If so , evaluate k. [Refer to General Notes - Graphical Analysis. How to evaluate the gradient of a log/linear graph].

Now consider the units of k; you will see from the general expression

$$\frac{N}{N_0} = \exp (kt) \qquad \{4\}$$

that (kt) on the right side is dimensionless since it is the power of the exponential function. For example if t is expressed in units of seconds, the units of k must be $[\text{seconds}]^{-1}$. Therefore when you quote the result of k in this experiment, also give the appropriate units.

Estimate how well you have measured both θ and θ', hence calculate the observational error in D. [Refer to your General Notes - Treatment of Observational Errors].

(b) DISCHARGE of a CAPACITOR

Procedure

In this experiment you will investigate how the potential difference across an initially charged capacitor varies with time when it has been connected in parallel with a resistor. Here the resistor is the resistance of a voltmeter.

Connect the circuit 1, and refer to the bench notes for help in making other connections. Choose a power supply voltage E of 10 volts.

When the switch S is closed the capacitor charges, and the potential difference across it is shown by the voltmeter. Let the starting potential difference be V_o.

You require to make voltage-time readings in a situation when both time and voltage change continuously. Open switch S and read V_1 at a time t_1 . Recharge the capacitor (close S),check V_o . Open S read V_2 at time t_2 . Repeat.

Analysis

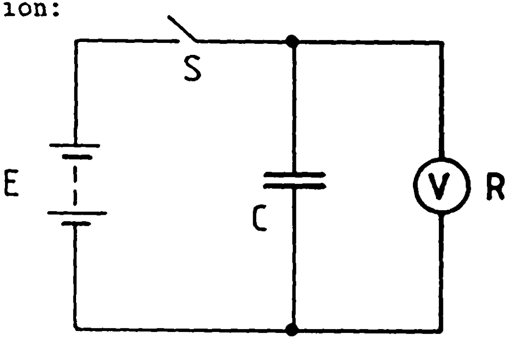
From your measurements plot a graph of lnV against t. Is this linear, within the estimated observational errors ? If so, evaluate k for this case and its observational error δk. Remember the units of k .

In this experiment you are investigating the relation:

$$V = V_o \exp(-kt)$$
$$= V_o \exp(-t/RC) \qquad (5)$$

where RC is the characteristic TIME CONSTANT of the circuit. Does your value of k agree with 1/RC ? (Take R ~200 kΩ, and check capacitor box for the value of C). Note that when t = RC.

$$\frac{V}{V_o} = \frac{1}{e} = 0{\cdot}37$$



Circuit 1

(c) CURRENT through a COIL

Procedure

In this experiment you will investigate how the current increases in a circuit containing an iron-cored coil connected to a power supply.

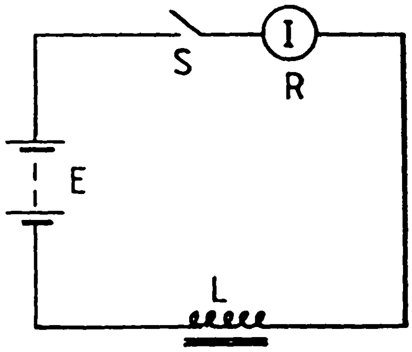
Connect the circuit 2, again making use of bench notes for other connections. Choose a power supply voltage of about 7 volts and a current meter capable of full scale of 1 mA. Use all the windings (connected in series) of the iron-cored coil.

When switch S is closed you will note that the current rises slowly to a maximum value. Let the current at any time be i and after a long time be I_o

Take readings of current as a function of time, similar to method of part(b).

Analysis

Plot $\ln(I_o - i)$ versus t. Is this a linear graph ? If so, evaluate k for this case. Again estimate the observational error. Here the time constan is R/L where L is the inductance of the coil. [Refer to Appendix (III), below].



Circuit 2

APPENDIX I

The rate of change may be either a **growth** process (n increasing with time)

$$\frac{dn}{dt} = kn \qquad \{1\}$$

or a **decay** process (n decreasing with time)

$$\frac{dn}{dt} = -kn \qquad \{2\}$$

where k is a positive constant.
Integrating equation {1}
(equation {2} similarly)

$$\int_{N_o}^{N} \frac{dn}{n} = k \int_{0}^{T} dt$$

giving

$$[\ \log_e n\ ]_{N_o}^{N} = k\ [\ t\ ]_{0}^{T}$$

$$\log_e N - \log_e N_o = kT \qquad \{3\}$$

or

$$\log_e \left\{ N / N_o \right\} = kT$$

or

$$N = N_o \exp\ \{kT\} \qquad \{4\}$$

Here exp or e is the exponential function. Sometimes the natural logarithm $\log_e$ is written as ln.

APPENDIX II

For experiment (b) we can apply Kirchhoff's rule to circuit 1

$$iR + \frac{q}{C} = 0$$

$$R\frac{dq}{dt} = -\frac{q}{C}$$

Integrating

$$\int_{Q_o}^{Q} \frac{dq}{q} = -\frac{1}{RC} \int_{0}^{T} dt$$

$$\ln\left\{ Q / Q_o \right\} = -\frac{T}{RC}$$

$$Q = Q_o \exp\ \{-T/RC\}$$

But $Q = CV$ and $Q_o = CV_o$
Hence

$$V = V_o \exp\ \{-T/RC\} \qquad \{5\}$$

APPENDIX III

For experiment (c) circuit 2 can also be analysed using Kirchhoff's rule

$$E - L\frac{di}{dt} = iR$$

The solution of this equation is

$$i = \frac{E}{R}\left[1 - \exp\left\{ -t\left[\frac{R}{L}\right]\right\}\right]$$

or

$$I_o - i = I_o \exp \left\{ -t\left[\frac{R}{L}\right]\right\} \qquad \{6\}$$

where

$$I_o = \frac{E}{R}$$

MEASUREMENT OF THE RATIO OF CHARGE TO MASS e/m OF THE ELECTRON

GENERAL AIM

To study moving electrons in a uniform magnetic field and hence measure their ratio of charge to mass e/m.

Objectives:

(i) to understand how the energy of electrons can be varied in an electron gun, and to calculate their speed v in terms of the potential difference V through which the electrons have been accelerated.

(ii) to appreciate that the magnetic field of flux density B in the central region of a pair of Helmholtz coils is fairly uniform, and to evaluate the magnitude of B from the current I in the coils, their dimensions and the number of turns.

(iii) to observe the effect of a transverse magnetic force on a beam of electrons and to measure the radius r of the resulting circular trajectory.

(iv) to plan an experiment involving three variables viz. V, I and r.

(v) to analyse the measured data graphically and hence calculate a value of $^{e}/m$.

(vi) to be aware of systematic errors and to attempt to correct for them.

(vii) to evaluate the random error in the experiment.

Introduction

In this experiment electrons are accelerated through a potential difference V, and pass through a slit in the anode to form a beam of electrons of defined speed v. The electrons then enter a uniform magnetic field in a direction perpendicular to the field lines so that they move in a circular path.

The apparatus includes the electron beam tube, the Helmholtz coils and two power supplies.

The electron beam tube comprises an electron gun which emits a ribbon of electrons within the evacuated bulb. The electrons can be accelerated by applying a positive potential between the anode A and the cathode C. The electron beam then strikes a luminescent screen held by the two plates P_1 and P_2. The voltmeter in the EHT power supply measures the potential difference V between A and C.

NOTE: Due care should be exercised when handling this apparatus. Remember that potential difference, of up to 5000 volts will be used. If the circuit is incorrectly wired, damage may result. Do not switch on mains to power supplies until ALL connections have been made and checked. If in doubt, ASK.

The two Helmholtz coils are wired in series and connected to the low voltage supply [ignore the meter on this power supply]. The number of turns in the coils is n = 320.

The electron beam is deflected by the magnetic field B produced by the Helmholtz coils. B can be varied by changing the current I passing through them. The force F experienced by an electron of charge of magnitude e travelling with a velocity v is perpendicular to the plane defined by B and v is given by

$$\underline{F} = e(\underline{v} \times \underline{B})$$

When v is normal to B the force F causes the electrons to move in a circular path of radius r.

PART I

PROCEDURE

(a) Check that the apparatus is connected as in figure 1

(b) In this experiment there are three parameters :-

the accelerating voltage V applied to the electrons
the current I in the deflection Helmholtz coils
the resulting radius r of the path of the electrons.

As a general principle you should hold one of these parameters constant, change the second and observe the resulting value of the third.

For example, keep r constant by letting the deflected beam pass through selected coordinates (x_1,y_1). This is achieved by varying V and adjusting I (or vice versa - which is the better procedure ? - consider the ease or otherwise of setting a value on the high voltage supply) to make the beam pass through your selected (x_1,y_1). In this way you get a table of values of V and I for constant r.

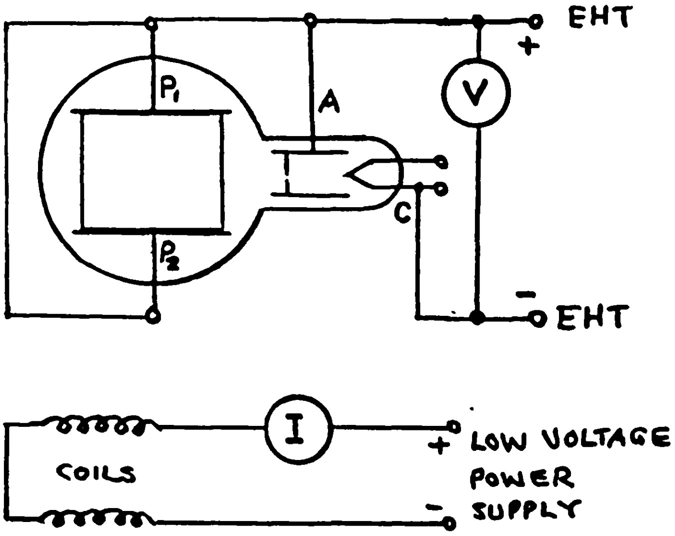


Figure 1

ANALYSIS

(a) When an electron of charge of magnitude e is accelerated from rest by a potential difference V its kinetic energy increases to $1/2mv^2$ where

$$eV = \frac{1}{2} mv^2 \qquad [1]$$

Let the electrons move so that their *velocity* v is at right angles to B, then by Newton's second law

$$F = e\ B\ v\ \sin \pi/2 = m\ v^2/r \qquad [2]$$

From [1] and [2] show that

$$e/m = \frac{2V}{B^2 r^2}$$

Here

$$B = k\ I$$

where

$$k = \frac{8\ n\ \mu_0}{5\ a \sqrt{5}}$$

as shown in Appendix 1.
Hence

$$e/m = \frac{2V}{k^2 I^2 r^2} \qquad [3]$$

(b) In general three points are required to specify a circle uniquely. Here the electron beam OX is tangential to the circular path at the origin O (which should be at the exit aperture of the anode slit). Hence we require to measure only *one* point to calculate r. In principle we read a coordinate (x,y) on the scale of the luminescent screen. The radius of curvature r of the electron path is then

$$r = \frac{x^2 + y^2}{2y}$$

- see figure 2.

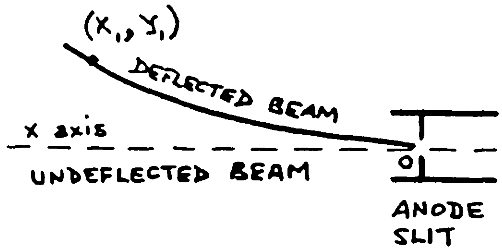


Figure 2

Due to the difficulty in manufacture of aligning the electron gun there is usually a systematic error in the apparatus, arising from the positioning of the scale with respect to the anode slit.
The systematic errors Δx in x and Δy in y have been evaluated for

you. To all readings of the coordinate x add algebraically Δx to give X_c, and add algebraically Δy to y to give Y_c. From the corrected values X_c and Y_c you can calculute r from

$$r^2 = \frac{X_c^2 + Y_c^2}{2Y_c}$$

APPENDIX

The magnetic field B on the axis of a circular coil (of *mean* radius a, number of turns n, and carrying a current I) at a distance z from the centre of the coil is

$$B = \frac{\mu_o nI a^2}{2(a^2 + z^2)^{3/2}} = \frac{C}{(a^2 + z^2)^{3/2}} \quad \text{where} \quad C = \frac{\mu_o nI a^2}{2}$$

where $C = \mu_o nI a^2/2$ and $\mu_o = 4\pi \times 10^{-7}$ H m^{-1}

The direction of this magnetic field is along the z-axis.

We wish to find the separation of a pair of similar coils, parallel and coaxial and carrying equal currents in the same direction, so as to give nearly constant magnetic field between them.
Let the combined magnetic field of the *two* coils be B_T

$$B_T = B(z_1) + B(z_2)$$

It can be shown that

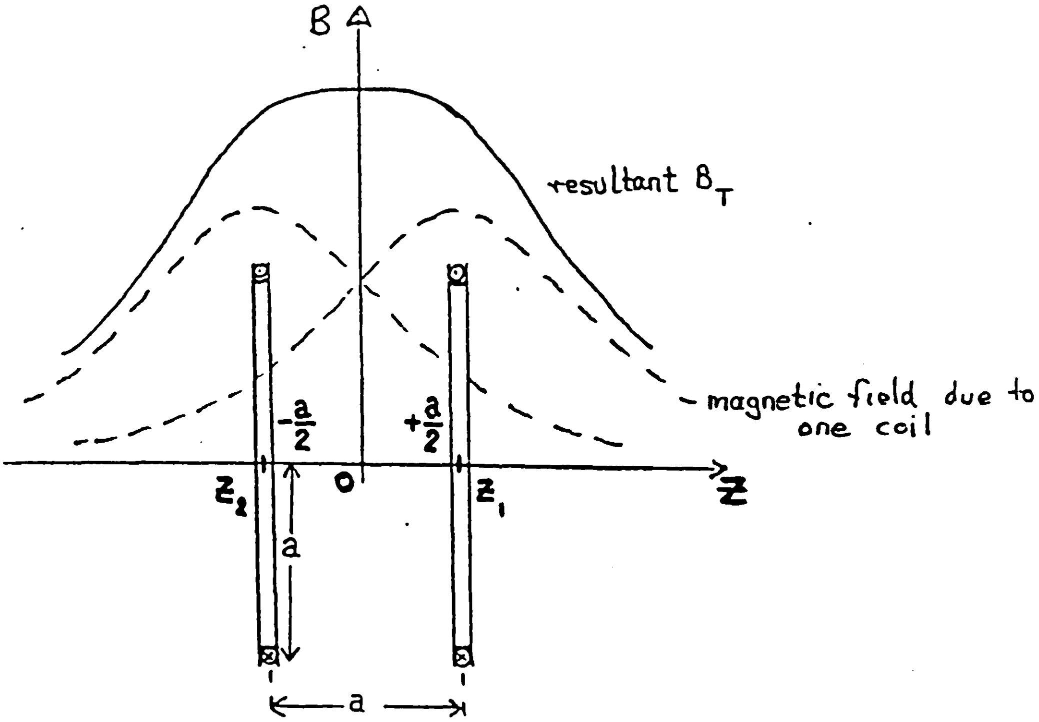
$$\frac{dB_T}{dz} = 0 \text{ at } z = 0 \text{ where } z_1 = -z_2$$

Also

$$\frac{d^2B_T}{dz^2} = 0 \text{ at } z = 0 \text{ where } |z_1| = |z_2| = a/2$$

In other words the separation of the coils should be equal to their radius a. Hence for a pair of such coils connected in series, the combined magnetic field on their axes at a distance of a/2 from each of their centres is

$$B_T = \frac{8 n \mu_o I}{5 a \sqrt{5}}$$



(c) From [3], for constant r

$$V = K\,I^2$$

where the constant K is

$$K = |e/m|\,\frac{k^2\,r^2}{2}$$

(d) Compare $V = K\,I^2$ with $y = mx$.

Plot V against I^2. From the gradient of this graph calculate |e/m|.

(e) Compare your value with the accepted value 1.76×10^{11} C kg^{-1}

PART II

Repeat the above procedure and analysis for a different value of r.
Calculate |e/m|.
What conclusions can you make ?

OBSERVATIONAL ERRORS [random errors]

Make personal estimates of the observational error δV in V and δI in I.
Remember

$$\delta(I^2) = 2\,I\,\delta(I)$$

Show these as error bars on your graphs.

DYNAMICS ON AN AIR TRACK

GENERAL AIM : to determine

(i) the instantaneous velocity of a glider at a point on an air track
(ii) the acceleration of the glider
(iii) the mass of the glider from the dynamics of the system.

INTRODUCTION

You will make measurements with a glider moving on an air track. Refer to tle Appendix of this experiment for notes on the use of an air track. Timing measurements will be made with a photodiode-gate and electronic timer.

Levelling the track

Turn on the air supply and place the plastic glider gently on to the air track. Level the track by using the levelling screw at one end. If the track is level the movement of the glider at any position on working length of the track should be small and random. Remove the glider from the track. (You should not spend any more than about 10 minutes on this levelling procedure - otherwise seek help).

PART I : MEASUREMENT of INSTANTANEOUS VELOCITY

PROCEDURE

(a) Now tilt the track by placing a metal block under the levelling screw.

(b) Check that the photodiode-gate measures the interval of time for which the light beam is interrupted.

(c) If the glider is now (gently) placed on the inclined track and released, it will be accelerated. We want to determine the instantaneous velocity v after the glider has moved a measured distance s from rest. Write down a kinematical equation which shows the relationship between these quantities.

(d) How do we determine the instantaneous velocity v ? Strictly we cannot, but we can make a good experimental approximation.
Fix a flag centrally to the glider (middle of flag aligned with the middle of the glider) . Smoothly release the glider from rest at a chosen position on the tilted track. The time interval Δt of the interrupted light beam and the length of the flag Δx will enable you to calculate the **AVERAGE VELOCITY** of the glider during this time interval. For a given flag, repeat this timing measurement a few times to check the reproducibility of data - this will give you information about how good your technique is in releasing the glider from rest.

(e) Replace the flag with one of different length, and repeat measurements. Take data for a total of six different flag lengths.

(f) How do you measure the length of the flag, Δx ? With a metre rule ? Perhaps this is acceptable for long flag lengths. Try this method : move the glider with its attached shortest flag to a position in the photodiode-gate where the timer just starts to count and note the position of some point of the glider using the scale on the side of the track. Push the glider slowly through the gate until the timer just stops and again read the position of the same point of the glider. The difference gives Δx. Is this different from the length measured with a metre rule ? Why ? Discuss with your demonstrator.

(g) Make measurements to give the distance s travelled by the glider. Think carefully about this. Discuss with your demonstrator, if necessary.

ANALYSIS

(a) Calculate the average velocities $\Delta x/\Delta t$, and plot these on a graph of $\Delta x/\Delta t$ against Δt.

(b) The definition of instantaneous velocity v is

$$\lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = v$$

Hence from the graph you can find v, the value of the intercept on the $\Delta x/\Delta t$ axis when $\Delta t = 0$.

PART II : ACCELERATION of the GLIDER.

PROCEDURE and ANALYSIS

(a) From v and your measured value of s calculate the acceleration a using your kinematical equation.

(b) Note that the acceleration a is related to the acceleration due to gravity g by Newton's II law

$$Mg \sin \theta = Ma$$

where M is the mass of the glider. See figure 1.

(c) Take measurements to give you the angle θ of the tilted track. Think about what θ means - refer to figure 2.

(d) Take the Glasgow value of $g = 9.81\ m\ s^{-2}$ and hence calculate a from $g \sin \theta$.

(e) From your measured value of s calculate what value of v results from using $g = 9.81\ m\ s^{-2}$. Plot this v on your graph. What can you conclude ?

(f) Repeat for other inclinations (if your demonstrator advises).

(g) Consider how well you have measured Δx, Δt, s, and θ. Calculate the errors in the average velocities. Plot error bars on your graph. Discuss with your demonstrator how to calculate the error δa in a.

PART III : MASS of GLIDER from the DYNAMICS of the SYSTEM

In this part, you will apply a measurable force to the glider on a level track, measure its acceleration and hence calculate its mass M.

PROCEDURE

(a) Return the track to its level position by removing the metal block. Check the track to ensure it is level.

(b) Attach a piece of plastic tape to the post on the glider, and pass the tape over the air pulley. The tape should be horizontal between the glider and the pulley.

(c) In this part of the experiment choose a flag length that allows the instantaneous velocity to be deduced from a single measurement of the average value - perhaps the second shortest flag (refer to your results in **PART I**). Add a small mass m, eg 5 grams, to the free end of the tape. Let the glider now accelerate from a position of rest. Measure Δt, and check the reproducibility of Δt. Again, as above, take measurements to give the travel distance s. Calculate a.

(d) Repeat for different values of the mass m.

ANALYSIS

(a) Apply Newton's II law to this situation (see figure 3):

(1) firstly to the mass M $\qquad T = Ma$

(2) and to the mass m $\qquad mg - T = ma$

Hence $\qquad M = [(g/a) - 1]\ m$

(3) Therefore by measuring a and knowing m, you can calculate M. Calculate M for each set of data taken for different m values.

(b) Use a balance to weigh the glider.

(c) Do the values of M, from the dynamics and from the balance, agree within their observational errors ?

APPENDIX

In this experiment you use a linear air track - a relatively simple and elegant device which allows the observation of motion with little friction. Gliders move above a straight track on a thin cushion of air, produced by blowing air out of small holes in the track - the hovercraft principle. The only friction is that associated with the viscosity of the layer of air on which the glider floats. You will also use an air pulley.

Although the tracks appear quite rigid they are sensitive to small changes of alignment. Take care not to move the track - small irregularities in the table top can have a significant effect on the alignment of the track. If the track has been correctly set up, all points on the track should be within a few hundredths of a mm of a straight line. In practice your track may not be as good as this - choose a working length which minimizes these effects.

The angle of the glider is precisely made - please handle them with care. Do not move the glider on the track unless the air supply is on.

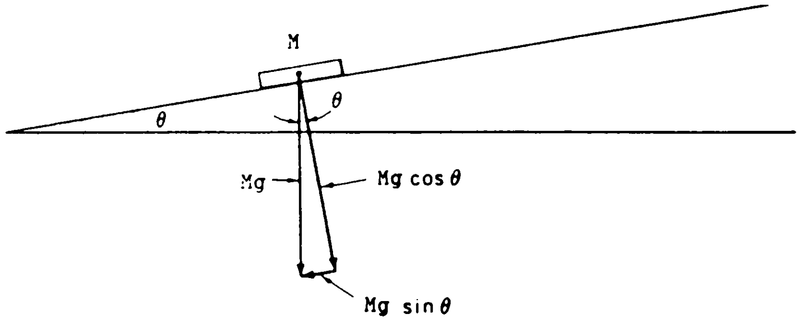


Figure (1) Resolution of forces acting on a glider on a tilted air track.

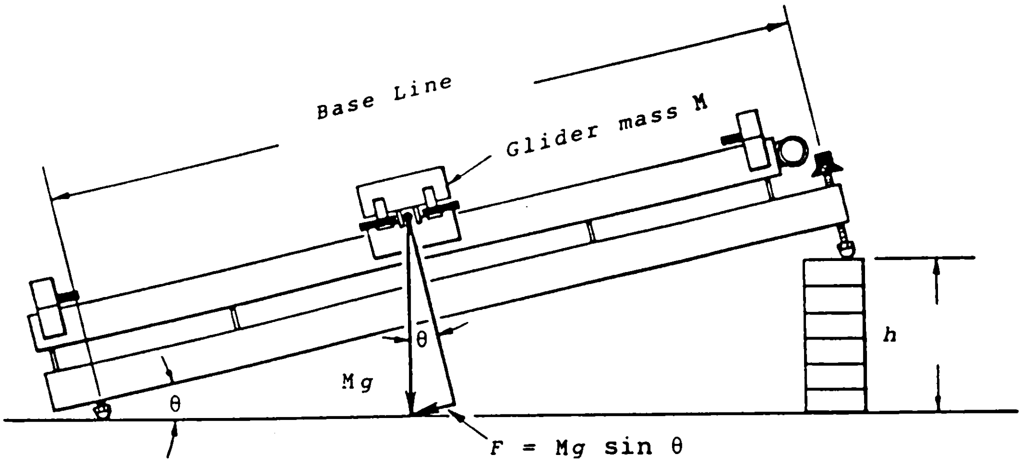


Figure (2) A block with height h is placed under the leveling screw to tilt the air track to an angle θ with respect to the horizontal.

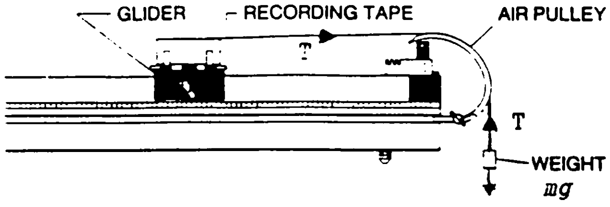


Figure (3) A constant force can be applied to a glider by using recording tape, an air pulley and a small hanging weight.

Appendix 6-2-A

% frequency of positive responses for CSYS students

Comparison between original and new version experiments

Category Expt	Interesting	Easy	Well organized	Enjoyable	Worth while	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Theory improved	Obj clear at the begining	Obj clear part way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
Air track	90 65	71 73	90 69	76 61	81 73	62 61	87 96	48 73	57 85	90 96	52 42	62 61	29 23	10 4	48 31	67 96	24 23	90 96	19 31
S H M	70 64	75 84	85 100	60 72	85 84	45 96	80 96	45 80	70 84	90 80	65 60	55 72	44 20	5 0	50 56	90 92	20 20	90 100	10 20
Meled's expt	69 56	48 68	100 88	61 44	83 81	87 88	91 94	43 69	43 81	35 63	78 67	35 50	56 31	4 0	39 50	87 88	0 0	100 94	4 0
Spectro-meter	83 76	50 86	87 86	58 71	92 86	75 95	92 95	46 71	54 76	71 87	92 71	54 48	37 29	8 10	37 67	79 81	50 43	100 95	37 29
Refraction	80 67	75 81	95 95	75 62	90 91	60 81	85 90	50 71	50 81	90 81	80 76	55 52	35 48	5 0	55 48	80 86	60 29	60 95	35 14

Appendix 6-2-A. Continued

Lenses	87 71	70 75	96 88	70 71	100 88	35 63	96 92	74 63	65 71	91 90	100 67	65 46	35 42	0 0	57 46	91 83	26 4	96 100	26 17
Compound pendulum	50 59	60 77	95 86	50 63	90 77	70 95	90 100	45 50	35 86	33 27	70 82	60 45	20 45	5 0	35 36	80 95	45 23	100 100	10 5
Solenoid	33 67	60 78	93 89	80 67	67 67	93 89	100 89	40 56	60 78	60 100	60 78	47 44	33 33	20 11	40 56	87 78	20 56	100 89	0 11
Vibrating blade	54 52	85 70	88 91	42 44	85 65	92 86	100 96	50 57	54 74	69 48	65 83	65 52	27 44	0 0	42 30	96 91	27 44	96 91	23 4
Growth & decay	50 60	78 80	86 80	43 80	64 80	64 80	93 100	28 60	43 100	100 100	71 100	57 60	28 20	0 0	21 60	71 80	14 20	93 100	14 20
Properties electron	69 90	43 74	66 100	52 79	87 90	87 95	96 95	43 68	56 74	52 37	83 79	56 53	35 37	4 0	26 63	83 84	30 32	96 95	4 16

Original expt

New version expt

Appendix 6-2-B

% frequency of positive responses of SCE students

Comparison between original and new version experiments

Category Expt	Interesting	Easy	Well organized	Enjoyable	Worth while	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Improved theory	Obj clear at the begining	obj clear part way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
Air track	83 / 81	52 / 62	91 / 98	62 / 71	78 / 81	70 / 64	74 / 98	48 / 52	62 / 86	87 / 88	62 / 71	57 / 50	22 / 45	17 / 2	48 / 19	62 / 98	35 / 36	91 / 98	35 / 36
S H M	80 / 86	67 / 62	97 / 90	80 / 76	93 / 86	40 / 83	93 / 98	63 / 38	57 / 83	60 / 83	87 / 81	40 / 62	43 / 19	17 / 5	43 / 57	87 / 76	30 / 38	93 / 76	27 / 21
Meled's expt	79 / 83	59 / 62	97 / 90	65 / 66	94 / 93	85 / 90	91 / 90	41 / 76	47 / 76	26 / 76	85 / 72	44 / 62	47 / 31	6 / 0	44 / 59	85 / 83	12 / 10	100 / 86	9 / 3
Spectro-meter	87 / 84	53 / 65	93 / 94	81 / 77	93 / 77	87 / 84	97 / 94	53 / 58	53 / 77	62 / 82	81 / 74	53 / 48	41 / 42	6 / 3	53 / 42	97 / 90	47 / 68	97 / 100	37 / 32
Refraction	92 / 70	65 / 43	92 / 87	73 / 60	85 / 73	58 / 43	92 / 100	42 / 50	58 / 60	92 / 73	73 / 63	54 / 57	31 / 33	8 / 3	62 / 23	73 / 83	46 / 33	96 / 93	27 / 17

Appendix 6-2-B. Continued

Lenses	90 92	69 62	90 97	72 74	93 74	34 55	100 100	55 44	69 77	90 76	79 45	69 62	24 31	3 7	41 33	90 87	17 28	100 87	28 7
Compound pendulum	62 44	42 82	92 85	50 47	42 73	71 100	92 83	37 41	46 94	42 44	66 74	17 59	54 33	25 8	37 29	71 88	54 18	96 91	21 6
Solenoid	65 39	76 73	90 96	62 42	86 69	90 77	96 92	59 50	59 62	52 73	41 80	45 62	41 27	14 0	52 54	96 89	24 27	100 92	10 8
Vibrating blade	78 62	75 59	91 97	75 52	81 86	72 100	97 100	50 83	50 79	47 52	91 79	59 31	25 55	9 7	44 35	91 79	25 55	97 97	31 7
Growth & decay	74 50	74 86	95 90	79 59	84 82	68 90	100 100	47 55	68 90	74 82	53 82	68 59	21 36	5 0	31 32	95 96	26 18	100 96	16 5
Properties electron	68 83	100 67	93 94	55 61	84 72	81 94	93 100	58 61	68 78	58 50	68 83	58 72	22 12	13 11	42 40	87 89	32 44	100 78	3 6

Original expt →

← New version expt

Appendix 6-3

% frequency of positive responses

Comparison between FI and FD students

Category Expt	Interesting	Easy	Well organized	Enjoyable	Worth while	Enough time	Enough help from demonstrator	Enough help from books	Enough help from notes	Understood back-ground theory	Theory improved	Obj clear at the begining	obj clear part way through	Obj clear at the end	Enough time to record	Sufficient instructions	New equipment	Equipment available	Learned new techniques
Air track	87 61	60 54	93 92	87 54	80 77	80 69	100 92	73 61	80 92	87 77	67 54	60 54	33 38	0 0	13 7	100 92	33 61	93 100	47 54
S H M	89 75	89 62	100 94	89 75	95 75	95 87	100 94	67 44	95 81	83 81	61 87	83 56	33 25	5 12	50 56	100 100	25 44	95 100	22 31
Meled's expt	63 60	81 80	94 100	63 60	94 80	94 80	100 100	81 40	75 80	63 80	75 80	56 80	31 20	0 0	63 40	88 80	0 20	88 100	0 0
Spectrome-ter	100 67	83 58	100 92	83 58	100 83	92 100	100 50	83 75	83 75	67 75	83 67	50 42	42 42	0 8	50 25	92 83	42 58	100 100	25 25
Refraction	70 80	90 60	100 90	60 50	70 90	90 60	100 80	80 50	80 70	80 80	60 80	40 50	60 40	0 0	60 20	90 90	30 20	100 100	20 20

Appendix 6-3. Continued

Lenses	79 80	100 93	86 87	64 60	79 80	79 80	100 93	71 73	79 80	86 80	75 73	64 60	36 40	0 0	75 13	86 80	7 34	100 93	7 0
Compound pendulum	64 36	93 82	93 82	50 55	86 67	100 100	93 82	42 46	86 90	21 18	86 73	57 36	43 45	7 0	50 9	100 90	14 27	100 100	14 9
Solenoid	60 38	70 38	100 88	50 25	80 75	90 75	90 100	60 38	70 38	20 38	90 88	40 38	60 38	0 0	4 25	80 63	50 63	100 75	0 0
Vibrating blade	25 60	75 80	100 80	0 60	100 60	100 100	100 100	100 60	100 100	100 80	50 60	50 20	0 0	100 40	100 100	25 20	100 80	25 20	
Growth & decay	43 57	86 44	100 90	57 67	57 67	100 67	71 100	71 45	43 57	86 78	86 78	71 44	29 22	0 11	71 22	100 67	29 33	100 89	0 11
Properties electron	78 86	78 43	100 100	67 43	89 71	100 86	89 100	56 71	100 71	44 43	78 43	67 29	33 29	0 14	67 43	78 86	56 43	78 71	33 0

FI students

FD students

Appendix 7-1-A (Glasgow)

Problem 1

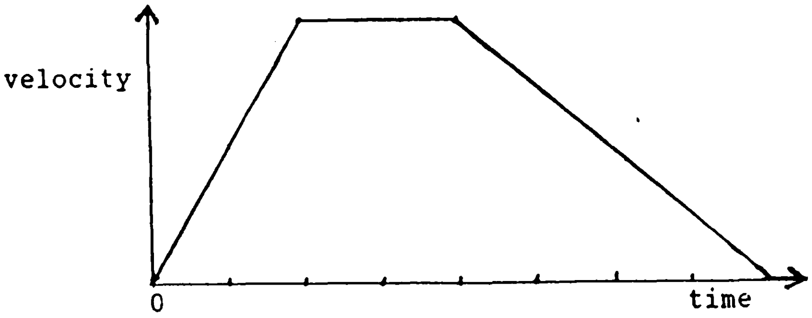
Form A

A lift goes down a mine shaft 1200 m deep in 1 minute. It accelerates uniformly from rest, then travels with constant speed, and finally it is decelerated to rest with a retardation which is numerically one half of the acceleration. The time of deceleration occupies one half of the total time of travel.

Calculate the maximum speed attained during the descent.

Form B

A lift goes down a mine shaft 1200 m deep in 1 minute. Its velocity-time graph is shown in figure.

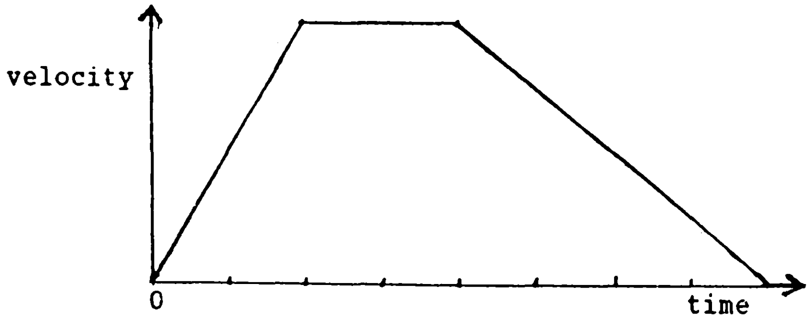


It is decelerated to rest with a retardation which is numerically one half of the acceleration. The time of deceleration occupies one half of the total time of travel.

Calculate the maximum speed attained during the descent.

Form C

A lift goes down a mine shaft 1200 m deep in 1 minute. It accelerates uniformly from rest, then travels with constant speed, and finally it is decelerated to rest with a retardation which is numerically one half of the acceleration. The time of deceleration occupies one half of the total time of travel.



Calculate the maximum speed attained during the descent.

Problem 2. As shown on page 220

Problem 3

Form A

A sphere of mass m_1, is fastened to a light inextensible cord of length L. It is released from rest when the cord is horizontal. When the cord reaches the vertical position the sphere makes an elastic collision with a block of mass m_2 which is at rest on smooth horizontal surface.

In terms of m_1, and m_2, L and g derive expressions for

(a) the speed of the sphere at its lowest point just before the collision

(b) the speed of the block after the collision.

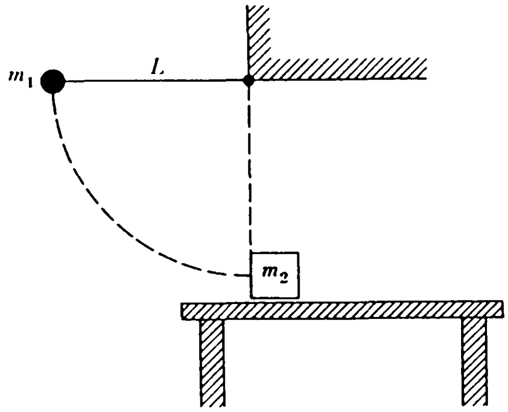
Form B

A sphere of mass m_1, is fastened to a light inextensible cord of length L. It is released from rest. When the cord is hrizontal, as shown in the diagram. When the cord reaches the vertical position the sphere makes an elastic collision with a block of mass m_2 which is at rest on smooth horizontal surface.

In terms of m_1, and m_2, L and g derive expression for

(a) the speed of the sphere at its lowest point just before the collision

(b) the speed of the block after the collision.



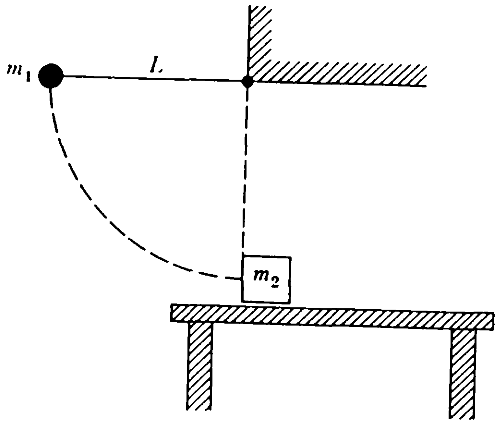
Form C

Consider the situation shown in the figure;the sphere, initially at rest,makes an elastic collision with the block of mass m_2 which is initially at rest on a smooth horizontal surface.

In terms of m_1, m_2, L and g derive expression for

(a) the speed of the sphere at its lowest point just before the collision

(b) the speed of the block after the collision.



Appendix 7-1-B (Glasgow)

Problem 1

Form A

A particle moving with simple harmonic motion has velocities of 4.0 ms^{-1} and 3.0 $m\ s^{-1}$ at distance of 30 mm and 40 mm respectively from its equilibrium position.

Calculate the velocity of the particle as it passes through the equilibrium position.

Form B

A particle moving with simple harmonic motion has velocities of 4.0 ms^{-1} at distance of 30 mm from its equilibrium position. The period of the oscillation is 0.063 s.

Calculate the velocity of the particle as it passes through the equilibrium position

Form C

A particle moving with simple harmonic motion has velocities of 4.0 ms^{-1} and 3.0 $m\ s^{-1}$ at distance of 30 mm and 40 mm respectively from its equilibrium position.

Determine

(a) the amplitude

(b) the period of the oscillation.

Calculate the velocity of the particle as it passes through the equilibrium position.

Problem 2 as shown on pages 229-231

Problem 3

Form A

A particle of mass M is constrained to move in a vertical circle. It is attached to a light inextensible string of length 2.5 m, the other end of which is attached to a fixed point.

The particle is given an initial velocity of 14 ms^{-1} at the lowest point of its path. The particle then collides with a stationary second particle of equal mass M at the highest point in its path, in such a way that the two particles stick together.

Show that the combined particles will only just manage to maintain motion in a complete vertical circle.

Form B

A particle of mass M is constrained to move in a vertical circle. It is attached to a light inextensible string of length 2.5 m, the other end of which is attached to a fixed point.

The particle is given an initial velocity of 14 ms^{-1} at the lowest point of its path. The resulting velocity of the particle at the highest point H is is 9.9 ms^{-1}, the particle then collides with a stationary second particle of equal mass M at the highest point H. The particle then collides with a stationary second particle of equal mass M at H, in such a way that the two particles stick together.

Show that the combined particles will only just manage to maintain motion in a complete vertical circle.

Form c

A particle of mass M is constrained to move in a vertical circle. It is attached to a light inextensible string of length 2.5 m, the other end of which is attached to a fixed point.

The particle is given an initial velocity of 14 ms^{-1} at the lowest point of L of its path.

(a) Determine the speed of the particle at highest point H. The particle then collides with a stationary second particle of equal mass M at H, in such a way that the two particles stick together.

(b) Determine the speed of the combined particles after the collision.

(c) Show that, in general, the tension T in the string is given by $T-Mg \cos ß=2Mv^2/R$

Where v is the tangential velocity of the combined particles at the instant that the angle the string makes with the radius to L is ß.

(d) Show that the combined particles will only just manage to maintain motion in a complete vertical circle.

Appendix 7-2

Problem solving Questionnaire

Name:...

When you have read the problem, please answer this question: ***How sure are you will be able to solve the problem?***

Answer by circling ONE responses which best describes your reaction.

5. very sure I can do it
4. fairly sure I can do it
3. not sure whether I can do it
2. fairly sure I can not do it
1. very sure I can not do it

Problem solving Questionnaire

Name:.................................

After you have attempted the problem, please answer:

How sure are you that your answer is correct?

5. very sure I am correct
4. fairly sure I am correct
3. not sure whether I am correct or not correct
2. fairly sure I am not correct
1. very sure I am not correct

Appendix 8-1-A (Algeria)

Problem 1

Form A

A hobo wishes to catch a freight train that stands in front of a train station. He waits 50 m behind the train, whose last car is 50 m from the station. As the train starts to leave the station with an acceleration of 2 m/s^2, the hobo runs towards the train at a constant speed of 15 m/s. Will he catch the train before the last car reaches the station, or will he have to run past the station to catch the train?.

Form B

Consider the situation shown in the figures 1 and 2.

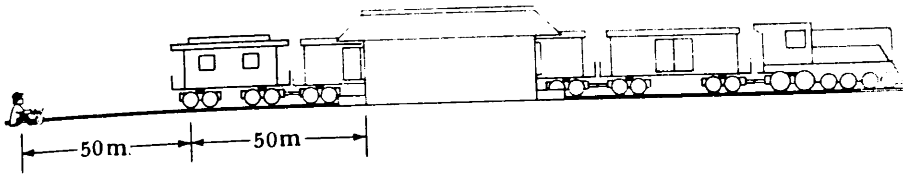


Figure 1

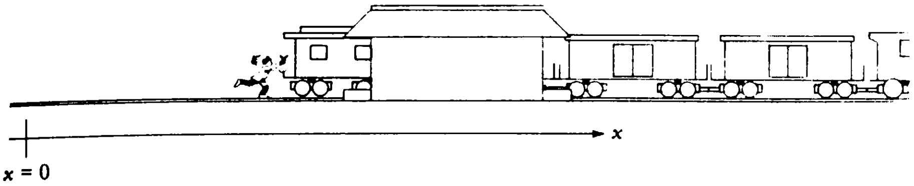


Figure 2

As the train starts to leave the station with an acceleration of 2 m/s^2, the hobo runs towards the train at a constant speed of 15 m/s. Will he catch the train before the last car reaches the train, or will he have to run past the station to catch the train.

Form C

A hobo wishes to catch a freight train that stands in front of a train station. He waits 50 m behind the train, whose last car is 50 m from the station as shown in the figures 1 and 2. As the train starts to leave the station with an acceleration of 2 m/s^2, the hobo runs towards the train at a constant speed of 15 m/s.

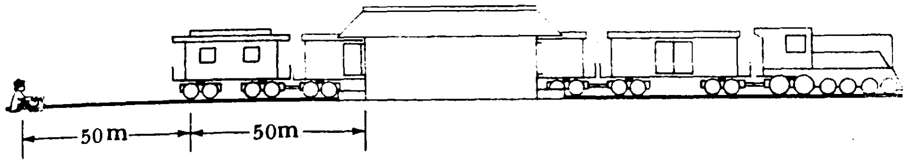


Figure 1

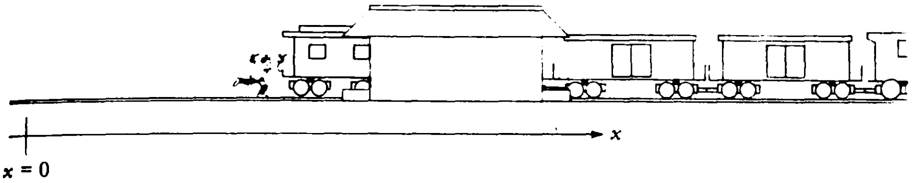


Figure 2

Will he catch the train before the last car reaches the station, or will he have to run past the station to catch the train ?.

Problem 2: As shown in on page 220.

Problem 3

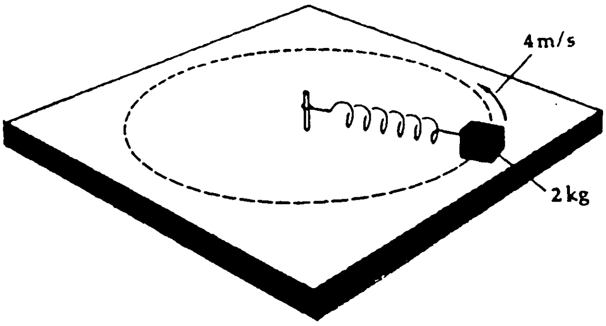
Form A

A 2.0 kg mass is attached to a spring having an unstretched length of 0.30 m and an elastic constant of 2000 N m^{-1}. The mass rotates in a circle on a horizontal frictionless surface and its tangential velocity is 4.0 ms^{-1}.

Calculate the radius of curvature of the path of the particle.

Form B

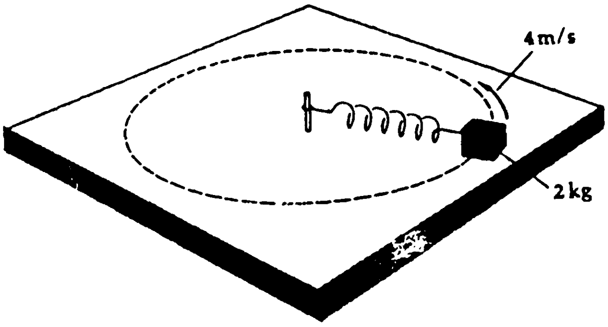
A mass is attached to a spring having an unstretched length of 0.30 m and an elastic constant of 2000 N m^{-1}. The mass rotates as shown in the figure below:



Calculate the radius of curvature of the path of the particle.

Form C

A 2.0 kg mass is attached to a spring having an unstretched length of 0.30 m and an elastic constant of 2000 N m^{-1}. The mass rotates in a circle on a horizontal frictionless surface and its tangential velocity is 4.0 ms^{-1} as shown in the figure below:



Calculate the radius of curvature of the path of the particle.

Appendix 8-1-B (Algeria).

Problem 1: As shown on pages 229-231

problem 2

form A

A block A, of mass 4.0 kg rests on a inclined plane that makes an angle of 30° to the horizontal. A second block B, of mass 2.5 kg, is attached to A by a light inextensible string which passes over a light smooth pulley at top of the plane. The block B hangs freely. The coefficient of kinetic friction between A and the plane is 0.2. The length of inclined plane is 2.5 m. When the system moves down from the rest. Calculate:

(a) The tension of the string

(b) the velocity of mass A at the lowest point on the inclined plane.

Form B

A block A, of mass 4.0 kg rests on a inclined plane that makes an angle of 30° to the horizontal. A second block B, of mass 2.5 kg, is attached to A by a light inextensible string which passes over a light smooth pulley at top of the plane. The block B hangs freely. The force of friction on the block A is 6.79 N. The length of inclined plane is 2.5 m. When the system moves down from the rest Calculate:

(a) the tension of the string

(b) the velocity of mass A at the lowest point on the inclined plane.

Form C

A block A, of mass 4.0 kg rests on a inclined plane that makes an angles of 30^{o} to the horizontal. A second block B, of mass 2.5 kg, is attached to A by a light inextensible string which passes over a light smooth pulley at top of the plane. The block B hangs freely. The coefficient of kinetic friction between A and the plane is 0.2. The length of inclined plane is 2.5 m. When the system moves down from the rest.

Calculate:

(a) The force of friction on the block A

(b) the acceleration of the system

(C) the tension of the string

(d) the velocity of mass A at the lowest point on the inclined plane.

Appendix 5-2

UNIVERSITY OF GLASGOW

Department of Physics and Astronomy

Ordinary Physics A - Laboratory Notes - Martinmas Term

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* 'University Physics' - Sears, Zemansky and Young - 7th edition.

DYNAMICS

Introduction

In this series of experiments, you will observe several basic phenomena of classical Newtonian mechanics. A variety of experimental arrangements will give you experience in applying the basic principles of mechanics, such as Newton's laws of motion, momentum and energy relations, and the associated kinematic descriptions of motion, to the analysis of phenomena which you can observe and measure.

Most of the experimental situations will be simple enough so you can represent the properties of the system under study by means of simple mathematical relations. For example, if the amount a spring stretches is approximately proportional to the force making it stretch, we express this behaviour with the relation $F = -kx$. It must be understood, however, that such relationships are seldom exact, but instead are part of an idealized model used to represent the properties of the system. Many real springs do behave very nearly according to the above relationship, although if the spring is stretched too far, the elongation may no longer be directly proportional to the force.

Thus, a mathematical analysis of a physical system almost always involves the use of idealized models which provide an approximate description of the properties of the system. It is important to bear this in mind when comparing your analytical predictions with actual observations of the behaviour of the real system; the two will seldom agree exactly. The disagreement can be caused either by experimental errors (that is, errors in the measurements) or by the lack of precision of the model, or both, and it is important to understand the distinction.

Although much of your experimental work is concerned with making quantitative measurements, the importance of qualitative observations should not be overlooked. Often qualitative observations, including the effects of changing the variable quantities in the experimental setup, will help you gain additional insight and physical intuition for the physics of the situation. It is always useful to record these qualitative observations, as well as the numbers resulting from your quantitative measurements, for later reference.

The experiments in this series all make use of a linear air track, a simple but elegant device which permits the observation of motion with almost complete absence of friction. Gliders are supported above a straight track on a cushion of air the order of 0.1 mm thick, produced by blowing air out of rows of small holes in the track. The principle is the same as that of the hover-craft; the only friction is that associated with the viscosity of the layer of air on which the glider floats.

To this basic setup, we add timing devices, bumpers on the ends of the gliders for various kinds of collisions, and equipment for applying controlled time-varying forces to gliders. This auxiliary equipment is described in the individual experiments.

The timing measurements needed in studying motion can be made in a variety of ways. The two methods used in these experiments are an ordinary stopwatch, which measures a time interval, and photocells with a light beam interrupted by the glider. In all these schemes, the object is to observe the motion of the glider without having the observations affect the motion.

Note /

Note

Several general precautions should be observed while using the air tracks. Although the tracks appear quite rigid, their use makes them extremely sensitive to small changes in alignment.

Be careful not to bump, jar, or drop the gliders unnecessarily. Dropping the gliders from a height of even a few inches will probably ruin them. To avoid damaging surfaces, do not slide gliders on the track when the air supply is turned off. When additional masses are attached to gliders, be sure to add them symmetrically; if the glider is lopsided, it will rub on the track.

VELOCITY AND ACCELERATION

Introduction

According to Newton's first law, an object set in motion on a perfectly smooth, level, frictionless surface continues to move in a straight line with constant velocity. By observing how closely the gliders on the air track obey this prediction, you can form some conclusions about how straight and level the track is and about how important the small friction caused by viscosity of the supporting air layer is.

According to Newton's second law; when a force is applied to an object, the object experiences an acceleration proportional in magnitude to that of the applied force. This relationship is usually expressed as

$$\Sigma F = ma \tag{1}$$

in which the symbol Σ, which means sum, indicates that if more than one force acts on the object, the vector sum of forces must be used. In this experiment the principal forces will be constant; that is, they will not vary with time. A simple way of providing an accelerating force is to tilt the track by a measured amount; the acceleration may be predicted from the angle of tilt, and it may also be determined experimentally from measurements of the positions of the object at a succession of time intervals.

Experiment

1. Operation of the air track

First familiarize yourself with the operation of the air track by turning on the air supply and observing the motion of the gliders on the track. Now carefully place a glider near the centre of the track and release it so as to give it no initial velocity. Adjust the levelling screw at the end of the track until the glider accelerates neither to the right nor to the left. Now move the glider to other positions on the track and check to see how straight the track is. If the track has been properly aligned, all points on the track should be within 0.002 in. of a straight line. After the track is levelled, carefully avoid bumping it, since small irregularities in the tabletop can have a significant effect if the track is moved. Handle the gliders carefully; the angle of the gliders is precisely manufactured.

Therefore place the gliders gently on the table when not in use. Do not do anything which would block the air holes. Do not move the gliders on the track with the air supply off.

2. Measurement of instantaneous velocity, and g

For a moving body the instantaneous velocity is defined as

$$\lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = v \quad . \; . \; . \; . \quad (2)$$

If we measure the time Δt which it takes a glider to move a distance Δx, the ratio $\frac{\Delta x}{\Delta t}$ is the average velocity during time interval Δt. If we use smaller and smaller Δt we approach the instantaneous value.

Procedure

Level the track, and then tilt it by a predetermined amount, using the metal blocks of measured thickness. Check that the photocell/scaler system measures the interval of time for which the light beam is interrupted. Make sure you understand how to operate the photocell gate. If in doubt, ASK your demonstrator.

Note that the flag length Δx is the length as seen by the photocell gate. To measure Δx place the glider with its attached flag at a position in the gate where the scaler just begins to count and note the glider's position against the scale on the track. Push the glider through the gate until the scaler just stops and again read the position. This gives Δx. This is an important consideration for short flags.

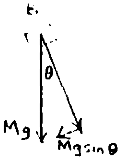
In the following measurements place the flag on the glider so that the middle of the flag is aligned with the middle of the glider. Think carefully about the total distance travelled s by the glider.

With the track inclined, start the glider from rest at A and measure the values of Δx and Δt at a given place B for a series of flag lengths Δx. You will also need to know the total distance travelled s or the total time of motion t from A to B. Decide which is easier to do and which is the more accurate. Find the extrapolated value of the instantaneous velocity from your graph of $\frac{\Delta x}{\Delta t}$ against Δt.

From your measured values of v and s (or v and t) calculate the uniform acceleration a. Apply Newton II to the glider of mass M on the plane inclined at an angle θ.

$$Mg \sin\theta = Ma \quad . \; . \; . \; . \quad (3)$$

Hence determine g



3. Mass of glider

The final measurement in this experiment is to determine the mass of a glider. This is accomplished by applying a known force to the glider and measuring its acceleration. Return the track to its level position, and carefully check to see that it is level. Attach a small mass (for example

3. Contd

5 grams) to a length of ¼ inch wide recording tape which is passed over the air pulley and attached horizontally at its other end to the glider.

Let the mass of the glider be M, and the mass of the end weight m. Thus the equation of motion for m is mg - T = ma and that for M is T = Ma (where T is the tension in the tape).

Hence $M = \left[\frac{g}{a} - 1\right] m \quad . \; . \; . \; . \quad (4)$

The acceleration a may be measured by the method discussed above.

SIMPLE HARMONIC MOTION

Introduction

The object of this experiment is to study an oscillating system, viz a mass suspended at the end of a vertical spiral spring. It is also an exercise on analysis of experimental data by graphical methods.

A body executes SHM when its acceleration varies directly with its displacement x, but opposite in direction. If a mass m moves under the influence of a force described by

$$F = -kx$$

and if the cause of the force is removed the mass will vibrate about its equilibrium position, with a period T

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where k is the force or elastic constant. You should be able to derive this relationship.

It is suggested you carry out parts (a) and (b), then try (c). It is better to study a few parts in full rather than treat the whole experiment qualitatively.

Procedure

(a) Find out the static behaviour of the spiral spring when stretched by observing the extension as a function of load by adding masses to it. What happens when you decrease the load? Devise a suitable method of measuring the extension. Draw a suitable graph and from it obtain the force constant k of the spring. Pay attention to units; it is simplest to work in newtons and metres.

(b) With a load on the spring (does it matter how large?) set the mass vibrating vertically. Measure the period T by timing many vibrations (how many?) using the stop clock, or by the photocell gate. Repeat for different loads. From a suitable graph obtain k. Compare with the value of k obtained in (a). The simple analysis assumes negligible mass of the spring, M'. If instead

$$T = 2\pi\sqrt{\frac{m+\alpha M'}{k}} \qquad (\alpha\ \text{constant})$$

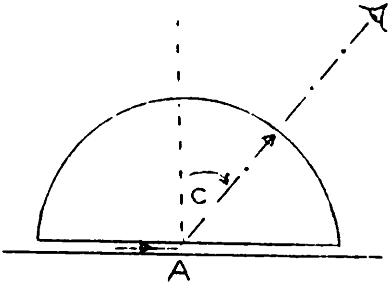
what value of α do you obtain if you use k from part (a) and T and m from part (b)? Does this investigation show that the motion of the mass is SHM?

(c) Study the vibrating mass on the spiral spring by other means, e.g. suspended magnet vibrating in the coil. Do your oscilloscope measurements agree with the earlier parts of the experiment? What is the relationship between the motion of the magnet and the signal from the coil?

REFRACTION

The index of refraction of a material may be measured by making use of total internal reflection of light.

1. **Semi-circular slab method**

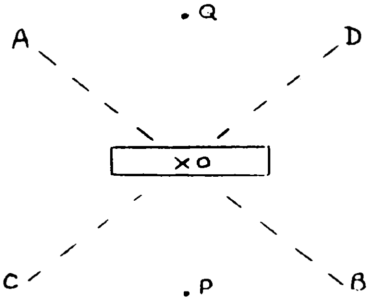


The semi-circular glass (or perspex) slab is placed centrally on the stand and its position adjusted until the line between the black and white base appears unbroken when viewed through the slab and through air (outside the slab). It will be noticed that this line is not visible through the glass at large viewing angles with respect to the vertical i.e. the slab appears dark. The upper edge of this dark part marks the position of the limiting ray from A. A card is laid horizontally along the edge and the largest angle C read off. Since there is a thin film of air between the slab and the stand, C is the critical angle from glass into air. Hence determine the refractive index of the glass.

Repeat the experiment introducing a thin film of water between stand and glass, and measure C', the critical angle from glass into water. Hence calculate the refractive index of water.

2. **Air-cell method**

An air-cell, consisting of two parallel thin sheets of glass, separated by an air-film, is introduced into water contained in a glass trough, placed at the centre of a sheet of paper. A direction PQ is defined by two pins P and Q on opposite sides of the trough, on a line normal to the faces of the trough. Then looking through in the direction PQ, the pin Q should be visible through the water and the air-cell. If the cell is now rotated, a position is found when the pin Q just disappears, and one half of the field appears dark. In this position, the angle of incidence of the direction PQ with the surface of the air-cell is equal to the critical angle from water into air. (Draw a ray diagram, and prove this relationship). Mark the positions A and B of the mid-points of the legs of the bridge carrying the air-cell, when this condition is reached: now rotate the bridge until a second position is found at which the pin Q just disappears, and mark the corresponding position CD of the bridge. If AB, CD intersect at O then angle AOC (the angle not containing P or Q) = 2 x critical angle from water to air. Measure this angle and hence determine the refractive index of water.



3. Compare the results obtained by the two different methods. Write a concluding sentence based on this comparison.

EXPERIMENTS IN GEOMETRICAL OPTICS

In this series of experiments you will study in practice how images are formed by simple spherical mirrors and lenses. You will learn how to set up and use an optical bench, and how to make use of the parallax method. Later you will assemble and study the properties of simple optical instruments.

It is essential in all this work that you *draw ray diagrams*. It is good practice to note your readings in tabular form (remember units). As well as making a simple clear table of results at the end of a section you should also draw some conclusions e.g. compare the different methods of measuring the radius of curvature of a concave mirror, stating what factors contributed to the experimental error.

1. Spherical Mirrors

We define the focal length of a concave mirror as the distance from the mirror to the image of an infinitely distant object. Draw a ray diagram to illustrate this statement.

(a) Use a distant source of light as object, form an image from the concave mirror and measure the focal length f directly. Make sure you satisfy the requirement that the reciprocal of the object distance is negligibly small.

(b) Obtain an image on the same plane as an illuminated object (e.g. a triangular hole in a screen). Measure the radius of curvature of the concave mirror directly and hence f.

(c) Now choose an object distance. For f obtained from (b) calculate the image distance and its expected accuracy. Set this system up in practice by arranging the illuminated object screen with a large aperture and concave mirror on the optical bench. Measure the image distance. Does it agree with your estimated value? What do you conclude? Repeat for one or two other object distances.

(d) To measure the focal length of a convex mirror when the image is virtual, use an illuminated pin as object near the mirror so as to form a virtual image behind the mirror. Use a second pin, the image marker, behind the mirror so that while viewing the image of the object pin in the mirror you can also see the top of the image marker above the mirror. The problem is to set the image marker at the position where the image appears to be. This is done by the method of parallax. Make use of the videotape programme.

When two objects nearly in line with the eye are viewed by moving the eye sidewise, the apparent change in their relative positions is called parallax. Experiment for yourself the relative lateral movement of eye and two objects just out of line.

Now with the position of the object pin fixed, move the image pin back and forward until, with one pin in the mirror and the other pin above the mirror, all parallax is eliminated. Note the image pin distance from the mirror and the object distance. Calculate the focal length of the convex mirror. Repeat.

2. **Lenses**

The focal length of a lens is the distance from the lens to the image of an infinitely distant object.

In the following measurements, the focal lengths of various lenses are obtained by different methods. Express the focal length in metres and the power P in dioptres.

(a) Use a distant lamp as object, measure directly the focal length of a convex lens. Calculate the power.

(b) Use the illuminated aperture as object, form an image on the object plane by reflection from a plane mirror on the side of the lens opposite to the object. Find the focal length and power. Repeat for all the convex lenses (of 50 mm diameter) provided.

(c) Select one of the convex lenses and form real images of the illuminated aperture for different object distances. Calculate the focal length in each case. Measure also the magnification and compare this with the ratio of the image to object distance.

(d) (i) Place two convex lenses in contact and measure the focal length of the combination by one of the above methods. Compare this with the focal lengths of the individual lenses.

Do your measurements agree with $P = P_1 + P_2$?

(ii) Repeat for one convex lens and one concave lens in contact (where the power of the convex lens is greater, numerically, than the power of the concave lens). Hence obtain the power of the concave lens.

(e) Use the strongest convex lens provided, form an image close to the lens. Note the image distance. Place a concave lens on the original image side of the convex lens and form a new image. Hence obtain the focal length of the concave lens.

Tabulate results and in your discussion compare and contrast the different methods.

3. **Lens and Mirror Combination**

Remember to draw ray diagrams.

(a) Select a convex lens of known focal length.

Using the illuminated triangular aperture as object, form an image on the object plane by refraction at the first spherical surface and reflection at the second. This is Boy's Method for obtaining the radius of curvature of a convex lens.

Measure both radii of curvature of the convex lens and hence calculate the index of refraction of the lens glass.

(b) Use a convex lens of known focal length and convex mirror to form an image on the object plane.

Hence calculate the radius of curvature of the mirror.

(c) Use a concave lens of known focal length and concave mirror to form an image on the object plane. Hence calculate the radius of curvature of the mirror.

4. Discuss the various methods used, and sources of experimental error.

DEFECTS OF A THIN LENS

(1) Spherical aberration

In this part you will investigate the effect of rays passing through a lens at different distances from the principal axis.

Use the illuminated triangle as object O. Cover the central portion of the 63 mm diameter biconvex lens L with the cardboard disc D and form a sharp image on the screen or ground glass S. Ensure that O lies on the principal axis. Measure object and image distances. Leave O and L untouched, readjust S and repeat the measurement.

Remove the disc and use the screen with the 10 mm central hole, B. Repeat the above measurements, the object distance remaining unchanged.

What are your conclusions?

(2) Astigmatism

This is a lens defect which appears when a narrow beam of incident light falls obliquely on the lens.

Replace the triangle with the small cross as object with one line vertical. Cover the lens with screen B and turn the lens through an angle of about 30° about a vertical axis.

Examine the positions where an image is formed, (a) of the vertical line of the cross and (b) of the horizontal line. Can you find a position where the whole cross is in focus?

(3) Chromatic aberration

This is an effect which arises because the refractive index of glass is a function of the wavelength of light transmitted through it.

Use the triangular screen as object O, and use the screen B with the 10 mm central hole in front of the lens. Place a blue (or green) filter at O and find the position of the image. Repeat for the red filter.

What are your conclusions?

Is your result consistent with the fact that a prism deviates red light least?

THE SPECTROMETER

1. Introduction

The purpose of this experiment is to set up a prism spectrometer and to measure the index of refraction of the prism for various colours and hence obtain a value for the dispersive power of the prism.

2. Apparatus

The essential parts of a spectrometer are:

(a) a horizontal collimator, at one end of which is a lens whose focal length is the length of the tube, and at the other end of which is a narrow vertical slit illuminated by light either from a hot solid (e.g. a metallic filament of a lamp) or from a hot gas (e.g. the gas in a helium lamp);

(b) a prism with vertical edges and resting on a table that may be rotated round a vertical axis. A graduated scale enables the rotation to be measured;

(c) a horizontal telescope focussed for infinity, and capable of being rotated round the same axis as the prism table. The rotation of the telescope can be measured by means of the scale.

3. Schuster's method for focussing telescope and collimator. View the spectrum from the helium lamp, through the telescope, and focus the cross wires. Turn the prism to the angle for minimum deviation (see later). Turn the prism slightly (about 5 degrees) away from minimum deviation and focus the collimator. Turn the prism through minimum deviation to a small angle on the other side. If the system did not happen to be focussed properly at the beginning, then the spectrum will now be out of focus. Now focus the telescope.

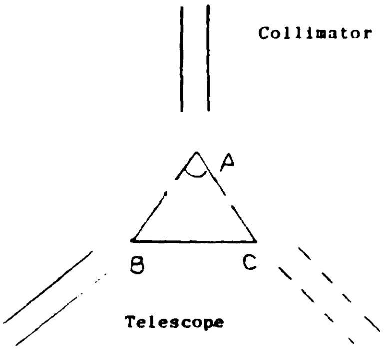
Repeat this alternating procedure until no further improvement in the focus can be made by this method. The telescope and collimator are then both focussed for parallel light.

Note: If it is found, in the course of this procedure, that the focus gets progressively worse, then interchange the rotations of the prism when the telescope and collimator are being focussed.

4. Measurement of the Prism Angle

Illuminate the slit, which should be as narrow as practicable, by means of a metallic filament lamp.

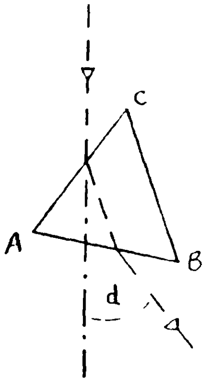
Set the prism so that the beam of light from the collimator is reflected from each of the two faces adjacent to the angle A that is to be measured. Turn the telescope until the right-hand edge of the image of the slit reflected from face AB coincides with the vertical wire in the field of the telescope.



Read the two vernier scales. (Why two?) Repeat for the reflection from face AC. The difference in corresponding readings is twice the angle A.

5. Measurement of Index of Refraction

Set the instrument so that the light from the collimator falls on face AC as shown. The beam will be refracted at surface AC, and at surface AB; the total angle through which the light has been turned is called the deviation. Turn the telescope until the light is seen. It will be noticed that a continuous spectrum has been formed, the red rays being least deviated. Replace the filament lamp by a helium lamp. A bright line spectrum will now be seen. Turn the prism table from one extreme position to the other extreme and note that the deviation first decreases and then increases, that is, there is a *minimum deviation*.



Set the prism table for minimum deviation of the yellow line, and clamp the prism table. Consider the best procedure for accurate alignment of the vertical cross-wire on the image of the slit. Note the two vernier readings. Move to a red image, and then to a violet or blue image, and repeat measurements. *Keep the prism table clamped,* remove the prism carefully and view the slit in the straight-through position by rotating the telescope. Again take two readings. Hence determine the deviations for yellow, red and violet (or blue) light. Calculate the indices of refraction of the prism for these colours. For the particular case of minimum deviation and for yellow light:

$$\mu_Y = \frac{\sin \frac{(A + d_Y)}{2}}{\sin \frac{A}{2}}$$

6. Obtain a value of the dispersive power D of the prism.

$$D = \frac{\mu_V - \mu_R}{\mu_Y - 1}$$

What is the significance of the dispersive power?

7. The angle A can also be measured by keeping the telescope fixed and rotating the prism. Verify this if time permits.

8. <u>Errors</u>

Error on μ

The error on μ due to that on A is:

$$\Delta_1 = \frac{\partial \mu}{\partial A} \Delta A = -\frac{\sin d/2}{2 \sin^2 A/2} \Delta A \qquad \text{(check this if you can)}$$

The error on μ due to that on d is:

$$\Delta_2 = \frac{\partial \mu}{\partial d} \Delta d = \frac{\cos (A + d)/2}{2 \sin A/2} \Delta d$$

where ΔA and Δd are the errors, in radians, on A and d. Since these two errors are independent, it can be shown that the total error in μ is:

$$\Delta\mu = \left[\Delta_1^2 + \Delta_2^2\right]^{\frac{1}{2}}$$

NEWTON'S RINGS

Objective

The purpose of this experiment is to measure the wavelength of sodium light using Newton's rings.

Method

Follow the instructions on the videotape.

The apparatus is to be arranged as shown in fig. 1.

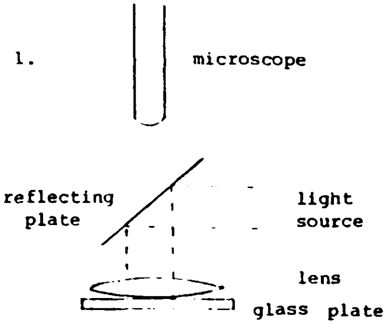


Figure 1

Theory

Let R be the radius of curvature of the lens surface, and e the thickness of the air gap above the point P.

The path difference between the two beams at Q is 2e.

But $r^2 = e\ (2R - e)$, see fig. 3

and so $e = \frac{r^2}{2R}$ since e is small.

Hence the path difference $= \frac{r^2}{R}$.

Now the phase of the wave reflected at P is changed by 180° on reflection. If there is also a path difference of $m\lambda$, where λ is the wavelength of the light and m is an integer, then the two beams will enter the microscope 180° out of phase and hence cancel. This is the condition that will hold on a dark ring. If the radius of the m^{th} dark ring is r_m then

$$\frac{r_m^2}{R} = m\lambda$$

As m is a number (the order of the fringe) and if R and r_m are measured, λ is obtained.

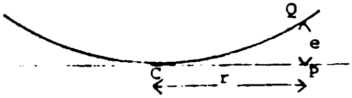


Figure 2

Analysis and Result

A graph of r_m^2 against m should be a straight line passing through the origin.

Determine a value for the wavelength of the light used in the experiment. Discuss the accuracy.

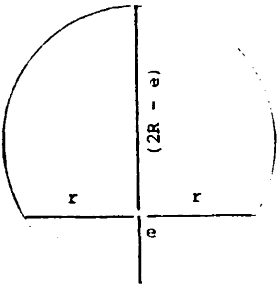


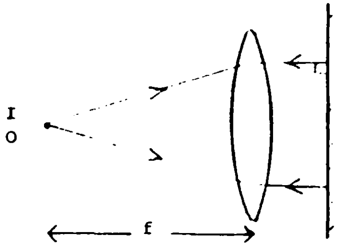
Figure 3

APPENDIX

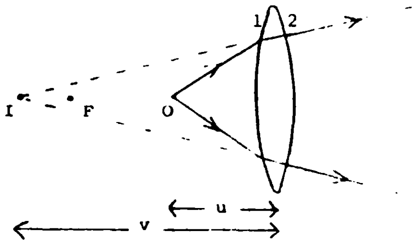
Boys' Method : to determine the radius of curvature of a lens surface.

Note which lens surface was in contact with the glass plate at C.

(a) Measure the focal length f of the lens, using a plane mirror to form an image on the object plane, for example.



(b) With the surface the radius of which is to be found furthest from the light source, reflect the light from this surface (2) so as to form an image on the object plane. This image is formed by refraction in surface 1 and reflection in surface 2.



The object at O, distance u from the lens, now forms a virtual image at I, by refraction at the 1st surface. But the light must strike the 2nd surface normally at all points, since it is reflected along its incident path. So the second surface does not refract the light, and I is the virtual image position for the lens as a whole, when the object is at O. But we may calculate the distance v from I to the lens, since $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ where u and f are known.

Since the rays strike the 2nd surface normally, clearly v is the radius of curvature of the 2nd surface, i.e.

$$|v| = R$$

MELDE'S EXPERIMENT

The objective of this experiment is to measure the frequency of the a.c. mains supply by Melde's method.

The experimental arrangement is shown schematically in figure 1; a steel wire is rigidly fixed at one end and passes over a pulley so that a tension F may be applied at the free end of the wire.

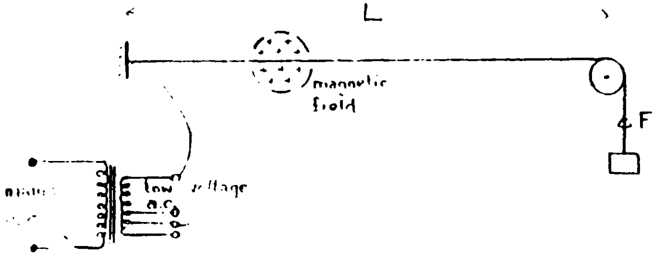


Figure 1.

Introduction

Some particular aspects of physics incorporated in this experiment are the following:

(i) a flexible wire rigidly held at both ends can vibrate transversely in standing waves of only certain frequencies, i.e. the normal modes of the wire,

(ii) an electric charge e moving with a velocity v at right angles to a uniform magnetic field of intensity B experiences a force $e\underline{v}\times\underline{B}$ = evB perpendicular to both $\underline{v}$ and $\underline{B}$,

(iii) when a conductor moves so that it cuts lines of magnetic flux an e.m.f. is induced in the conductor,

(iv) resonance, i.e. the transfer of energy from one vibrating system to another when both systems have a vibration of the same frequency.

Procedure

Set up the apparatus as shown in the figure and place the magnet at a suitable position for the mode of vibration you wish to find.

Vary the tension of the wire and find the optimum tension F_m for the normal mode m - see figure 2 - by tuning the system for maximum amplitude.

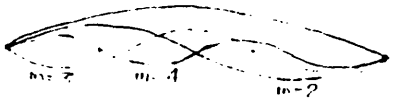


Figure 2

Investigate the small range of values of the tension F_m over which the m th mode is excited. This will give you the experimental error in F_m.

Repeat this procedure over as large a range of m as possible.

Analysis

The wire is initially at rest in the horizontal magnetic field of the permanent magnet. When a.c. is passed along the wire the electrons, and hence also the wire carrying them, experience an alternating vertical force. This is the driving force which may set the wire in motion.

The vibration of the wire will be easily observable when the frequency of the a.c. is nearly equal to a normal mode frequency of the wire. You will note that this is a fixed frequency experiment.

Let n be the frequency of the a.c. supply

- L length of vibrating wire
- F_m tension of wire for the m th mode
- λ_m wavelength of m th mode
- d linear density of wire
- m number of nodal points less one, i.e. the number of loops of the vibrating wire or displacement antinodes.

Refer to your textbooks for the derivation of the velocity of a transverse wave on the wire

$$v \quad \sqrt{\frac{F}{d}}$$

Also for a simple harmonic wave $v = \lambda f$.

You will see from figure 2 that for length L

$$\lambda_m = \frac{2L}{m}$$

This states that only certain wavelengths are allowed. These modes of vibration are the eigentones of the system.

Hence we have

$$\sqrt{\frac{F_m}{d}} = \lambda_m f_m$$

and for resonance $f_m = n$.

In which case $\lambda_m n = \sqrt{\frac{F_m}{d}}$ or $n = \frac{m}{2L} \sqrt{\frac{F_m}{d}}$.

Use this last relationship to analyse graphically your results and obtain a value for n, the mains frequency. Refer to the worked example of an error calculation.

Discussion

1. Check dimensionally $n = \frac{m}{2L} \sqrt{\frac{F_m}{d}}$.
2. The variables in the experiment are m and F_m.
   What functions of m and F_m do you take to give a linear graph?
3. Where does the energy come from when the wire is set in motion?
4. How sharp is the resonance? Try to sketch a response curve, i.e. the amplitude of vibration of the wire against $\sqrt{F_m}$. You will realise that $\sqrt{F}$ varies directly as the frequency for a [illegible]

VIBRATING BLADE

Introduction

This experiment is designed to emphasise experimental procedure and analysis of experimental data.

You will investigate the various parameters which influence the period of vibration T of an oscillating steel blade. For example, such parameters could be the length of the blade L, the total load at one end M, etc. You are encouraged to study systematically how such parameters influence T. You should take decisions about which parameters (e.g. L, M, etc.) you wish to study, and what range of the variables you can investigate and their frequency (i.e. how many different values of L should you take and should these be evenly spaced over the available range)?

Procedure

You should note that in an experimental system which has many variables you must hold constant all the variables except the two under study, i.e.,

i) for a constant unloaded blade and a constant amplitude of vibration A how does T depend on L?

ii) for a constant L and a constant A how does T depend on M? etc.

Does it matter whether the vibrations take place in the horizontal or in the vertical plane?

Analysis

Your measurements should give you a set of values of T and L, and T and M. How do you find a relationship between such variables? One method is to use graphical analysis. (Refer to the notes on Graphical Analysis).

Suppose for a given mass M it is assumed that

$$T = k_1 L^a$$

where k_1 and a are constants. A graph of log T against log L can give you values of a and k_1. What are the units of a and k_1?

The same treatment can be applied to your data of T and M for a given L.

$$T = k_2 M^b$$

Hence obtain b and k_2.

You should seek practice in the use of both linear graph paper (as in your notebook) and log-log graph paper in the graphical analysis of this experiment.

Discuss the analysis, results, observational errors, and conclusions with other students and with your demonstrator.

Appendix 5-2 Continued

UNIVERSITY OF GLASGOW

Department of Physics and Astronomy

Ordinary Physics A - Laboratory Notes - Candlemas Term

* 'University Physics' - Sears, Zemansky and Young - 7th edition.

TO MEASURE THE THERMAL CONDUCTIVITY OF POOR CONDUCTORS

The objectives of this experiment are:

(i) to introduce the meaning of thermal conductivity and to use this information to grade materials in terms of their thermal conductivity by handling them,

(ii) to calibrate a thermocouple for use as a thermometer,

(iii) to measure the thermal conductivity of polystyrene, and knowing this,

(iv) to measure the thermal conductivity of another material using a sample of this material in contact with polystyrene.

Theory:

For steady heat flow across a parallel sided slab of area A, with the heat flow perpendicular to the faces of the slab, we have:

$$\dot{Q} = -kA\frac{d\theta}{dx} \qquad (1)$$

where $\dot{Q}$ = rate of heat transfer

A = slab area

k = coefficient of thermal conductivity

$\frac{d\theta}{dx}$ = temperature gradient

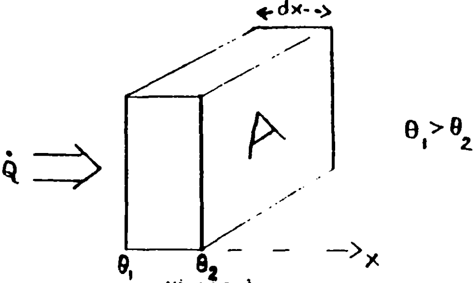


Figure 1.

and the negative sign signifies that the heat flow is in the direction of decreasing temperature (with increasing x).

From relationship (1) write down the units of k. In order to measure k we need to measure A, dx, dθ and $\dot{Q}$.

Experiment:

(1) Using arguments based on the relationship (1), grade the samples provided in terms of their thermal conductivity by handling them. Explain clearly your reasoning.

(2) Calibration of a thermocouple

The temperatures in this experiment are to be measured with thermocouples. The small thermal capacity of the thermocouples is an advantage in this experiment because they come to the temperature of their surroundings quickly, and do not disturb the temperature of the system in which they are being used.

Typical outputs from a thermocouple are about 5mV per 100 degrees so amplification of this signal is required. There are seven thermocouples in this experiment. Each hot junction can be switched into a common amplifier, and the cold reference junction is common to all of the thermocouples.

Thermocouple 1 is used to calibrate the junction response over a temperature range from room temperature to about 40°C.

Junctions 2,3,4 are in sample 1 and junctions 5,6,7 are in sample 2.

OL/I/78

RADIOACTIVITY

The objects of this experiment are:

1. To learn how to operate a Geiger-Muller (G.M.) counter and to measure the plateau curve.
2. To measure the background counting rate.
3. To study the statistical nature of the emission of radiation.
4. To study absorption of gamma radiation.
5. To study the relationship between the counting rate and the distance of a radioactive source from the G.M. counter.

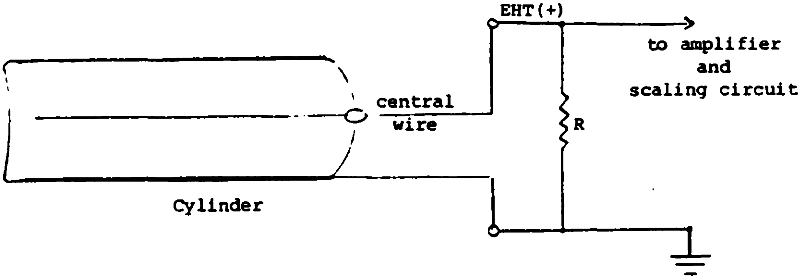
> You are instructed to read thoroughly "Laboratory Practice for Handling Radioactive Material" and to adhere to the Rules during the whole of the experiment.

Introduction

The following notes are for information only and this material should not appear in Record or Report Books.

Radioactive radiations ionize the material through which they pass, i.e., when the radiation (either charged particles or gamma rays) collides with the atoms or molecules of the material some of these are broken down into positive ions and electrons.

This ionizing property is utilized in the operation of many devices designed to detect radioactive radiation, e.g., the Geiger-Muller (G.M.) counter shown in the diagram:



The G.M. tube consists of a wire at a positive potential, mounted along the axis of a cylinder (negative potential), the whole being enclosed in a sealed glass or metal tube. This tube has been evacuated of air and filled with a gas mixture. It is this gas which is ionized by the incident radiation. There may be a very thin window (few mg per cm^2) at one end of the tube.

When radiation enters the G.M. tube, some of the energy of the incident particle (or gamma ray) may be transferred to a gas atom (or molecule) within the tube. The absorption of this energy by the gas atom results in ionization, whereby an outer electron is ejected from the atom. The ejected electron being negatively charged is attracted to the positive charged wire of the G.M. tube, and the positive ions to the cylinder. If the potential difference between the wire and the cylinder is sufficiently high, these primary ions acquire a high speed within a very short distance, and, on their way to the cylinder, will collide with other gas atoms and produce additional ions, and so on.

This cascading effect produces an "avalanche" of ions. The arrival of this avalanche of ions at a charged electrode causes a change in the charge of the electrode. This change in charge causes a sudden momentary change in the potential difference between the wire and the cylinder, resulting in a current pulse to be sent through the circuit. This current pulse causes a difference of potential across the ends of the resistance R. When amplified this current pulse can operate scaling circuits and in turn give a displayed number.

After the development of an avalanche, the cloud of ions decreases the electric field at the wire so as to make further multiplication by collision impossible. A second charged particle (or gamma ray) entering the counter at this time will not produce a pulse. As the ion cloud (space charge) moves towards the cathode, the field increases again. It becomes sufficiently large so that a second particle (or gamma ray) may produce a small pulse after a certain time t, the dead time, following the passage of the first particle.

It should be noted that while gamma rays are penetrating they have low ionizing ability so that only about 1% of the gamma rays which enter the G.M. counter cause any ionization. On the other hand beta particles have high ionizing ability and most of the beta particles which enter the G.M. tube produce ionization. In measurements with G.M. tubes, such characteristics of radioactivity must be understood in order that correct conclusions can be drawn from the data.

The scaler supplies the high voltage (EHT), and the current pulse is taken along the same coaxial cable which supplies the high voltage to the G.M. tube. The scaler is basically a pulse amplifier followed by counting circuits, the display given on 7 segment filament tubes. The scaler sums the accumulated counts for whatever counting time used. An automatic timer controls the scaler with seven preset periods ranging from 10 s to 1000 s. Reset occurs automatically when a new measurement is started.

The G.M. counter is fragile and must be handled with care. On no account must the marked maximum voltage be exceeded. Normally the high voltage connections are not accessible but due caution is necessary as the scaler/timer can supply up to 700 volts.

Procedure

1. Count Rate Plateau

Set the voltage EHT control to minimum, and then switch on mains to the scaler/timer unit.

Select a timing period, e.g. "Count 20 sec." Press the Reset/Start switch.

Slowly increase the voltage on the G.M. counter until signals are registered on the display. These signals are due to background radiation (all radioactive sources should be shielded at this point). Adjust the voltage to be about 20 volts above this threshold.

Bring up a radioactive source, pointing to the end window of the G.M. counter and away from the experimenter, until about 500 counts/per 20 seconds are recorded. Fix the source counter distance.

Turn back the voltage to minimum and find the threshold.

Measure counting rates at 20 volt steps, for example, until 10 volts below the manufacturer's recommended maximum voltage for a given G.M. counter.

The maximum voltage (positive potential on wire) applied to the G.M. counter must not exceed the stated value.

Reduce the voltage to minimum.

Plot the count rate (ordinate) against voltage. This is the G.M. plateau curve. It is the general shape of this graph that is of interest. What is the significance of this curve? The G.M. counter should now be operated in the middle of the plateau. Why?

2. Background Counting Rate

With all sources shielded, observe background counting rates in 100 second periods. Take five such readings and find the average background rate.

3. Fluctuation at Low Counting Rate

Suppose that we have a random process which occurs $\bar{N}$ times per given time interval Δt on average. If we measure the numbers N_i of these events in repeated intervals Δt, our numbers will vary about $\bar{N}$. It can be proved from statistical theory that the standard deviation of N_i about $\bar{N}$ is $\sqrt{\bar{N}}$. The purpose of this section is to investigate this prediction.

Bring a source towards the counter until tens of counts per second are recorded. Now keep the source-counter distance fixed.

Measure the number of counts in each of $M = 30$ intervals of 60 sec.

Draw a frequency distribution of your measured number of counts.

Find the average

$$\bar{N} = \sum_{i=1}^{M} \frac{N_i}{M}$$

Calculate the "experimental" adjusted root mean square deviation for the series of measurements

$$s = \sqrt{\sum_{i=1}^{M} \frac{(N_i - \bar{N})^2}{(M - 1)}}$$

Compare this with $\sqrt{\bar{N}}$. Discuss with your demonstrator.

Calculate the "theoretical" standard error of the mean

$$s' = \sqrt{\frac{\bar{N}}{M}}$$

State your final result as $\bar{N} \pm s'$.

4. Absorption of Gamma Rays

In this part of the experiment, you will study absorption of gamma radiation in a material, e.g. lead. This can be measured by finding how the counting rate varies with thickness of absorber.

Set the G.M. counter to operate in the middle of its plateau.

Find the average counting rate with the γ-ray source placed about 10 to 15 cm from the end window of the G.M. counter and with the holder for the absorber placed against the source. Measure how the counting rate N depends on the thickness of absorber x. Correct for background.

Attempt to fit your data to an absorption process described by

$$\frac{dN}{N} = - kdx$$

i.e.

$$\log_e N = \log_e N_o - kx$$

$$N = N_o \exp(-kx)$$

where k is the absorption coefficient. In what units is k expressed? Here N_o is the counting rate in the absence of absorber.

Plot a suitable graph and evaluate k, and its observational error.

ORDINARY NATURAL PHILOSOPHY LABORATORY

Radioactivity Experiment

A few important points:

(i) Your demonstrator will assume you have read the notes describing the experiment.

(ii) It is imperative that you follow the code of practice for handling radioactive material.

(iii) The measurements for the graph of the G-M plateau should only take about 15 minutes. Exceptionally here we are not interested in the gradient of the graph but only in its shape.

(iv) You may use the Department's calculators (Advance 16R) and the written routine to calculate the standard deviation of the mean in part 3.

Laboratory Practice for Handling Radioactive Material

A. General

Radioactivity should be respected but not feared. In many research laboratories people handle radioactive material constantly but they are required to keep a set of safety rules for protection against the serious effects which may result from mishandling. Either through ignorance or carelessness of the experimenter, it is possible for radioactive material to gain entrance to the body via the hands to the eyes, nose or mouth. It is then that there is danger.

B. The sources used in the Ordinary Laboratory have been carefully mounted so that it is never necessary for the student to touch the source itself. The level of radiation received from these sources during a three hour experiment is NOT dangerous.

C. Adherence to the following rules will ensure that no injury can occur in the course of these experiments.

D. Rules for Handling Radioactive Material

1. There must be NO SMOKING and NO EATING in the laboratory while using radioactive sources.
2. When working with radioactive sources:
   - (a) do not touch eyes, nose, ears or mouth,
   - (b) do not handle sources if you have a cut on your hands. Polythene gloves are available on request.
   - (c) do not carry sources in your pockets, and do not handle sources any more than necessary.
   - (d) after the experiment, wash your hands.
3. You will be asked to sign for radioactive sources. When you return the source make sure that the duty technician receives it and checks you off as the holder. NEVER leave a source at the office if the technician is absent.
4. If any mishap should occur, notify a DEMONSTRATOR at once.

ATOMIC PHYSICS

Measurement of the ratio of charge to mass $^e/m$ of the electron

General Aim: to study the behaviour of accelerated electrons in a uniform magnetic field and thereby measure their ratio of charge to mass $^e/m$.

Objectives:

(i) to understand how the energy of electrons can be varied in an electron gun, and to calculate their speed v in terms of the potential difference V through which the electrons have been accelerated.

(ii) to appreciate that the magnetic field of flux density B in the central region of a pair of Helmholtz coils is fairly uniform, and to evaluate the magnitude of B from the current I in the coils, their dimensions and the number of turns.

(iii) to observe the effect of a transverse magnetic force on a beam of electrons and to measure the radius r of the resulting circular trajectory.

(iv) to plan an experiment involving three variables viz. V, I and r.

(v) to analyse the measured data graphically and hence calculate a value of $^e/m$.

(vi) to be aware of systematic errors and to attempt to correct for them.

(vii) to evaluate the random error in the experiment.

Introduction

In this experiment electrons are accelerated through a potential difference V, and pass through a slit in the anode to form a beam of electrons of defined speed v. The electrons then enter a uniform magnetic field in a direction perpendicular to the field lines so that they move in a circular path.

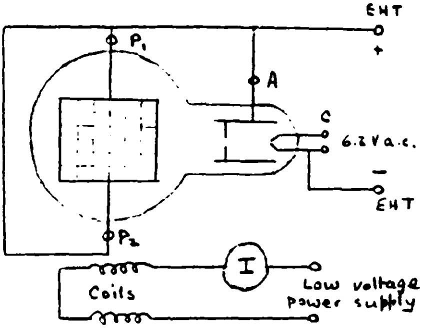
The apparatus includes the electron beam tube, the Helmholtz coils and two power supplies.

The electron beam tube comprises an electron gun which emits a ribbon of electrons within the evacuated bulb. The electrons can be accelerated by applying a positive potential between the anode A and the cathode C. The electron beam then strikes a luminescent screen held by the two deflection plates P_1 and P_2. The voltmeter in the EHT power supply measures the potential difference V between A and C.

NOTE: Due care should be exercised when handling this apparatus. Remember that potential difference, of up to 5000 volts will be used. If the circuit is incorrectly wired, damage may result. Do not switch on mains to power supplies until ALL connections have been made and checked. If in doubt, ASK.

The two Helmholtz coils are wired in series, and connected to the low voltage d.c. supply. The ammeter measures the current I in the coils. (Ignore the voltmeter on the low voltage d.c. power supply). Do not exceed the stated current rating of the Helmholtz coils.

Procedure



Set up the circuit as in the diagram.

The deflecting plates P_1 and P_2 are both connected to the anode, i.e. we are not using electrostatic deflection in this experiment. One side of the filament supply should be connected to negative EHT.

In this experiment the electron beam is deflected by the magnetic field of the coils. Remember that the force $\underline{F}$ experienced by an electron travelling with velocity $\underline{v}$ is perpendicular to the plane defined by $\underline{B}$ and $\underline{v}$. With reference to the screen observe how r varies with I when V is constant, and how r varies with V when I is constant.

The relationships governing the motion of the electrons are

$$eV = \frac{1}{2} mv^2$$

$$Bev = \frac{mv^2}{r}$$

where an electron of mass m and charge e moving with speed v at right angles to a magnetic field of flux density B experiences a force Bev, causing the electron to move in a circular path of radius r. Show for yourself that

$$\frac{e}{m} = \frac{2V}{B^2r^2}$$

If I is the current through the Helmholtz coils

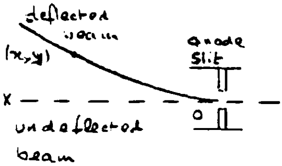
$$B = kI$$

where $$k = \frac{8n\mu_0}{5\sqrt{5}\,a}$$ as shown in the Appendix.

Hence the experimental quantities to be measured are V and I (both from meters) and the radius of the trajectory r.

Measurement of r

In general three points are required to specify a circle uniquely. In this experiment the electron beam OX is tangential to the circular path at the origin O (which should be at the exit aperture of the anode slit). Hence we require to measure only one point to calculate r. In principle of we read a coordinate (x,y) on the scale of the luminescent screen, the radius of curvature r of the electron path is



$$r = \frac{x^2 + y^2}{2y}$$

Due to the difficulty, in manufacture, of aligning the electron gun there is usually a systematic error arising from the position of the scale with respect to the anode slit.

First check any asymmetry in the y deflection by selecting a point (x,y) through which the beam passes. Reverse the direction of I (and the ammeter) and hence reverse the direction of B. This should produce a deflection through (x, -y). Note any differences along the length of the screen. You should now be in a position to correct any observed value of y to give the "true' value Y.

To investigate any systematic error in the abscissa, arrange the apparatus to produce a deflection of the electron beam for example through the points (x_1, y_1) and (x_2, y_2) corresponding to one value of r. Correct y_1 and y_2, as above, to give Y_1 and Y_2. Here you are finding out if there is any small difference Δx between the origin of the scale on the screen and the slit in the anode, i.e.

$$X = x + \Delta x$$

Hence
$$r = \frac{(x_1 + \Delta x)^2 + Y_1{}^2}{2Y_1}$$

and
$$r = \frac{(x_2 + \Delta x)^2 + Y_2{}^2}{2Y_2}$$

From this calculate Δx. This is the quantity which you add algebraically to all observed values of x to give the "true" values X.

Therefore you now calculate r from

$$r = \frac{X^2 + Y^2}{2Y}$$

Analysis

You have sets of data of V, r and I. How do you obtain a value of $^e/m$ by graphical analysis?

One way is to choose to hold r constant (and you must know this value) and draw a graph of V against I^2. Remember to work in SI units.

Determine from the gradient of this graph a value of $^e/m$. Calculate the observational error.

Compare your value of $^e/m$, with its error, with the accepted value. Write a concluding statement.

Questions

1. What other graphs could you draw using your experimental data? Is one of these graphs to be preferred to another?

2. For a given value of r you have the choice of changing V and then setting I to give the coordinate you want. Alternatively you could change I and then set V. Which of these two methods is better? Why?

Appendix

The flux density of a magnetic field on the axis of a circular coil (mean radius a, number of turns n, carrying a current I) at a distance Z from the centre of the coil is

$$B = \frac{\mu_o nI\ a^2}{2(a^2 + Z^2)^{3/2}} = \frac{C}{(a^2 + Z^2)^{3/2}} \quad \text{where} \quad C = \frac{\mu_o nI\ a^2}{2}$$

What is the direction of $\underline{B}$?

We wish to find the spacing of a pair of similar coils so as to give nearly constant magnetic field between them.

$$\frac{dB}{dZ} = -C\ 3Z(a^2 + Z^2)^{-5/2}$$

$$\frac{d^2B}{dZ^2} = -3C\left[(a^2 + Z^2)^{-5/2} - 5Z^2(a^2 + Z^2)^{-7/2}\right]$$

If $\frac{dB}{dZ}$ is to be constant, $\frac{d^2B}{dZ^2} = 0$

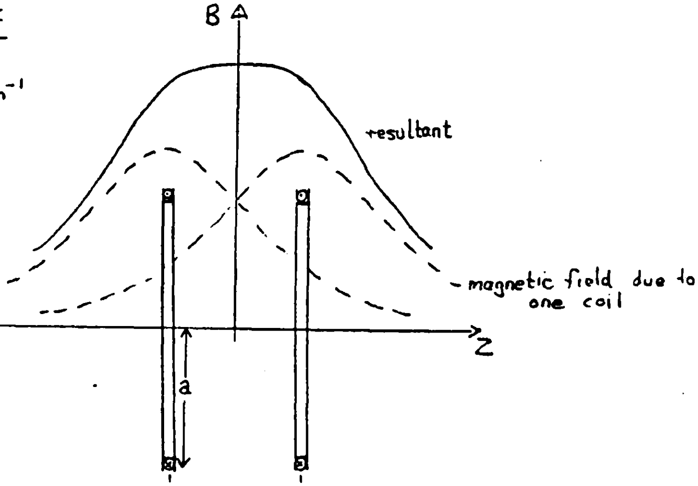
$$\Rightarrow \quad 5Z^2(a^2 + Z^2)^{-1} = 1$$

$$\Rightarrow \quad Z = \pm \frac{a}{2}$$

i.e. spacing of the coils should be equal to their radius a. In which case, for a pair of coils, connected in series, the combined field on their axes at a distance of $\frac{a}{2}$ from each of their centres is

$$B = \frac{8n\ \mu_o\ I}{5\sqrt{5}a}$$

$\mu_o = 4\pi . 10^{-7}$ H m^{-1}



MAGNETIC FIELD OF A SOLENOID.

Introduction.

The purpose of this experiment is to investigate the variation of magnetic induction along the axis of a long solenoid.

From your textbooks find out what is meant by a solenoid and how to calculate the magnetic induction along its axis. Hence you will be able to compare the calculated and the measured values of the magnetic induction B along the axis of the solenoid.

Procedure.

Set up the circuits shown schematically in figure 1; the primary circuit consists of the solenoid, a variable power supply and an ammeter.

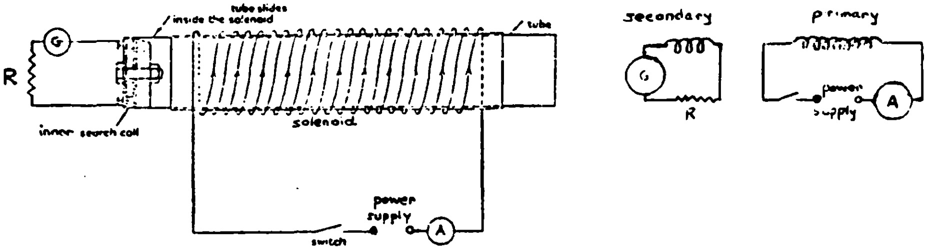


FIG. 1 SOLENOID AND CIRCUIT DIAGRAM.

The separate secondary circuit is made up of a short search coil, and a ballistic galvanometer with its damping resistance R.
Find out what happens in the secondary circuit containing the ballistic galvanometer G when a current of 300 mA (for example) is made and broken in the primary circuit. G is a Scalamp used in the DIRECT position with the damping resistance R included in the circuit.

Discuss with your demonstrator why you observe a reading in G.
Show theoretically that the magnetic induction at a given position along the axis of the solenoid is given by

$$B = \frac{R_2 \; k \; d}{N \; A}$$

where R_2 is the total resistance of the secondary circuit. The moving-coil resistance R_G is marked on the front of the galvanometer.

k is the quantity sensitivity of G (C mm^{-1})

d is the deflection observed in G (mm)

N is the number of turns of the inner secondary coil, of resistance r

A is the cross sectional area of the secondary coil (m^2)

(The quantity sensitivity is given on the instrument.)

Note: $R_2 = R + R_G + r$

For different positions (how many?) of the secondary coil along the axis of the solenoid, obtain d as a function of position and show this graphically. Note that $B = Cd$ where $C = \frac{R_2 K}{NA}$. Calculate C, and hence obtain B as a function of position on the axis. Show on the same graph the magnetic induction $\underline{B}$ along the axis of the solenoid as measured and as calculated. (see Appendix).

APPENDIX.

The magnetic flux density on the axis of an infinitely long solenoid is given by

$$B_\infty = \mu_o \, nI \qquad (\text{Wb m}^{-2})$$

where μ_o = permeability of free space

= $4\pi \times 10^{-7}$ Wb A^{-1} m^{-1}

n = number of turns per unit length (you require to measure this)

I = current in solenoid

(B_∞ is the magnitude of the vector B_∞. What is its direction?)

When corrections are applied to account for the finite length of a practical solenoid, we obtain

$$B = \frac{B_\infty}{2} (\cos \theta_1 - \cos \theta_2)$$

where θ_1 and θ_2 are shown in figure 2.

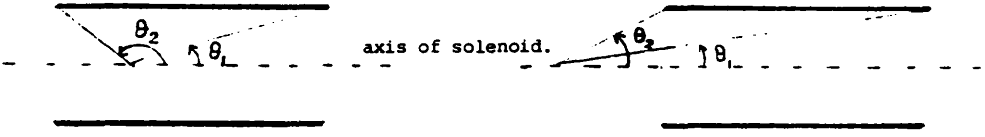


Figure 2.

Note the solenoid current I and measure n, the number of turns per metre of the solenoid.

Select various positions along the axis of the solenoid and make measurements to give you various sets of θ_1 and θ_2. Hence calculate

$$B = \frac{\mu_o nI}{2} (\cos\theta_1 - \cos\theta_2)$$

CURRENT ELECTRICITY AND RECTIFICATION

General Aim: to study the electrical characteristics of a carbon resistor, and a semiconductor diode, and to investigate the performance of simple circuits incorporating these components.

Objectives:

(i) to connect simple d.c. circuits and to use correctly a multirange meter

(ii) to measure and plot the current-voltage characteristics of a carbon resistor and a semi-conductor diode

(iii) to set up correctly and use an oscilloscope

(iv) to study half-wave rectification and interpret the observations in terms of (ii) and simple circuit theory.

This experiment is concerned with linear and non-linear circuit elements, with the interpretation of characteristics and waveforms but not with the microscopic aspects of electric current conduction.

CURRENT ELECTRICITY

The object of this part of the experiment is to observe the current in various conductors as a function of the potential difference applied to them.

Procedure:

Use the circuit board provided to obtain i against V relationships for (1) a carbon resistor, and (2) a semiconductor diode. Consider the range of your measurements and how many readings you require to specify the characteristics. Arrange your method of working to allow you to plot your data immediately on a graph.

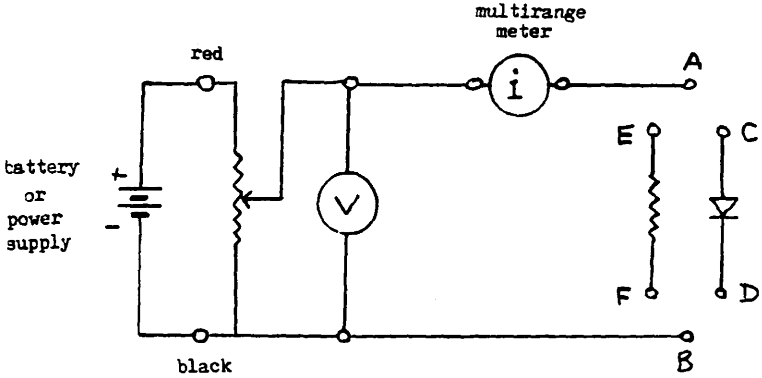


Figure 1

1. The left hand part of the circuit up to A and B is common to these measurements. By linking A to E and B to F, for example, you can study the i/V behaviour of the resistor.

   Reverse connections (e.g. A to F, B to E) and record results graphically.

   Discuss with your demonstrator the operation of the voltage divider, ammeter, voltmeter and Avometer.

   Can ohm's law be checked by this arrangement?

2. Repeat the measurements for the semiconductor diode.

Note:

Use a battery of e.m.f. of 3 volts (two 1½V Flag cells) as your supply, or a power supply which is limited to 3 volts.

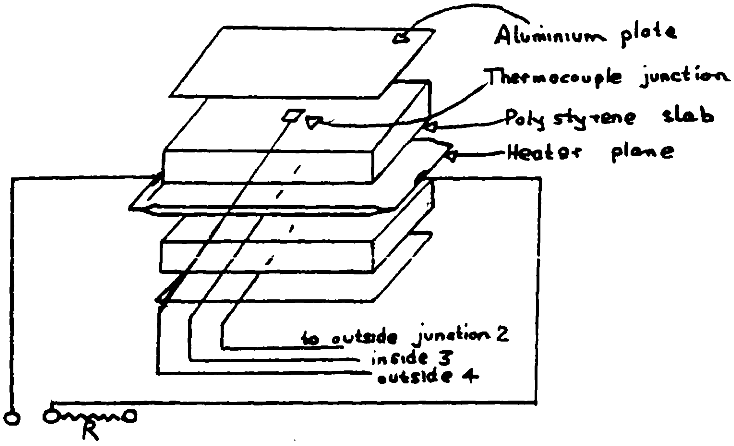
If you change the range of the ammeter to measure high currents through the diode, you may notice inconsistencies in the readings. Why do these occur?

Procedure

Fill up the ice bucket with crushed ice; this keeps the common cold junction at 0°C - (do not let the ice level fall too low during the experiment). Switch on the galvanometer to the range indicated and set the pointer spot to mid-scale, using the set zero of the galvanometer. Place the sampling junction of thermocouple 1 in the ice bucket also, select junction 1 on the amplifier, and switch on the amplifier. Because both junctions of thermocouple 1 are at the same temperature, we expect no thermoelectric emf. Zero the pointer spot using the set zero of the amplifier. Now insert the sampling junction of thermocouple 1 into a beaker of water and note the temperature reading on the mercury thermometer. Add cold water to change the temperature of the water bath. Note the thermocouple reading versus the mercury thermometer reading. Draw the calibration graph.

(3) Measurement of the thermal conductivity of polystyrene

Apparatus in exploded view



Connect the AC supply as shown, measure the voltage V across the resistive heating strip and the voltage drop V_R across R using the AC voltmeter. Calculate the current through the heater, and hence $\dot{Q}$. See Appendix.

Monitor the junction temperatures until thermal equilibrium is obtained. (About every 4 or 5 minutes, in between times think about the analysis of your data, and the questions at the end of this script).

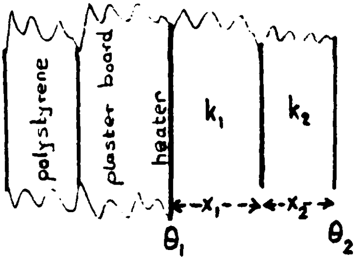
The measurements required are the thickness dx and area A of the polystyrene slab, and the temperature difference dθ across it.

If heat flow normal to the faces is obtained, half of the heat produced in the heating plane will flow through each slab. How is this achieved in your experiment? Draw the thermal gradient along an unlagged bar of material and compare this with your experiment.

From (1), evaluate k.

You can use the hot (sampling) junction of thermocouple 1 to measure any temperature you might think worthwhile, e.g. if you leave it in the ice, you can keep a check on any drift in the set zero control of the amplifier.

(4) Measurement of the thermal conductivity of another material



Derive the relationship giving k_1 in terms of k_2, x_2, x_1, θ_1, θ_2, A and $\dot{Q}$ where the subscript 2 refers to polystyrene. Measure as before, using junctions 5, 6, 7 this time.

The thickness of plaster board is 3/8".

The thickness of polystyrene is 5/16".

(5) Try to answer the following:

(A) Find out from tables the thermal conductivity of a good conductor.

(B) Using $\dot{Q}$ above, what temperature gradient would you expect for a reasonable sample size.

(C) Would you use this method for this good conductor?

(D) If not, try to find out what method you would use and why.

(E) Could you perhaps use a similar sandwich to part (4) for a good conductor - explain?

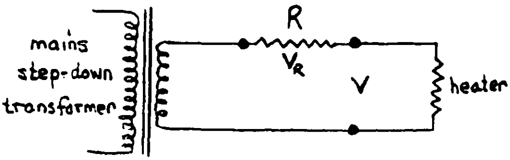
(6) Appendix

To measure the energy dissipated per second in the heating strip, we need to measure the potential difference V across it, and the current through it. To avoid breaking the circuit to measure current we have arranged a series resistance R of known value. By measuring the potential difference across R, V_R, we can calculate I:

$$I = \frac{V_R}{R}$$

Hence $$P = VI = V\left(\frac{V_R}{R}\right)$$

$$\dot{Q} = \frac{P}{2}$$



COMPOUND PENDULUM

General Aim

To study small oscillations of a compound pendulum and hence determine a value for g, the acceleration due to gravity.

Objectives

To set up a compound pendulum which has a non uniform mass distribution and to use a simple method for determining the centre of gravity of such a rigid body.

To measure the period of small oscillations of this pendulum using a photocell gate.

To plan the measurements i.e. to decide what range of variables to measure and their frequency.

To test the measurements for reproducibility.

To establish graphically the relation between T^2 and h.

To analyse the date described by a quadratic equation by plotting the sum of its roots against T^2.

To calculate a value for g.

To estimate the observational error in g.

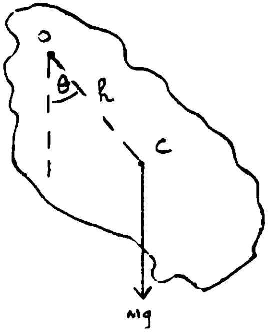
To evaluate g from the minimum in the T^2 against h graph.

Introduction

A rigid body, centre of gravity C, suspended from a point O, will oscillate about the vertical with period T given by

$$T^2 = \frac{4\pi^2}{g}\left(\frac{k_c^{\,2}}{h} + h\right) \qquad \text{(see appendix)}$$

where k_c is a constant of the body, called the radius of gyration about the point C, and h is the distance OC. Note that as $h \to 0$, $T^2 \to \infty$ and as $h \to \infty$ $T^2 \to \infty$. Hence a graph of T^2 against h should be asymptotic to the T^2 axis and also asymptotic to the line



$$T^2 = \frac{4\pi^2}{g} h$$

as shown in the diagram.

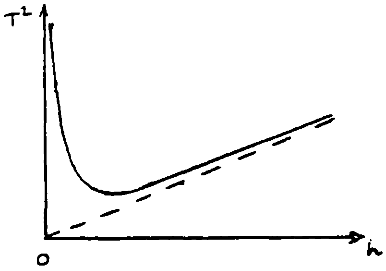
Further it is readily shown that the curve has a minimum at the point

$$h = k_c \,, \quad T^2 = \frac{8\pi^2 k_c}{g} \qquad \text{(see appendix)}$$

Now we may write $\quad T^2 = \dfrac{4\pi^2 L}{g}$

where $L = \frac{k_c^{\,2}}{h} + h$

Here L is the length of the equivalent simple pendulum



$$\therefore Lh = k_c^{\,2} + h^2$$

$$\therefore h^2 - Lh + k_c^{\,2} = 0$$

This is a quadratic in h and the two roots of the equation h_1 and h_2 are given by

$$(h_1 + h_2) = L = T^2 g/4\pi^2$$

Thus for a range of values T^2 we may determine the corresponding values of h_1 and h_2 and plot a graph of $(h_1 + h_2)$ against T^2. The gradient of this straight line is $g/4\pi^2$.

Method

Investigate the form of the graph of T^2 against h for a rigid body. The centre of gravity 'c' can be found by balancing the pendulum on a knife edge. Consider how many different values of h you should take and their distribution along the rigid body (evenly spread or not?). If it is found that the above theory applies, proceed to graph $(h_1 + h_2)$ against T^2 and deduce a value for g. Estimate the observational error in g.

APPENDIX

For the rigid body as described above, we may write

$$Mg\,h \sin\theta = I_o\alpha$$

where M is the mass of the body

θ is the angle OC makes with the vertical

I_o is the moment of inertia of the body about the point O

α is the angular acceleration of the body.

Hence $\alpha = \frac{Mgh}{I_o}\,\theta$ for small θ (when $\theta = \sin\theta$)

i.e. the motion is simple harmonic and the period is given by

$$T = 2\pi\sqrt{\frac{I_o}{Mgh}} = 2\pi\sqrt{\frac{k_c^{\,2} + h^2}{gh}}$$

Further $\frac{d(T^2)}{dh} = \frac{4\pi^2}{g}\left(\frac{-k_c^{\,2}}{h^2} + 1\right)$ Hence show that $\frac{d(T^2)}{dh} = 0$ when $h = k_c$

When $h = k_c$, $T^2 = \frac{4\pi^2}{g}(k_c + k_c) = \frac{8\pi^2 k_c}{g}$

i.e. the function has a turning value of $\frac{8\pi^2 k_c}{g}$. Show that this is a minimum.

FORCE AND POTENTIAL ENERGY

If there is repulsive force between two objects, work must be done to bring them together from infinity to any distance x. This work is turned into potential energy, which varies with x, the separation of the objects. If the objects are now released, the potential energy may be converted into kinetic energy, which can be measured.

In general, potential energy may be defined for many physical systems, whether the forces are repulsive or attractive. Certain conditions have to be met, one of which is that forces such as friction, which dissipates energy, must be absent. (Refer to your textbook).

In this experiment we investigate the force and potential energy between two magnets, mounted on a glider and on an air track. Friction should thus be negligible. The potential energy U of the system at a given separation x is found by measuring the final velocity v of the glider after it is released. If m is the mass of the glider then

$$U = \text{kinetic energy gained} = \frac{1}{2} mv^2$$

We also measure the force F between the two magnets at given x values. We have then enough information to relate F and U.

1. To study the velocity of the glider as a function of initial separation of the two magnets.

   First of all level the track so that the glider hovers around the middle of the track.

   Pull the glider against the repulsive field of the interacting magnets to a measurable separation. Let the glider go and measure its velocity using a photocell gate.

   Find the mass of the glider and hence calculate its kinetic energy. Plot a graph of kinetic energy K(J) as a function of initial separation distance x.

2. To study the magnitude of the force needed to maintain the glider at a given separation distance.

   Secure the plastic tape to the pillar of the glider, and attach a small mass to the other end of the tape which should be guided over the air pulley. Take data of the mass which keeps the glider at a series of separation distances. Plot a graph of force F(N) against initial separation distance x.

3. Analysis

   From the curve obtained in part 1 obtain the gradient of this graph at a number of x values i.e. at average values of x over an interval Δx find the gradient $\frac{\Delta K}{\Delta x}$ where K is the kinetic energy.

   Plot these points $(\bar{x}, \frac{\Delta K}{\Delta x})$ on the same graph obtained in part 2. For the interacting magnets we can define a potential energy of the system (in one dimension) as

$$F = -\frac{dU}{dx}$$

   Can your experimental data be described by such a relationship? In what other fields of physics have you met this concept?

4. To find the relationship between the conservative force F and the separation distance between the force centres.

The physical separation x of the magnets you have measured is unlikely to be the distance r between the effective centres of magnetic force in the two magnet system, i.e. $r = x + \delta x$

Suppose $F = k\,r^n$

$\therefore \log F = n \log r + \log k = n \log (x + \delta x) + \log k$

Plot a graph of log F against log x. If your measured separation distance x was equal to r defined in this equation we should expect a linear log - log graph.

The following empirical method can be used to find r: on the same graph plot log F against $\log(x + \delta x)$ for several values of δx (e.g. between 0 and 10 mm) until a straight line is obtained (if possible). Then obtain n from the gradient.

Discuss this section with your demonstrator.

FREQUENCY BY MONOCHORD

In this experiment you will calibrate tuning forks against the frequency of a vibrating stretched wire, and compare the measured frequency with the nominal frequency of the fork.

1. The velocity V of a transverse wave along a wire stretched to tension T and having linear density d (= mass per unit length) is given by

   $$V = \sqrt{(T/d)} \tag{1}$$

   Since $V = n\lambda$, where n is the frequency of vibration of the wire and λ is the length of the wave and, also, since $\lambda = 2\ell$, where ℓ is the length of the sounding wire, we have:-

   $$n = \frac{\sqrt{T/d}}{2\ell} \tag{2}$$

2. Use a load of about 6 kg, strike one of the forks on the thumping block and tune the wire to sound in unison with it by adjusting the movable bridge. Measure the length of the wire between the bridges. Repeat a few times.

3. Repeat for other forks and other tensions (not exceeding a load of 7.5 kg).

4. Check the dimensions of the quantities on the right hand side of above relationship (2).

   Calculate the frequencies of the tuning forks, with errors. Comment on results.

If you have difficulty in tuning the wire you may make use of an electromagnetic detecting device and oscilloscope. Place the device under the wire (about 1 mm) and observe the output signal on the oscilloscope when the wire is gently plucked. Adjust the volts/cm and time base to give a suitable display. Now tune the wire (see Section 2) by observing the amplitude on the oscilloscope.

Take care to ensure you have the position which corresponds to $\frac{\lambda}{2}$. (Note that it may be possible, in certain circumstances, to drive the wire at TWICE the frequency of the fork). If you are in doubt, discuss with your demonstrator.

VELOCITY OF SOUND BY RESONANCE

In this experiment you will measure the velocity of sound in air by a resonance method.

Introduction

When a tuning fork is held at the mouth of a cylindrical tube closed at the other end, the length of the tube may be adjusted to give maximum resonance. Many positions of resonance can be found provided the tube is sufficiently long. The closed end is a displacement node but the antinode is a little above the open end, by a distance ε (the end correction) which is the same for all lengths giving resonance. Listen to the note from the fork and from the vibrating column of air when you think you have a resonance condition. These should be in unison.

Corresponding to the first two resonance positions, let the shorter length of tube be L_1 and the long length of tube L_2

where

$$L_1 + \varepsilon \doteq \lambda/_4$$

$$L_2 + \varepsilon = 3\,\lambda/_4$$

Since

$$v = n\,\lambda$$

$$\therefore \quad v = 2n\,(L_2 - L_1)$$

Where v is the velocity of sound in air at room temperature n is the common frequency of the tuning fork and stationary waves, and λ is the corresponding wavelength.

For several tuning forks of different values of n, the length L_1, of the tube for the first resonance position may be found for each. In which case

$$v = 4n\,(L_1 + \varepsilon)$$

Method

Graphically, find the average value of v from the L_1 data alone, and from the L_1 and L_2 data. Compare the value of ε from one of your graphs with the value from the empirical relation

$$\varepsilon = 0.6\,r$$

where r is the inside radius of the glass tube.

Express the measured velocity of sound in air at 0°C thus

$$\frac{V_o}{V_\theta} = \sqrt{\frac{273}{273 + \theta}}$$

where V_θ corresponds to a temperature of θ°C.

Comment on your result and error. Compare with the accepted value.

LAW OF GROWTH AND DECAY

Introduction

There are many systems in nature for which the rate of change of the size of a quantity with time varies directly as the size of the quantity at that time (e.g. population growth, radioactive decay).

Objectives

(i) to study a few physical systems which exhibit growth or decay behaviour,

(ii) to enquire whether such systems can be described by the law

$$N = N_o \exp (kT)$$

and if so to evaluate the constant k,

(iii) to learn how to take experimental data of a time-varying quantity,

(iv) to analyse experimental data graphically, using log-linear graphs.

Analysis

The rate of change may be either a growth process (n increasing with time t)

$$\frac{dn}{dt} = kn \qquad (1)$$

or a decay process (n decreasing with time)

$$\frac{dn}{dt} = - kn \qquad (2)$$

where k is a positive constant.

Integrating equation (1)

$$\int_{N_o}^{N} \frac{dn}{n} = k \int_{0}^{T} dt$$

gives

$$\Big[\log_e n\Big]_{N_o}^{N} = k\Big[t\Big]_o^T$$

$$\log_e N - \log_e N_o = kT \qquad (3)$$

i.e.

$$\log_e (\frac{N}{N_o}) = kT$$

i.e.

$$N = N_o \exp (kT)$$

where N_o is the value of n at t = 0.

Equation (3) may be rewritten as

$$\log_{10} N = \log_{10} N_o + \frac{kT}{2.303} \qquad (4)$$

Consequently if some quantity n obeys equations (1) or (2) a graph of $\log_e N$ against time should be a straight line (equation 3) of gradient k, OR a graph of $\log_{10} N$ against time should be a straight line (equation 4) of gradient $k/2.303$.

Experiments

(a) Cooling of a warm body

You are provided with a small container and two mercury-in-glass thermometers. Put warm water (e.g. 20 to 30 degrees above room temperature) into the container and insulate it thermally from its holder as far as possible. Obtain the temperature fall of the water and container as a function of time, taking room temperature over the same period. Take data until the fall in temperature is about ten degrees.

Let $\Delta = (\theta - \theta_{room})$ where θ is the temperature of the water.

We want to enquire if a relationship of the form

$$\frac{d\Delta}{dt} = - k_1 \Delta$$

holds in your experiment, i.e. is a graph of log Δ against time linear? If so, you can then evaluate k_1.

You will see from the general relationship

$$\frac{N}{N_o} = \exp\ (kT)$$

that the left side is dimensionless, and hence so must also be the right side, i.e. if T is expressed in units of seconds, the units of k must be $(\text{second})^{-1}$. Therefore when you evaluate k in this experiment also quote the appropriate units.

(b) Pendulum

A swinging simple pendulum gradually comes to rest (why?); as the oscillations become smaller the speed of the bob in each part of the swing decreases and hence one deduces the resistance is proportionately less.

Set the simple pendulum swinging and note the amplitude every quarter minute, for example, until it effectively stops. Let the amplitude change by dA in a time dt. Find out if the relationship

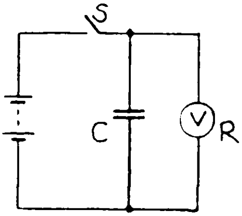
$$\frac{dA}{dt} = - k_2 A$$

holds. If it does, evaluate k_2.

(c) Discharge of a capacitor

Let a capacitor be charged. There is an initial charge Q_o on each plate and a potential difference

$$V_o = \frac{Q_o}{C}$$



between the plates, where C is the capacitance of the capacitor. When the switch S is opened electrons leave the negatively charged plate, pass through the meter (a resistance R) and reach the positive plate so that a current

$$i = \frac{V_o}{R}$$

exists in the circuit. This process continues until the capacitor becomes electrically neutral. In this part of the experiment you will investigate how the potential difference and hence the charge varies with time.

Connect the circuit. When the switch S is closed the capacitor charges and the potential difference across it is registered on the voltmeter. Charge the capacitor, read V_o. Open S and read V_1 after a given time t_1. Recharge the capacitor and repeat for a different time t_2. Plot a graph of log V versus t.

Does $\frac{dV}{dt} = - k_3 V$ hold? If so, evaluate k_3 (units).
Refer to the Appendix.

This law can be expressed

$$V = V_o \exp(- k_3 T) = V_o \exp(- \frac{T}{RC})$$

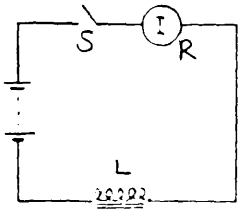
Here C may be 20μF and R is the resistance of the meter (about 200 Kohms. Does your value of k_3 agree approximately with $\frac{1}{RC}$?

For this circuit RC is a characteristic time since

$$\frac{V}{V_o} = - \frac{1}{e} = - 0.37 \text{ when } T = RC.$$

RC is called the time constant of the circuit.

(d) Current through a coil



When a battery is connected to a coil the current may not attain its maximum value immediately (what determines this value?) You will investigate how the current increases as a function of time in a coil with an iron core.

Use the 9 V battery or a power supply and the milliameter initially with a high current shunt. Select a battery emf (or power supply voltage) and a shunt to give you the best sensitivity (try 7.5 volts and 1 mA scales).

Plot log $(I_o - i)$ versus t (I_o is the maximum current).

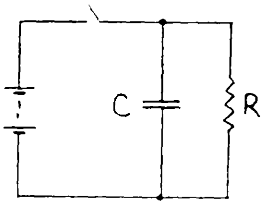
What is the slope of this graph and how is it related to the inductance and resistance of the coil? Refer to the Appendix.

Appendix

(i) Because the net change of potential around a closed path is zero, at any time

$$iR + \frac{q}{C} = 0$$

or $$R\frac{dq}{dt} = -\frac{q}{C}$$



$$\int_{Q_o}^{Q} \frac{dq}{q} = -\frac{1}{RC}\int_0^T dt$$

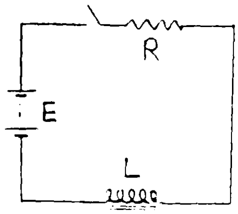
$$\ln\frac{Q}{Q_o} = -\frac{T}{RC}$$

$$Q = Q_o \exp\left(-\frac{T}{RC}\right)$$

But $Q_o = CV_o$ and $Q = CV$

$$V = V_o \exp\left(-\frac{T}{RC}\right)$$

(ii) We want to find how the current i varies with time after the switch has been closed until the final value $I_o = \frac{E}{R}$ is reached.



By Kirchhoff's second rule

$$E - L\frac{di}{dt} = iR$$

The solution of this equation is

$$i = \frac{E}{R}\left[1 - \exp\left\{-t\left(\frac{R}{L}\right)\right\}\right]$$

RECTIFICATION

The purpose of this experiment is to apply the results of the previous measurements and investigate rectification by a diode.

Introduction

The most convenient way to generate electricity on the commercial scale is by use of an alternator which yields an alternating voltage of the form $V = V_o \sin \omega t$ where V_o is the amplitude of the voltage and $\omega/2\pi$ is its frequency.

A transformer may then be used to change the value of this alternating voltage to the required level.

For many applications it is necessary to have a source of direct current and this may be produced from the alternating current using a diode rectifier circuit.

Procedure:

Set up the circuit as shown in figure 2.

A note on the use of an oscilloscope is given in the Appendix.

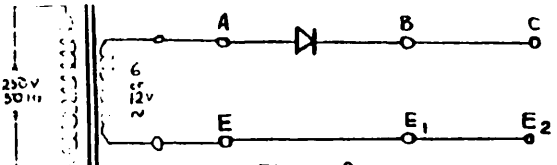


Figure 2

(i) Connect A and E between the output terminals of the transformer marked 6V or 12V and E respectively. Also connect E to "earth" or "ground" terminal of the oscilloscope. Note the waveforms at A, and B, by connecting these points to the "input" terminal of the oscilloscope. In these measurements you should make scaled diagrams of the waveforms, noting the amplitude and time scales. Ensure that any variable controls of the oscilloscope are in the "calibrated" positions.

(ii) Connect the 100 μF capacitor between B and E_1, observing polarity (red plug to B, and black plug to E_1). Why is this important? Note the waveforms at A, and at B.

(iii) Keep the 100 μF capacitor connected between B and E_1. Connect a 1 K ohm resistor (colour code: brown, black, red) between C and E_2 and note the waveforms at A, and at B. Repeat with 10 K ohm resistor (colour code: brown, black, orange). Use AC input to oscilloscope if necessary.

- Discuss the experiment with your demonstrator and give explanations of your observed waveforms.

Appendix:

The oscilloscope is an instrument which enables voltage signals to be displayed as a function of time. On the cathode ray tube the voltage signal is plotted vertically and time horizontally.

When setting up your oscilloscope for this experiment, the following points should be noted:

1. Ensure that the beam focus and astigmatism controls are set correctly, and that the trace is not too bright.
2. Ensure that the oscilloscope is correctly triggered (i.e. synchronised with the signal waveform). Refer to the videotape programme.
3. Adjust the timebase (time sensitivity) and vertical deflection to their calibrated (cal) positions. Only in this case can you measure the displayed waveforms accurately.
4. Make sure that you can distinguish between DC and AC inputs to the vertical amplifier of the oscilloscope, and know when to use these two modes. Refer again to the videotape programme.

If you are in doubt about any of these points, consult your demonstrator.