THE EVALUATION OF QUALITATIVE EXAMINATION QUESTIONS AT MATRICULATION LEVEL IN PHYSICS

THESIS

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by

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ABSTRACT

The style and format of Physics examination papers has changed markedly over the past hundred years. Physics was regarded formerly as a sub-division of Mathematics; hence, apart from giving formal statements of scientific laws, and some account of experimental procedures, examination candidates were required to spend most of their time, and to earn most of their marks by solving numerical problems.

Most Physics examination papers today retain the emphasis on problem-solving by calculation. It has been recognised,however, that the ability to obtain correct numerical answers by substition in a formula does not necessarily imply understanding of the physical principles which underly the problem. There has been a reaction against the awarding of marks for algebraic or arithmetical manipulation.

Bloom and his disciples, by calling on examiners to define precise behavioural objectives, have encouraged the development of qualitative questions. These require no calculation nor numerical answer, but do aim to test the candidate's insight, by requiring him either to explain phenomena in scientific terms, or to predict the outcome of changing conditions.

In this investigation samples of both quantitative and qualitative questions were extracted from Physics papers past and present. A

closer study was made of qualitative questions used in the Natal Senior Certificate Physics papers (both Higher Grade and Standard Grade) in November 1987.

The examiners were asked to state the objective of each question, as well as its categorization in terms of a simplified Bloom taxonomy. Candidates' answers to these questions were extracted from the scripts written at a representative sample of Natal schools. In the case of multiple-choice questions, an item analysis was performed, and discrimination indices were calculated.

The responses of individual candidates to the longer questions were collected, classified and discussed. In each case the effectiveness of the question was studied, as to whether or not it was successful in detecting the presence of correct scientific concepts in the candidates' thinking.

It was concluded that most of the qualitative questions used by the examiners were effective. Suggestions were made as to how their efficacy could be improved. Much further study and experimentation are needed to develop the effective use of this type of question.

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PREFACE

The flaws in our educational system are manifest - not least in our system of public examinations. The final examinations, and not educational considerations, determine the teaching programme. The success of "cram schools", which coach pupils according to the style of a particular examiner, is a credit to the skill of the coaches, but a disgrace to the educational system.

The author has himself encountered the difficulties of creating original and stimulating questions for a public examination. The criticism and advice received from Professor Hugh Helm and Dr David Schuster, who at different times served as Moderators to the Joint Matriculation Board, whetted his appetite to investigate the matter further.

An unsuccessful attempt was made to use, for the purpose of this research project, some of the author's own question papers (in the Republic of Transkei between 1980 and 1987) and the candidates' reponses to them. Unfortunately, it proved too difficult to obtain the necessary authority to use this material. Besides, Mr F. Castle, who initially supervised the project, advised that matriculants in Transkei represented an exceptionally restricted and specialized group. Mr Castle made contact with the Natal Education Department, whose co-operation was readily given. Special thanks are due to Mr J.A. Beukes and Mr Talbot of that Department; to Messrs Nel and Rouken-Smith of the Examinations Section; and perhaps above all to Mr L.F.B. Cornelius, who was the Physical Science Matriculation examiner (HG) for the Natal Department in November 1987, and to

Mr E.J.Brocklehurst, who was the Standard Grade examiner for the same period. All of these officials went out of their way to make the author's stay in Pietermaritzburg pleasant as well as fruitful. Mr Rouken-Smith went to considerable trouble in compiling and withdrawing from the archives the representative sample of examination scripts used in this project.

Thanks are due also to Mrs Heather Moore, for her skill and patience in typing from the author's none-too-legible manuscript, and to the Library staff of the University of Transkei, who undertook the binding as an urgent task at very short notice.

Finally, the advice and assistance of Mr Peter Glover in revising the original draft, and of Professor Terry Marsh in preparing the final typescript, were invaluable.

CHAPTER ONE: INTRODUCTION

PART 1

STATEMENT OF RESEARCH INTENT

A. Qualitative examination questions in Physics are questions which can be answered without calculation, and which do not require a numerical answer.

B. These include questions of an elementary nature, which can be answered by straightforward memory recall. They may be used to test the candidate's knowledge of scientific terminology, of phenomena which the candidate has observed or been taught about, and of the verbal formulation of scientific laws, principles and definitions.

C. They include also questions of a more elaborate kind, designed to identify scientific concepts which may exist in the candidate's mind, and to determine whether he is capable of using these concepts to explain phenomena and/or to predict their outcome.

D. The present study aims to select qualitative questions which have been used in a recent public examination (Natal Senior Certificate: November 1987), and to evaluate their effectiveness in identifying the presence or absence of specific concepts in the candidate's minds.

PART II

THE AUTHOR AND HIS PERSONAL INTEREST AND INVOLVEMENT

A. The choice of the topic for investigation was largely influenced by the interests, background and experience of the investigator. The following personal details are relevant.

B. 1. He holds a B.Sc.(Honours) Degree from St Andrews University, with Second Class Honours in Physics, and including Mathematics and Applied Mathematics as other major subjects; Chemistry and Zoology were taken as single courses.

2. After spending two years studying Divinity, four years working as Curate in a city parish in Scotland, and six years working as a Missionary in Transkei, he returned to Scotland to obtain the Diploma in Education at Edinburgh University, and, concurrently therewith, a professional qualification as Secondary School Teacher in Physics, Chemistry and Mathematics.

C. 1. His subsequent teaching experience included six years in a boys' boarding school in Transkei, twelve years in a co-educational (mainly boarding) school under the Cape Education Department, and four years as Principal of a co-educational High School under the Department of Education and Training.

2. During the above period he obtained the B.Ed. Degree of Rhodes University by part-time study, including an optional course on Physical Science in Education.

D. For six years he was Chief Examiner in Physics for the Transkei Matriculation Examinations. He is a member of the Department of

Education and Training's *Physical Science Subject Committee* and *Textbook Selection Committee*.

PART III

THE CASE FOR QUALITATIVE QUESTIONS

A. The author has noticed a fairly close correlation between pupils' performance in Mathematics and in Physics. The correlation is much less close between Mathematics and Chemistry. To a large extent, this contrast can be explained as due to the different styles adopted by Physics and Chemistry examiners. Physics question papers generally contain many numerical problems; Chemistry papers relatively few numerical problems.

B. D. Schuster (1983) showed that in Southern Africa, the Matriculation Physics examinations set in November 1982 allocated a range of marks to arithmetical manipulation from 14% to 30% of the total for problem-type questions; these percentages increased to 28% and 56% respectively if the naming of units (unavailable to candidates who could not tackle the arithmetic) was taken into account. The examiners thus awarded "gift" marks to the more capable candidates, without requiring any physical comprehension or skill beyond what they have already displayed.

C. Some examiners today try to balance quantitative with qualitative questions, in the belief that qualitative questions provide a purer test of the candidates' grasp of physical realities. Bloom's "Taxonomy of Educational Objectives" has provided a useful criterion for classifying examination questions, as well as a useful source for new types of question

D. It remains a difficult task, requiring considerable ingenuity, to devise effective new qualitative questions. Some such efforts succeed in producing questions which are *trivial rather than searching*. The examiner is tempted to take the easy course, and to fall back on numerical problems.

CHAPTER TWO

WRITTEN EXAMINATIONS IN SCHOOL PHYSICS

PART I

TRADITIONAL METHODS OF EXAMINING PHYSICS

A. Prior to the widespread adoption of behavioural objectives in the designing of examination questions (Bloom et al. 1956), traditional Physics questions were usually composed of four elements:-

1. Statements, in precise verbal form, of scientific laws or principles;
2. The repetition of these statements in mathematical form;
3. Description of experimental techniques to verify these laws or principles;
4. Solving problems requiring the use of these laws or principles - most often by substitution in algebraic formulae.

B. Describing traditional Science courses, L.E. Klopfer writes:-

> ..... science is presented as a body of knowledge which is stated and proven "true" .... the course has a very weak theoretical base..... little or no distinction is made between observation statements and interpretation statements.... little distinction is made between "facts" and mental constructs, abstractions or conceptual schemes..... in the laboratory

exercises that students perform, procedures are prescribed and observations are anticipated; confirmation of already learned conclusions is sought.

(L.E. Klopfer, P.564)

C. A somewhat differently-expressed, but basically similar outline is to be found in the description of a typical Science examination question of the immediate post - Second World War period, given by the Joint Committee of the Incorporated Association of Assistant Masters and the Science Masters' Association, in their report entitled "The Teaching of Science in Secondary Schools" (1947):-

> The familiar essay questions usually invite answers which involve:
>
> (i) an exposition of theories;
>
> (ii) an explanation of procedures;
>
> (iii) the solution of problems;
>
> (iv) descriptions of apparatus, instruments, etc.;
>
> (v) historical surveys;
>
> (vi) estimates of practical and theoretical values, applications to life, etc.
>
> (Joint IAAM - SMA Committee, P.192)

D. A further significant comment from the same source concerns the actual objective category which is (or was) tested by this type of question:-

> The essay-type examination tests mainly factual knowledge verbally expressed.... The concentration on factual knowledge has arisen from the well-meaning desire to set questions that can be marked objectively, and are not

beyond the ingenuity of the average child.

(Ibid., P.193)

E. <u>In terms of Bloom's taxonomy</u>, it is clear that the traditional Physics question tests student behaviours only in Category A (Knowledge and Comprehension). A breakdown of the sub-categories of Category A will indicate that (from A1 to A11) they exhaust all the behaviours required of a candidate writing this type of examination question:-

A1 : <u>Knowledge</u> of specific facts.

A2 : <u>Knowledge</u> of scientific terminology.

[These may be tested by means of "short questions"]

A3 : <u>Knowledge</u> of concepts (definitions of science).

A4 : <u>Knowledge</u> of conventions (symbols).

A5 : <u>Knowledge</u> of trends or sequence.

A6 : <u>Knowledge</u> of classification.

A7 : <u>Knowledge</u> of scientific techniques.

A8 : <u>Knowledge</u> of scientific principles or laws.

A9 : <u>Knowledge</u> of theories and broad conceptual schemes.

A10 : <u>Identification</u> of a fact, concept, procedure, principle or theory in an unfamiliar context.

A11 : <u>Translation</u> of a fact, concept, principle or theory to another symbolic form.

It is to be noted that A10 and A11 tend to be required less frequently in traditional examination questions.

F. 1. <u>The traditional approach is neatly summed up</u> in an official publication of the Scottish Education Department issued as recently as 1951:-

...... the school should give the pupil:

(i) some familiarity with scientific method;

(ii) a co-ordinated body of scientific knowledge.

(Science in Secondary Schools, P.3)

2. Unimaginatively interpreted, the above encourages the examiner to confine himself to asking for : -

(i) descriptions of apparatus and experimental procedures;

(ii) statements of observations and the general laws or principles which they illustrate.

3. To succeed in an examination of this type (assuming that the pupil has worked conscientiously under a capable and knowledgeable teacher), all that is required is effective recall, from memory, of verbal statements presented in aural or visual form. Klopfer confirms that Category A concerns:

.....science subject matter that the student obtains solely or almost exclusively from reading books, from listening to lectures, and from other secondary sources ......books, films, lectures, or other media.......

(L.E Klopfer, P.566).

G. Summary

The foregoing section demonstrates the broad types of Physics questions, referred to in paragraph I (A) of this chapter, viz,

(1) Statements of scientific laws;

(2) Mathematical formulae;

(3) Description of experiments;

(4) Solving problems.

PART II

SOME EXAMPLES OF TRADITIONAL - TYPE QUESTIONS

A. ON GRAVITATION

1. SAMPLE QUESTION.

(a) Write down an expression for the force of gravity between two masses, m_1 and m_2 kg respectively, separated by d m.

(b) If the two masses are each 1 kg and their distance apart is 1 m, what does your expression become?

(c) Can you write down the meaning of G?

(d) If the force of attraction between the two masses, each 1 kg, 1 m apart, is measured and found to be $6{,}67 \times 10^{-11}$ N, what is it between a mass of 1 kg and the earth, whose mass is $5{,}98 \times 10^{24}$ kg? Assume that the earth's radius is $6{,}37 \times 10^{6}$ m.

(e) What acceleration would this force produce on the mass of 1 kg?

(f) How does this value compare with the known value for the acceleration of a falling object?

(A.F.D. Maxwell, P.35-36 : 1967)

2. COMMENTS:

(a) The above is a "good" question of its kind : it has instructional value as well as effectiveness in evaluation.

(b) It asks neither for a verbal expression of the Gravitation Law, nor for an account of Cavendish's experiment.

(c) It is, however, of the classical pattern, in that it starts by asking for a mathematical expression (memory recall), and later asks for a calculation involving numerical substitution in the formula.

(d) The extra sub-divisions (b), (c), (e) and (f) serve to test the candidate's comprehension of and ability to apply his formula by combining it with another physical law (The Second Law of Motion).

(e) This question represents an unusually enlightened example of the traditional type.

B. ON THE GAS LAWS.

1. SAMPLE QUESTION

(a) State Boyle's Law and Charles's Law, and from them deduce the General Gas Equation.

(b) Describe in detail an experiment to investigate the relation between the pressure and the temperature of a fixed mass of gas at constant volume. Show graphically the result that would be obtained.

(c) A cylinder, when newly supplied, contains oxygen at a pressure of 10 atmospheres and a temperature of 22 °C. After some of the gas has been used, the pressure is 4 atmospheres and the temperature 12 °C. What fraction of the mass of gas originally in the cylinder has been used?

(Scottish L.C. Examination, 1954, P.20).

2. COMMENTS.

(a) A nearly perfect example of the traditional format! The Laws must first be stated verbally, and then reduced to a mathematical formula; a verification experiment has to be described in detail; and a problem involving substitution in the formula has to be solved.

(b) The problem is "good" for Higher Grade candidates, in that it requires clear perception and analysis to decide precisely what substitutions must be made in the General Gas Equation.

C. ON MOMENTUM

1. SAMPLE QUESTION

(a) State the Principle of Conservation of Linear Momentum, and show how it follows from Newton's Laws of Motion.

(b) A 400 g mass hangs from the end of a light string so as to form a plumb-line of length 1 m. A bullet of mass 50 g, fired from a rifle and travelling horizontally, hits the mass of the plumb-line and sticks to it. The system is deflected through an angle of 30^{o}. Calculate the velocity of the bullet just before impact.

(T. Ellis Jones, P.6 : 1979)

2. COMMENTS

(a) This question, although set within the present decade, still follows the classical pattern, with the exception that no experimental description is asked for.

(b) The numerical example requires a calculation of potential and kinetic energy, as well as the use of momentum conservation. A relatively high order of ability will be required.

D. ON COULOMB'S LAW

1. SAMPLE QUESTION

(a) State (in words) Coulomb's Law of Electrostatic Force.

(b) Give the mathematical formulation of this Law, stating clearly what each symbol represents.

(c) Two small spheres A and B carry electric charges. The charge on sphere A is 4×10^{6} C. If the distance between the two spheres is 2 m, and they are attracted towards each other by an electrostatic force of magnitude 27 N, calculate the magnitude of the charge on the sphere B.

(Transkei Senior Certificate HG, 1982).

2. COMMENTS

(a) A typical question of the classical type, except that Coulomb's experimental methods are not asked for.

(b) The numerical problem presents a difficulty to candidates whose mathematics is weak, since the formula has to be turned round and solved for Q_2. A student unable to re-arrange the formula stands to lose 6 marks out of 15 for the whole question, which thus becomes partly a test of algebra and arithmetic rather than of physics.

(c) Schuster comments, on the way in which marks are often allocated in the marking memorandum for this type of question, that it deprives the weaker candidates even of the marks they might have gained for numerical substitution and arithmetical computation if, for example, their formula is incorrect to begin with.

(D. Schuster, 1983)

E. ON INTERFERENCE

1. SAMPLE QUESTION

In the laboratory, a pupil uses a razor blade to cut two very narrow slits in a card; the slits are very close together, and parallel to each other. He looks through the two slits at a monochromatic light source.

(a) What is monochromatic light?

(b) Using a diagram to assist you, describe in words what the pupil would see.

(c) What phenomena occur when the light passes through the slits in the card?

(Indian Senior Certificate SG, 1981).

2. COMMENTS

(a) Although capable of classification under the classical model, this question lacks both the mathematical formulation and the numerical problem. It does include a formal definition (monochromatic) and, later, the correct identification and labelling of phenomena (interference; diffraction). It also includes description (with diagram) of experimental observations.

(b) It requires only accurate memory recall.

(c) In spite of the above remarks, this question also falls into the category of "qualitative". Even although no original thinking is needed, it does require the ability to "describe and explain".

(d) The danger is that this could be done successfully by rote verbal memorization, and could perhaps gain full marks without clear conceptual grasp.

F. ON THE PHOTO-ELECTRIC EFFECT; ON ELECTROSTATICS

1. SAMPLE QUESTION

(a) A disc of clean zinc is placed on the plate of an electroscope, which is then charged negatively.

(i) A very bright beam of white light (from a lamp) irradiates the zinc disc. Describe briefly, with reasons, what you would see.

(ii) The electroscope, still negatively charged and with the zinc disc on top, is taken out of the laboratory into very bright sunlight. Describe briefly, with reasons, what you would see.

(b) What particles can (and do) travel at the speed of light (3×10^{8} m. s^{-1})?

(c) A pair of large, parallel, metal plates are 20 mm apart in air; the magnitude of the electric field intensity between them is 10^{5} N.C^{-1}.

(i) Draw a neat diagram showing the plates, their polarity, and the electric field pattern between them.

(ii) Calculate the potential difference between the plates.

(Indian Senior Certificate SG, 1981).

2. COMMENTS

(a) Very like Sample E and from the same examiner.

(b) Requires identification of a scientific term (photon).

(c) Requires description of experimental results (the photo-electric effect with zinc).

(d) Requires theoretical knowledge (explaining the discharge of the electroscope; mapping the electric field).

(e) Requires a calculation using formulae derived from the definitions of field strength and potential difference.

G. QUANTUM THEORY : WAVELENGTH AND FREQUENCY.

1. SAMPLE QUESTION.

(a) Write down the formula used to calculate the energy of a photon. What quantity is represented by each symbol?

(b) The wave-length of X-rays from a certain source is 10^{-9} m. Calculate the:

(i) frequency; and

(ii) energy of an X-ray photon.

(Cape of Good Hope Senior Certificate SG, 1980).

2. COMMENTS

(a) There is no verbal, but only mathematical formulation.

(b) There is a two-stage calculation but the question is structured in order to help the candidate to work through it.

(c) Definitely a question of classical type - no description, explanation or prediction is required.

(d) Experimental details and observations also are absent.

H. THE ELECTROMAGNETIC SPECTRUM ; PHOTO-ELECTRIC CELLS.

1. SAMPLE QUESTION.

(a) Indicate how it can be deduced that:-

(i) electromagnetic waves are transverse waves;

(ii) X-rays are electromagnetic waves.

(b) [Refer to Sketch No. 1]

Make use of the sketch of the photo-electric cell, and draw in your examination book a circuit diagram which contains a photo-electric cell, a micro-ammeter and a battery connected in series. Yellow light is shone on the cathode. Show in the sketch the direction of electron flow in the circuit.

(c) A stopping-potential is applied to the circuit in section (b), to just stop the flow of electrons. The micro-ammeter now shows no reading. What do you observe on the micro-ammeter when:-

(i) the intensity of the light is increased?

(ii) the light is replaced by light of a higher frequency?

(d) The frequency of an electromagnetic wave is 4×10^{4} Hz. Calculate the wavelength of the wave.

(O F S Senior Certificate SG, 1981)

2. COMMENTS

(a) Not really a Standard Grade question!

(b) Part (a) is memory-recall.

(c) Part (b) requires clear understanding of the process.

(d) Part (c) requires even clearer thinking, and ability to apply theoretical knowledge.

(e) Part (d) is a typical classical calculation.

(f) The entire question is a searching test (mostly qualitative), but nicely structured so that no long discussion is needed. Thus the poor verbalizers are not penalized.

PART III

GENERAL COMMENTS ON TRADITIONAL - TYPE QUESTIONS

A. *The classical type has survived into the 1980's,* though it is used much less frequently than in earlier decades.

B. Sample questions E, F, G and H - all selected from recent Standard Grade question papers - seem to indicate that *the classical type tends to be used more often in Standard Grade than in Higher Grade papers* - probably owing to the desire to include more lower order skills in the Standard Grade examination. Recent Higher Grade papers yield hardly any examples of the unmodified classical pattern.

C. It appears that *the classical pattern has been modified recently in the following ways:-*

1. There is *less emphasis* on the formal (verbal) statement of scientific laws and principles.
2. There is *no* requirement that experimental apparatus and techniques be described - perhaps a concession to the inescapable reality that many (perhaps the majority of) matriculation candidates have not had the opportunity of performing experiments for themselves.
3. Mathematical formulations are still *occasionally* asked for.
4. Problems involving calculation after substitution in a formula are *rarely absent.*

5. Qualitative questions of the "describe and explain" type *are much more frequent*, and are effectively used, with the help of detailed structuring.

6. The modern version of the classical type *tends to avoid* "essay-type" answers - most of the writing is contained in the question itself, and the answers are single words or sentences. This, besides being suited to candidates whose verbal skills are weak, has the added advantage that it lends itself to easy standardization of marking procedures.

D. Certain of the examples given (particulary E, F and H) are *transitional in the process of evolution* from the classical question type to the qualitative question type.

E. *Prospects of success in assessing students' grasp of scientific concepts.* Note that the examples chosen are representative of syllabus areas, and do not result from statistical sampling.

1. Examples A, B, C and D do little to penetrate the candidates' thought processes. Only *facility in scientific and mathematical "jargon"* is required for success.
2. Example E requires *visual* as well as verbal perception.
3. Example F requires a fairly high degree of verbal skill (or else rote recall of textbook or notes), as well as of insight into what is happening. This is a good test of comprehensive *knowledge* (up to sub-category All).
4. Example G is a *"throw-back"* to the classical type - no real insight is demanded.

5. Example H (like F) tests knowledge up to sub-category All, but requires less verbal skill; the expected answers are either brief or in diagrammatic form.

F. How to Pass a Physics Examination, by One Who Knows.

Coaching or cramming for examinations is an ancient art, made easy by the stereotyping of questions, as discussed above. The following is advice given to examination candidates in the United Kingdom, as recently as 1961:-

> The following hints will be found useful in answering examination questions:-
>
> 1. Descriptive questions, e.g. "Describe a moving-coil ammeter."
>   (a) Draw a neat diagram with ruler and pencil.
>   (b) Either label the diagram with letters A, B, C etc. and use the letters in your desription, or write the names of the main parts of the apparatus on your diagram.
>
> 2. Experiments, e.g. "Describe how the latent heat of steam is measured".
>   (a) Draw a neat, labelled diagram with ruler and pencil.
>   (b) Write out the experiment under these headings:-
>   (i) Apparatus used - refer to the diagram.
>   (ii) Method (or Account) - describe the experiment step by step, stating what readings or observations are taken, and any special precautions needed to obtain an accurate result.

(iii) Calculation - take imaginary but reasonable values, or use symbols, and show how the result is calculated.

(iv) Conclusion - state the conclusion of the experiment if it is one to verify a particular law, or state the result if a calculation has been done, and give the units.

3. Problems. There is an appropriate formula to every problem, e.g. in questions on uniform acceleration the formula required may be $v = u + at$ or $v^2 = u^2 + 2as$. Even if the whole question cannot be done, write down the appropriate formula or formulae, and substitute the numerical values of the quantities given in the question. Be particularly careful to consider the units of the quantities before substitution.

(M. Nelkon, 1961)

The advice given clearly depends on a fixed pattern to be expected in the examination question paper. The advice is largely worthless today, since there is much variety of format.

PART IV

THE DEVELOPMENT OF BEHAVIOURAL TECHNIQUES IN THE FORMAL EXAMINATION OF SCHOOL PHYSICS

A. EDUCATIONAL OBJECTIVES PRIOR TO BEHAVIOURISM.

1. The objectives of science teaching, prior to behaviourism, were expressed in vague, general terms, except insofar as the content of the syllabus was concerned.

2. In 1867, Wilson (a science master at Rugby) advocated Natural Science as a necessary part of education, because it developed

> ....the habits of accurate observation, exact reasoning, and power to judge evidence .....
>
> (J.M. Wilson, quoted by Joint IAAM-SMA Committee, P.5)

3. The Joint Committee itself begins the chapter entitled "The Aims and Functions of Science Teaching" with these words:-

> Science seeks knowledge and understanding of the world and of life itself by a method which consists essentially of careful observation and classification of phenomena, of experiment, and of the formulation of... laws which summarize our knowledge of groups of observed facts ......
>
> .... The Scientist must be trained to estimate the value of evidence, to suspend judgement in the face of incomplete information, and to subordinate personal prejudices to the acceptance of facts revealed by careful observation and

> wisely devised experiment.....Science teaching in a school.. must give the student a systematic training in careful observation, in experiment, and in the estimation of the relative value of results .....Science requires exact and accurate observation, care and thoroughness in techniques, the logical interpretation of data and the intelligent estimation of the reliability of results.
>
> (Joint IAAM-SMA Committee, P.11-12)

4. The above ideals echo closely the "Novum Organum" of Francis Bacon. They may be regarded also as a fair description of the philosophy governing the life and work of a professional research scientist of our time. As descriptions of what happens in school science, and even more as descriptions of what is examined in school science examinations, they are nothing short of ridiculous.

5. To elaborate: over and over again we are told that "accurate observation, exact reasoning, and power to judge evidence", leading to "the formulation of laws....." are the characteristics of Science. Yet what happens in practice? Even where an enthusiastic and conscientious teacher, provided with all the apparatus he needs, allows his pupils to perform a comprehensive range of experiments on all topics of the syllabus, the transfer of skills thus acquired to other topics and fields is rarely accomplished. "Accurate observation" may indeed be inculcated, but the guiding hand of the teacher is always at work to point out what needs to be observed, and to suggest or hint at what conclusions might be expected. "Exact reasoning" has to follow the particular path indicated by syllabus or text-book, and the

process becomes, for most students, mere memorization of what has been done by the great discoverers of the past. It is not surprising that, despite the efforts of some educationists to eliminate the names of famous scientists - under the claim or pretext that we are teaching present reality, not ancient history - these names keep cropping up, as in "Boyle's Law", "Newton's Laws of Motion", "Coulomb's Law of Electric Force", "Faraday's Laws of Electromagnetism", "Planck's Constant", "Schrodinger's Wave Equation", and, of course inevitably in the S.I. system of units itself: volt, from Volta; ampere, from Ampere; ohm, from Ohm; etc., etc. Finally, when it comes to the "judging of evidence", and "the formulation of laws", the story of H.E. Armstrong's "heuristic method" is instructive. Armstrong's ideal ("The Teaching of Scientific Method", 1910) was to let every pupil perform the experiments, make the deductions and formulate the laws for himself, and in so doing retrace the development of Science as established by the pioneer researchers of the past. The ideal seemed attainable in the days when physics consisted of elementary mechanics, hydrostatics, heat, light, sound, magnetism and a little electricity. Even then, however, the enthusiastic teacher found that the time available was far from sufficient. At best, the heuristic method could be applied to a few sample topics; the rest being covered much more quickly by lecture/demonstration methods. This remains official policy in most syllabi: extensive theory, accompanied by a limited range of demonstrations, and an even more limited selection of pupil experiments. In practice, too, the pupil experiments are prescribed in detail, and there is little scope for individuality or independence of thought. If one recalls for how many years the great scientists struggled - and disagreed among themselves - before arriving at, say, the quantum/wave theory of light, it is clearly out of the question to follow the same tortuous path every year in the classroom - even if every class is composed of "mute inglorious Newtons or Einsteins".

B. <u>THE USE OF BEHAVIOURAL OBJECTIVES.</u>

1. It would appear that one of the major influences in the changing patterns of school Physics examination has been the desire <u>to specify behavioural objectives</u> for every question or part of a question.

2. The classical style of examining, as exemplified in sections II and III above, is concerned primarily with <u>subject content</u>. The aim is to ensure that the candidate is <u>familiar with the content of the syllabus</u>, and also - almost as an afterthought - <u>is able to apply what he has learned to problem-solving.</u>

3. The syllabus content is regarded as a kind of divine revelation - <u>an unchanging and absolute body of accepted truth.</u> Moreover, this truth is revealed in specific verbal form, using accepted scientific terminology, and statements of laws and principles in traditional language, e.g. "Action and reaction are equal and opposite". If the candidate can quote the text verbatim, it is considered unnecessary to probe further as to his understanding of it. To a certain extent, the usual problem-solving will weed out erroneous concepts.

4. The changes which have been implemented since the middle of this century began with a new approach to the curriculum: this new approach in turn arose from the style of thinking introduced by the behaviourist school of psychologists.

> Education for us is a process which changes the learners. Given this view, we expect each programme, course and unit of education to bring about some significant change in the students. Students should be different at the end of a unit from what they were before it. Students who have completed a unit of education should be different from those who have not had it.
>
> (B.S. Bloom, P.8)

5. DEFINITION OF "OPERATIONALISM."

(a) In the formulation of scientific definitions, operationalism is the doctrine that vague abstractions and generalizations should be avoided, and that terms should be defined by describing the concrete operations which lead to the term being defined. Thus, a physical quantity is defined operationally by listing the actions (operations) which have to be performed in order to measure that physical quantity in practice.

(b) In the defining of educational objectives, operationalism is the doctrine that objectives should be specified in precise operational terms. Thus, the objectives of any educational programme should be defined by listing the actions (operations) which a student is expected to perform at the end of the programme, which he was unable to perform at the start.

(c) In defining the objectives of an examination question, operationalism is the doctrine that, in answering any question, the student should be required to perform a specific operation or operations which will indicate that some objective of the educational programme has successfully been achieved. Thus operationalism requires that the examiner should set out to compile his question with specific behavioural objectives in mind.

6. With the advent of behaviourism and operationalism, it was considered necessary to state simply and clearly, in operational terms, what changes in the students had to be brought about. Thus, a unit on the topic of universal gravitation might have, among its objectives, not only the following "traditional" operations:-

(a) To write down Newton's Law of Gravitation;

(b) To write down a mathematical formula for the above;

(c) To describe Cavendish's experiment on gravitation;

(d) To calculate the gravitational force exerted by one object on another, given the masses and the distance between them;

but also the following additional operations (designed to ensure comprehension as well as memorization):-

(e) <ins>To sketch</ins> the gravitational field in the neighbourhood of a point mass.

(f) <ins>To measure and note</ins> how the distance between the field lines increases in proportion to the radial distance from the point mass.

(g) <ins>To predict differences</ins> in force as the distance changes, in terms of "greater" or "less".

(h) <ins>To show</ins> that, for a two-dimensional system, the relation in (f) is one of <ins>inverse proportionality</ins>.

(i) <ins>To visualize</ins> how, in a three-dimensional system, this must be replaced by an <ins>inverse square</ins> law.

C. OPERATIONAL (BEHAVIOURAL) OBJECTIVES AS DEVELOPED BY TYLER ET AL

1. Ralph Tyler was a mid-20th century American pioneer of the use of defined educational objectives, both in compiling the curriculum and in the summative evaluation of what had been achieved in the case of each pupil. In the present study we are not concerned with Tyler's curriculum theories; but his evaluation techniques are relevant, and, in their time, marked the beginning of the new epoch during which the "fuzzy" objectives of the older educators were replaced by detailed and specific behavioural objectives. Bloom sums up Tyler's achievements in two telling sentences:

> Tyler built on the premise that education

> is a systematic process designed to help produce behavioural changes in the learner through the vehicle of instruction ....
> The function of evaluation, as he saw it, is primarily to determine the extent to which students have or have not changed in relation to the set of desired behaviours.
>
> (Bloom, B.S., P.24)

2. Tyler's techniques found immediate contemporary application in the technical training of American Army recruits (World War II and the Korean War). Although his approach to assessment could most easily be applied to training in straightforward mechanical operations (stripping and re-assembling a weapon), a considerable number of researchers extended Tyler's techniques into the academic and abstractly scientific fields. Thus R.M. Gagne in "Mathematics Teacher" (1963), E.Klinckmann in "Biological Sciences Curriculum Study Newsletter" (1963), J.M. Atkins in "Journal of Research in Science Teaching" (1963), and L.E. Klopfer in "Handbook on Formative and Summative Evaluation of Student Learning" (1971) made the transfer to their own special fields. At a slightly earlier period, B.S. Bloom and his colleagues produced their monumental "Taxonomy of Educational Objectives: The Classification of Educational Goals" (1956) - a book on which almost all examiners in the scientific and technical fields have based their work ever since. It is worth noting that at the present date (1988) the joint committee of Physical Science examiners and moderators in Southern Africa continues to use a simplified version of the Bloom taxonomy in

classifying matriculation examination questions. (Crossley B., 1982).

D. USE OF TWO-DIMENSIONAL MATRIX

1. Tyler introduced the technique of displaying educational objectives by means of a matrix, in which the various sub-divisions of the syllabus content are listed on the vertical axis, whereas student behaviours are specified along the horizontal axis. L.E. Klopfer (1971) has developed this technique specifically to apply to Science education, listing the syllabus topics vertically as before; the student behaviours on the horizontal axis are listed according to the Bloom classification for the Cognitive Domain. (See Appendix 3)

2. With regard to the behavioural categories (see horizontal axis of the matrix in App 3), the following observations relating to the examining of matriculation candidates should be noted:-

(a) Category B cannot be examined unless there is the opportunity to conduct a practical laboratory examination - this is not normally the case in present circumstances.

(b) Category C is extremely difficult to examine in any realistic way, without using data which belong to branches of the subject not covered by the syllabus. If data from familiar experiments are used, all well-prepared students should recognize the appropriate hypotheses from their classroom experience. In that case, the behaviour being tested reduces itself to

A8 or A9, not C at all. On the other hand, to make the exercise realistic by introducing data not previously handled, leading to hypotheses not previously discussed, is automatically ruled out of order by examining bodies as "unfair to the candidates". This situation leads one to the conclusion that official examining bodies (concerned as they are with maintaining a certain average pass rate) are mainly or exclusively concerned with testing Category A behaviours.

(c) Category D could lead to interesting, though lengthy examination questions. In fact, Category D questions are rarely set. We shall not consider them here, in any case, since they involve the handling of numerical data.

(d) Category E suffers from similar limitations to those referred to above in connection with Category C : unless the data go beyond the bounds of the syllabus, any such question reduces itself to Category A9 or All.

(e) Categories A and F are in practice the only ones from which the examiner is free to choose; Category F is likely to be effective only within a small group of original thinkers in the Higher Grade section. Hence, all of the Standard Grade questions and nearly all the Higher Grade questions have to be selected from Category A.

(f) Category G, like B, requires a practical examination.

(g) Category H is difficult to introduce into a competitive examination, since candidates will tend to look for answers the examiner expects, rather than to give honest expressions of their own attitudes.

(h) Category I lends itself to interesting possibilities for examination questions; such questions would, however, be rejected by moderators as "outwith the syllabus."

3. CONCLUSION FROM THE ABOVE.

We shall confine our study to questions which can be classified under A1 to A11 together with a few "Higher Grade" questions classified under F1 to F3.

E. THE USE OF MULTIPLE-CHOICE QUESTIONS.

1. One result of the emphasis on behavioural objectives in the setting of examination questions has been the increasing popularity of the multiple-choice format, which lends itself to the precise identification of behavioural objectives which may have been attained. It has the additional advantage that the individual idiosyncrasies of sub-examiners are completely eliminated, and consistency of scoring can be obtained. A common practice in Physical Science examinations today is to allot up to one-third of the total marks to a "Section A" consisting entirely of "short questions", of which all or most are of the multiple-choice type.

2. From the examiner's point of view, multiple-choice questions

involve much thought, time and labour in the setting, but great ease and speed in the marking.

3. At first impression, multiple-choice questions may seem very easy in comparison with the older essay or problem types. That this need not be so is confirmed by the writer's personal experience in setting and marking, that in many examination scripts the percentage score in the multiple-choice section correlates surprisingly well with the total score on the whole paper. There are also candidates who score badly on the multiple-choice section in comparison with the longer questions : one suspects that these may be conscientious, hard-working pupils who lack any very clear grasp of the basic physical concepts. There would seem to be scope here for a separate study on correlations between multiple-choice and longer questions: there is no time to delve into it deeply here.

4. There are some educators who have gone so far as to set papers consisting solely of multiple-choice questions. For example, L.E. Klopfer, in his chapter entitled "Evaluation of Learning in Science" (Bloom, B.S. 1971) gives examples drawn from all the categories in Bloom's Taxonomy of the Cognitive Domain, and all his examples are in the multiple-choice format. Perhaps this is going too far. It can be agreed that one of the advantages of the multiple-choice format is that it eliminates the handicap suffered by candidates who have difficulty in expressing themselves in literary form : but this may actually become a disadvantage if it allows "illiterate" candidates to qualify as scientists. One has heard often from University

lecturers that the present generation of students may have the right ideas, but cannot get them down intelligibly on paper.

5. In 1977, 1217 Physical Science teachers in South Africa were asked this question:

> Are you of the opinion that standardized, objective, short questions are reliable enough to serve as the <u>only</u> measure to evaluate pupils?
>
> (A.W. Drost, 1982)

6. Only 233, i.e., 19,15% answered "Yes"; the majority (80,85%) were against the proposal. On the other hand, 94% responded positively to other questions concerning the use of the multiple-choice format, indicating that the <u>opposition was not directed at this type of question per se</u>. In answer to another question:

> What percentage of the total number of marks should, in your opinion, be allocated to objective, short questions, which include insight, reasoning and memory work, in the external examination in Standard Ten?
>
> (A.W. Drost, 1982)

nearly 70% of the teachers selected proportions within the range 20% to 33 1/3% of the total marks for allocation to multiple-choice questions.

7. Although it may be doubted whether the consensus of opinion among serving teachers, as obtained by a questionnaire, is a valid premise on which to base theoretical conclusions, at least the above discussion seems to indicate a high degree of <u>satisfaction with the format of question papers as customary today</u>.

8. In our present study, some of the qualitative-type questions to be discussed will be in the multiple-choice format, and some will be in the traditional form. Multiple-choice questions yielding a choice of numerical answers have frequently been used (or abused) by examiners. It is generally felt today (e.g. by the J.M.B. examiners' committee)[1] that multiple-choice answers which can be arrived at only by calculation should be avoided, since computational skills should be tested in the longer questions in any case.

[1]See J.M.B. Report (1982) P. 187, para. 3.3.

PART V

MATRICULATION LEVEL EXAMINATIONS IN PHYSICS

IN SOUTHERN AFRICA

A. MODIFIED BLOOM CATEGORIES USED IN SOUTHERN AFRICA

1. The annual meetings of examiners and moderators of Physical Science (drawn from all four Provinces of the R.S.A, all education departments within the R.S.A. and from the Republic of Transkei*, called together under the auspices of the Joint Matriculation Board) has adopted a simplified categorization of examination questions, with only four sections, as follows:-

CATEGORY	ITEM DESCRIPTION
A	Items assessing recall only
B	Items assessing the understanding of subject matter.
C	Items assessing the application abilities of candidates, with the proviso that the item must be new to the candidates, or presented in an unfamiliar context.
D	Items requiring the candidates to analyse data; to put data together to form a meaningful whole; to evaluate data or a conclusion or a mode of action.

(B. Crossley, 1982).

* The other three independent states still write the examinations of the D.E.T.

2. A little thought, and <u>comparison of this scheme with Klopfer's matrix</u>, leads to the following conclusions:-

(a) <u>J.M.B. Category A</u> corresponds with Klopfer's A1 to A9.

(b) <u>J.M.B. Category B</u> covers Klopfer's A10 and A 11, but may also include items based on A3 (concepts), A4 (conventions), A5 (trends and sequences), A6 (classifications, categories and criteria), A8 (principles and laws) or A9 (theories or major conceptual schemes), <u>depending on the way in which these questions are framed</u> (to exclude mere verbal recall).

(c) <u>J.M.B. Category C</u> corresponds with Klopfer's F1 to F3.

(d) <u>J.M.B. Category D</u> corresponds with Klopfer's C1 to C4, D1 to D6 and E1 to E6.

3. In view of points made in paragraph IV (D) above, it is clear that, of the J.M.B. Categories, <u>we shall have to concentrate on A and B, with a few examples from C.</u> J.M.B. Category D does not concern us, because it will inevitably involve the handling of numerical data.

4. Crossley has <u>proposed the subdivision of J.M.B. Category B</u> (assessment of understanding) into three sub-categories, as follows:-

Category B1 : elementary understanding only.

Category B2 : items requiring elementary understanding, and some descriptive ability.

Category B3 : items requiring a deeper understanding and logical development.

(B. Crossley, 1982)

5. This proposal did not meet with acceptance by the Committee of Examiners and Moderators - mainly because of the difficulty in reaching consensus as to the precise classification of individual items.

6. The four J.M.B. Categories have been applied to determine the optimum distribution of item types in both Higher Grade and Standard Grade papers. The recommended proportions - which are not binding upon examiners, but are intended as guidelines - are as follows:-

CATEGORY	TYPE	HIGHER GRADE %	STANDARD GRADE %
A	Knowledge	20%	25%
B	Comprehension	50%	60%
C	Application	20%	15%
D	Higher Abilities	10%	NIL
		100%	100%

(B Crossley, 1982)

B. ARITHMETIC IN PHYSICAL SCIENCE QUESTIONS.

1. D. Schuster (1983) has drawn attention to the fact that an analysis of Physics examination papers set in November 1982 by six different South African examining bodies indicates that, on average, 8% of the marks for an entire paper are allotted for purely arithmetical operations. If only the "problem-type"

questions are considered, the average percentage alloted to arithmetical operations is as high as 25%. If, further, marks allotted to the correct stating of units in answers to problems are included, the percentages are 15% for the entire paper, and no less than 48% of the marks for problems.

2. If we accept that the situation arises from the common (and perfectly logical) practice of allotting one mark for each step in the solution of a problem, the weighting in favour of "arithmetic plus units" is understandable. It is, nevertheless, astonishing that in examining Physics, 15% of the marks are given for what is hardly Physics at all; even more, that when the art of problem solving is tested, almost half the marks are given for operations which have little to do with understanding the nature of the problem or the physical principles involved in it.

3. Schuster notes that "arithmetic is .....tested and rewarded in every problem in the paper." A further significant observation deserves repetition in full:-

> ......this high allocation of marks to simple routine matters actually penalizes the weaker students, while giving gifts to the stronger. The weaker student may not be able to even start a problem, or get far enough in it, to get the marks allocated for arithmetic and units. Thus, if a "gift" mark is assigned for (the step in the memorandum:) $40 \div 8 = 5$, this mark may be unavailable to the weaker

student, even though he surely <u>knows</u> that $40 \div 8 = 5$ and would get it if asked directly! Similarly the mark for the unit is unavailable.

(D. Schuster, 1983)

4. The above discussion indicates that a new approach is called for in the allocation of marks to questions involving calculations.

PART VI

THE DANGER OF INERT IDEAS

A. A.N. Whitehead, on the first page of "The Aims of Education" (1929), warns as follows:-

> Above all things we must beware of what I will call "inert ideas" - that is, ideas that are merely received into the mind without being utilized, or tested, or thrown into fresh combinations.

B. A.B. Arons, in a series of articles in "The Physics Teacher", develops Whitehead's warning, and relates it to contemporary practice on the part of teachers and examiners. He claims that, today,

> .....in far too many instances, we confront our students with only the "inert ideas".
>
> (Physics Teacher 22[2], P.90,1984)

C. Arons instances the failure of teachers (and text-books) to give operational definitions of technical terms. Very often a word is learned instead of a concept, and pupils imagine they are professional scientists if only they can spout the correct jargon, whether or not they understand its precise meaning.

D. In a teaching situation, this can be dealt with by refusing to accept the use of technical terms which have not been precisely defined : the technique used by Arons is both salutory and amusing:-

> When students try to exhibit their erudition..... by name-dropping technical terms not yet defined .....

I and my staff go completely blank and uncomprehending.

(Physics Teacher 22[1], P.22, 1984)

E. In the examination room, the task is more difficult. If, in answering a question, a candidate uses the correct technical jargon, or the correct algebraic formula, must we give him full credit for understanding the problem? Maybe so; yet there is a certain type of student who likes to create a smoke-screen of learned language (for which he knows he will score marks), behind which he hides his failure to grasp what the problem is all about. The aim of the qualitative examination question is to pinpoint the concepts, verbally expressed, as opposed to the terminology and the formulae. Correct terminology and mathematical formulation are, of course, essential; equally essential is the link between them and the real world of phenomena. This link can best be tested by means of questions expressed verbally, and requiring verbal answers, preferably avoiding the technical jargon. In this connection, it is worth remembering that our present scientific terminology, as well as our technique of algebraic formulation, are practical aids of comparatively recent origin in the history of Science. (In this respect, they are like the pocket calculator and the computer.) Not only scientists of the ancient world, but also our "own men" up to and including Newton and Faraday, tended to use verbal and mental imagery, in describing and explaining phenomena, as often as or more often than they used mathematics. Just as the pocket calculator ought not to be allowed to supersede basic arithmetical procedure, so the technical term and the formula should not be allowed to eliminate clear conceptual thinking related to operations performed or observations made in the real world.

F. That there is a hiatus in many students' link between their calculations and the real world is revealed by how often a candidate will labour through a calculation and produce a numerical answer (perhaps even the correct number) and then spoil it all by writing an entirely inappropriate unit, e.g. $m.s^{-1}$ for a displacement, or A for a resistance. This, to the writer, indicates that for that candidate the problem is an operation on paper only: he has not even thought at the end what the physical meaning of his answer might be.

G. Arons gives a number of examples of how "inert ideas" can be avoided if the usual numerical "end-of-chapter" examples are supplemented by qualitative questions. For example:-

> In dealing with two-source interference of waves in a ripple tank, students are usually given some numerical data and asked to solve for one or other unknown, using the governing equation. Their learning, however, can be greatly enhanced by pointing to some particular location in the photograph of the interference pattern, and asking them to describe in words what is going on at that particular point. Many conventional end-of-chapter problems leading to algebraic or numerical results can be greatly enriched by asking the student to interpret the results verbally.... Such questions can include prediction concerning results of experiments.
>
> (A.B. Arons in Physics Teacher 22[1], P.23, 1984)

PART VII

CURRENT USAGE OF QUALITATIVE QUESTIONS

A. Although there are still public examinations in which all or most of the questions involve calculation and the provision of numerical answers, most examiners have changed the style of their questions by including qualitative types to a greater or lesser extent. To devise effective and original qualitative questions requires considerable thought, effort and ingenuity. The attempt to test understanding of concepts by questions set in unfamiliar contexts is doomed to fail in its purpose if the questions, year after year, become stereotyped, since then the wide-awake teacher can start coaching his candidates in the particular field which is clearly the examiner's favourite. This regrettable but inevitable decline to the routine and prosaic has already occurred with multiple-choice questions. There are many publications dating from the 1960's and 1970's which provide material with which the teacher can drill his pupils in answering typical multiple-choice quetions. Two examples only are given:-

1. "Multiple-Choice Physics" by R.W. Adams (1973);
2. "Multiple Choice A Level Physics" by A.G. Harmston (1979).

B. Mention may be made, in addition, of the fact that, about 15 years ago, the then Physical Science examiner in the Cape Province himself published a book of sample multiple-choice tests. It is surpising that no one seems to have thought this worthy of condemnation; on the contrary, the book was widely recommended by the inspectorate for revision purposes prior to the Matriculation examinations. Of course its use did actually improve the scores (and perhaps symbols) of candidates who had studied it carefully: they knew, within a narrow range, what to expect of the examination paper. In the case of weaker candidates, the answers could be learned by rote - to obtain a good score, which did not necessarily indicate understanding of the underlying concepts which were meant to be tested.

C. Perhaps the only remedy for the above dilemma is to change examiners more frequently. Even this may not succeed, since an inexperienced examiner tends to base his questions closely on what his predecessor did.

D. Qualitative questions are not all sophisticated, nor do they necessarily test advanced Bloom categories. The simplest qualitative questions may require only one-word answers, indicating factual knowledge of, e.g., scientific terminology or units of measurement. We shall now proceed to look at a selection of such questions, picked from recent South African Matriculation papers; after that, we propose to concentrate on the answers given, by a fairly random group of candidates, to the papers set in November 1987 by the Natal Education Department, who kindly permitted access to their files of marked scripts.

CHAPTER THREE

THE EVALUATION OF QUALITATIVE QUESTIONS IN SCHOOL PHYSICS

PART I : SAMPLES OF QUALITATIVE QUESTIONS USED IN RECENT SOUTH AFRICAN MATRICULATION PHYSICS PAPERS

N.B. (i) The following questions have been selected arbitrarily, to give an indication of what a good qualitative question should look like : none of these were used in the investigation which follows.

(ii) Trivial qualitative questions, which can be answered easily by simple memory recall, have not been included. This is not meant to imply that such questions are useless: they may be used to test basic knowledge of definitions, units, etc.

(iii) The following examples have been arranged, first, according to the examining body, and second, by date; none are earlier than 1982.

A. DEPARTMENT OF EDUCATION: CAPE OF GOOD HOPE

1. NOVEMBER 1982 (Higher Grade)

(a) SAMPLE QUESTION

You wish to buy a pair of "Polaroid" sunglasses at a chemist.

(i) How could you test whether you are buying the right product? Explain your answer. (10 marks)

(ii) What name is given to the phenomenon illustrated in (i) above? (2 marks)

(iii) What does this phenomenon tell us about the nature of light waves? (2 marks)

TOTAL : 14 marks.

(b) COMMENT

This is a straightforward way of testing knowledge of, understanding of, and the theoretical importance of the phenomenon of polarisation.

2. MARCH 1984 (Higher Grade)

(a) SAMPLE QUESTION

(i) What is an electric current? (2 marks)

(ii) Explain why a thick copper wire has a lower resistance than a thin copper wire of the same length. (6 marks)

(iii) State two other factors which determine the resistance offered by a conductor. (4 marks)

TOTAL: 12 marks

(b) COMMENT

This is a straightforward test of understanding the mechanism of conduction in a metal wire, together with a grasp of the concept of resistance, in terms of visual imagery rather than formal definition.

B. ORANGE FREE STATE DEPARTMENT OF EDUCATION

MARCH 1984 (Higher Grade)

1. SAMPLE QUESTION

(a) Explain what is meant by a monochromatic light source.

(2 marks)

(b) A hydrogen discharge tube is connected to a high voltage source. The tube emits light.

(i) Is this an example of a monochromatic light source? (2 marks)

(ii) Explain your answer in (b) (i) by referring to the electrons in the hydrogen atom. (6 marks)

(iii) Name an apparatus which you could use to determine whether it possibly is a monochromatic light source. (2 marks)

TOTAL: 12 marks

2. COMMENT

A good composite question, testing several concepts simultaneously, viz, the term "monochromatic" the nature and source of the hydrogen spectrum, and the use of a spectroscope (or prism, or diffraction grating).

C. TRANSVAAL EDUCATION DEPARTMENT

1. NOVEMBER 1982 (Higher Grade)

MULTIPLE CHOICE SECTION

(a) SAMPLE QUESTION

A boy throws a stone vertically upwards and catches it again when it comes down. Which one of the following quantities remains constant throughout the flight of the stone? (Ignore air resistance)

(A) Acceleration (B) Velocity (C) Momentum

(D) Potential energy (E) Kinetic energy.

(3 marks)

(b) COMMENT

This requires understanding of all five concepts listed, as well as the ability to analyse mentally the motion of the stone.

LONGER TYPE QUESTION

(a) SAMPLE QUESTION

A trolley to which a block of wood has been secured, is at rest on a frictionless, horizontal surface. A bullet is fired horizontally and directly from the front into the block of wood, and embeds itself in it.

(1) Which conservation law can be used to calculate the velocity of the bullet? (2 marks)

(2) What quantities must be measured in order to determine the original velocity of the bullet?

(3 marks)

(3) Assume that the bullet did not embed itself in the block. How will the speed of the trolley in each of the following cases compare

with the speed in the previous case?

I The bullet passes through the block and leaves with a slower speed. Give the reason for your answer. (4 marks)

II The bullet rebounds from the block in the direction from where it came. Give the reason for your answer. (4 marks)

TOTAL: 13 marks

(b) COMMENT

This question has the advantage that it tests knowledge of, and understanding of the conservation of momentum, without requiring formulae, equations or manipulation of figures. Answers to part (3) may be expected to reveal how far the candidates have been able to internalize the concept of momentum conservation, i.e., how far they can visualize the effect of changing circumstances. The question remains worthwhile even although part (3) II posits a somewhat unrealistic situation.

2. NOVEMBER 1982 (STANDARD GRADE)

MULTIPLE CHOICE SECTION

(a) SAMPLE QUESTION

A beam of monochromatic red light moves from air into a glass prism. Which two properties change on entering the glass?

(i) Frequency and wavelength.

(ii) Wavelength and speed.

(iii) Speed and frequency.

(iv) Colour and speed. (3 marks)

(b) COMMENT

To answer this correctly requires a clear understanding of the mechanism by which waves are refracted.

D. NATIONAL SENIOR CERTIFICATE

1. NOVEMBER 1986 (STANDARD GRADE)

MULTIPLE CHOICE SECTION

(a) SAMPLE QUESTION

Which one of the following particles will experience the greatest acceleration when placed in a given electric field?

(1) a proton (2) a neutron (3) an electron

(4) an alpha particle (4 marks)

(b) COMMENT

Really more suitable for a Higher Grade paper, since the effects of two different concepts - the electric field of force and the acceleration due to a given force acting on a given mass - have to be considered simultaneously.

LONGER-TYPE QUESTION

(a) SAMPLE QUESTION

(A) How would the normal eye interpret a difference in frequency or wavelength of light? (2 marks)

(B) What is a line spectrum? (2 marks)

(C) Name three phenomena, which are exhibited by light, which cannot be explained by assuming a purely particle nature of light. (6 marks)

TOTAL: 10 marks

(b) COMMENT

Tests the scientific concepts of colour and of line spectra, as well as understanding the theoretical importance of diffraction, interference and polarization.

2. NOVEMBER 1987 (HIGHER GRADE)

MULTIPLE-CHOICE SECTION

(a) SAMPLE QUESTION

For a body falling from rest through the atmosphere which one of the following quantities decreases during the initial stages of the motion (i.e., before terminal velocity is reached)?

(i) Momentum (ii) kinetic energy (iii) velocity (iv) air resistance (v) acceleration. (5 marks)

(b) COMMENT

An excellent composite question! It not only requires understanding of the five concepts listed, but also requires the ability to visualize what happens to a falling body subject to air resistance as it approaches terminal velocity. Well worth its 5 marks!

3. NOVEMBER 1987 (STANDARD GRADE)

MULTIPLE-CHOICE SECTION

(a) SAMPLE QUESTION

An electroscope is charged by the method of induction, using a positively charged rod. Which one of the following statements in connection with the electroscope is true?

(i) The electroscope is positively charged.

(ii) Protons have been removed from the electroscope.

(iii) Protons are in excess on the gold foil.

(iv) There is an excess of electrons on the electroscope. (4 marks)

(b) COMMENT

A searching question, requiring not only knowledge of the gold-leaf electroscope and of how to charge it by induction, but also very clear thinking as to the movement of electrons at each stage of the process.

Better for a Higher Grade paper, and certainly worth 5 marks.

E. THE REPUBLIC OF TRANSKEI

1. NOVEMBER 1986 (Higher Grade)

MULTIPLE CHOICE SECTION

(a) SAMPLE QUESTION

A man rides a bicycle, without applying any force to the pedals, along a perfectly horizontal road. Why does the bicycle slow down?

(i) No force is acting on the bicycle.

(ii) An object will keep moving uniformly only if a forward resultant force acts on it.

(iii) Forces of friction cause a negative acceleration.

(iv) The force of friction is greater than the force of gravity.

(v) The force of gravity causes a negative acceleration. (4 marks)

(b) COMMENT

Requires understanding of Newton's First Law of Motion, as well as the ability to visualize the forces acting on the bicycle. Separates the Aristotelians from the Galileans.

2. NOVEMBER 1986 (HIGHER GRADE)

LONGER-TYPE QUESTION

(a) SAMPLE QUESTION

A star S and its planet E exert gravitational forces on each other.

(i) Is the gravitational force exerted by S on E equal in magnitude to the gravitational force exerted by E on S? Explain your answer.

(5 marks)

(ii) Is the acceleration of S equal in magnitude to the acceleration of E? Explain your answer.

(6 marks)

TOTAL: 11 marks.

(b) COMMENT

Requires understanding of Newton's Third Law of Motion and also of Newton's Second Law, plus the ability to apply them to this realistic situation.

PART II : THE METHOD USED TO EVALUATE QUALITATIVE QUESTIONS SET IN THE NATAL SENIOR CERTIFICATE EXAMINATIONS FOR PHYSICAL SCIENCE : NOVEMBER 1987

A. COOPERATION RECEIVED FROM NATAL EDUCATION DEPARTMENT

Willing and enthusiastic cooperation was elicited from the Natal Education Department, who provided copies of the November 1987 Matriculation Examination papers in Physical Science (Higher Grade and Standard Grade), as well as comments by the Examiners on the objectives and modified Bloom categories of the qualitative questions selected by the author. Access was granted for a full week, in April 1988, to the marked and filed scripts in Physcial Science. Staff members of the Examinations Section kindly assisted in obtaining a representative sample from schools in the Province.

B. SELECTION OF SCHOOLS

1. Fifteen schools were selected for study of the Higher Grade responses, representing a wide spectrum of school types and pupil environments, as follows:-

TABLE 1 HIGHER GRADE

School No.	Medium	Sex	Control	Situation
1	Afrikaans	Co-Ed	Departmental	City
2	English	Girls	Private	Boarding School
3	English	Boys	Private	Boarding School
4	English	Boys	Private	Boarding School
5	English	Boys	Departmental	City
6	English	Boys	Departmental	City
7	English	Boys	Departmental	City
8	English	Girls	Departmental	City
9	English	Girls	Departmental	City
10	English	Girls	Departmental	City
11	Parallel	Co-Ed	Departmental	Rural
12	Parallel	Co-Ed	Departmental	City
13	Parallel	Co-Ed	Departmental	Rural
14	English	Co-Ed	Departmental	Rural
15	English	Co-Ed	Departmental	Semi-Urban

2. These schools fell into five groups of three schools each, as follows:-

TABLE 2

Group	Description	Medium	Schools
A	Private Schools (1girls',2boys')	English	2,3,4
B	City Boys' Schools	English	5,6,7
C	City Girls' Schools	English	8,9,10
D	Urban Co-Educational Schools	1English,1Afrikaans, 1 Parallel	1,12,15
E	Rural Co-Educational Schools	1English, 2 Parallel	11,13,14

3. Seven schools were selected for study of the Standard Grade responses, representing a more limited spectrum of school and pupil types than was secured for the Higher Grade study. The only reason for this limitation was that the time available was restricted: circumstances made it impossible to spend a second week in Pietermaritzburg.

TABLE 3 STANDARD GRADE

School	Medium	Sex	Control	Situation
A	English	Boys	Private	Boarding School
B1,B2	English	Boys	Departmental	City
C	Afrikaans	Co-Ed	Departmental	Semi-Urban
D	Parallel	Co-Ed	Departmental	City
E	Parallel	Co-Ed	Departmental	Rural
F	Parallel	Boys	Departmental	City(Technical)

4. None of the above schools was included in the list of fifteen selected for the Higher Grade study.

C. SELECTION OF QUESTIONS

1. The author selected a limited group of qualitative questions from both the Mutiple Choice section and the longer questions. This was done for both the Higher Grade and the Standard Grade papers.+

2. The following questions were selected from the Higher Grade paper reproduced in full in appendix 1:-

(a) Multiple Choice; Questions 1 (a),(b),(c),(d),(e),(h) and (i).

+ In fact, all the Physics questions (as opposed to Chemistry) which did not require numerical or algebraic answers were included.

Question 1(k), although found in this section of the question paper, required original answers (correction of errors, with reasons given), and was discussed separately from questions 1 (a) to 1 (i).

(b) Longer Questions; Questions 2 (d) (1)
3 (a) (1) and (2)
3 (c) (1)

3. The following questions were selected from the Standard Grade paper reproduced in full in appendix 2:-

(a) Multiple Choice: Questions 1 (c),(d),(e),(g),(h) and (i)
Question 1(k), although found in this section of the question paper, required original answers (correction of errors, with reasons given), and was discussed separately.

(b) Longer Questions: Questions 2 (b) (1) and (2)
2 (d)
2 (e) (2)
3 (a) (3)
3 (c)

D. RECORDING OF CANDIDATES' RESPONSES.

Candidates' responses were recorded as follows:-

1. Multiple Choice Questions.

All candidates' reponses from the 15 selected schools (Higher Grade) were recorded and tabulated. Incorrect responses were recorded and tabulated, as well as the correct ones.

2. Question Type: Correction of Faulty Statements (1k)

From each school, a more restricted set of responses (approximately 10% of candidates) had their answers copied verbatim (photocopied). These are reproduced here for discussion.

Selection of the first few candidates from each school (as arranged in overall order of merit) seemed sufficient for this stage. Statistical sampling was not attempted. It was clear from an examination of candidates' scripts that many had not attempted this type of question, and others had written unintelligible sentences which were not susceptible of logical analysis. Those chosen were from scripts of candidates who were successful on the paper overall; but even these responses gave answers ranging from correct to quite wrong. Thus, while a comparison of the best candidates with the worst was not made, it was possible to gain some insights into the reasons for poor answers to questions of this type. Thus the "elitism" of the sample would appear to have been nullified.

3. Sub-Sections of Longer Questions.

Responses were tabulated by, first, separating correct from incorrect, and then by classifying the incorrect responses into a few possible types. Most of the questions were such that the number of possible error types was limited to two or three.

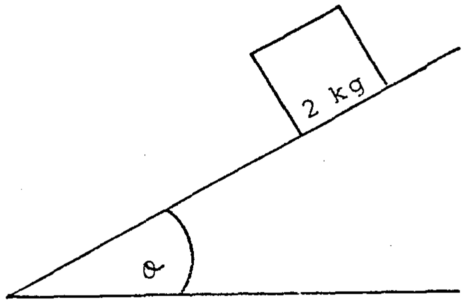
4. Standard Grade Responses.

The Standard Grade candidates' responses were recorded, tabulated, copied and analysed as described above for the Higher Grade.

E. DISCUSSION OF QUESTIONS AND RESPONSES.

1. The multiple choice responses were further analysed in order to calculate discrimination indices.
2. The accumulated material was subsequently examined, question by question, in order to determine:-
   (a) whether the question focussed sharply on particular scientific concepts, phenomena and/or principles. This characteristic of an examination question will be described as the Objective Efficacy of the question.
   (b) whether the question identified unmistakeably those candidates who had correctly grasped the specified concepts, phenomena and/or principles. This characteristic will be described as the Discriminatory Efficacy of the question.

FIGURE 2



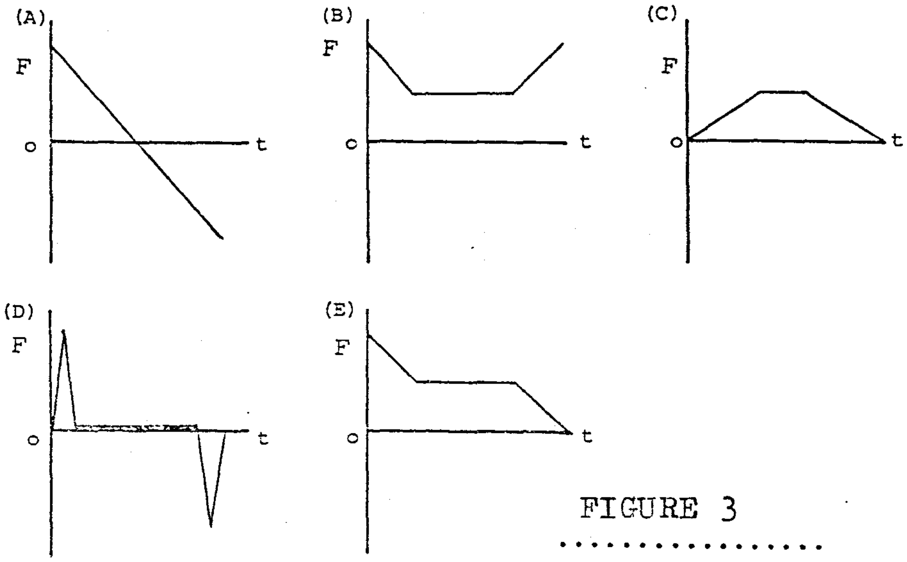


FIGURE 3

FIGURE 4

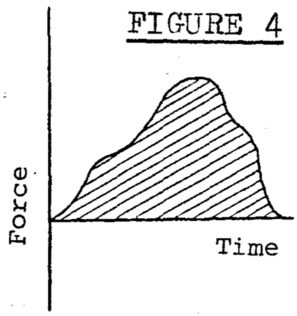
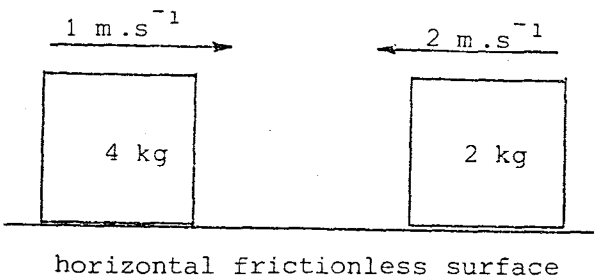


FIGURE 5



(c) whether the candidates' responses reveal clearly the false concepts which have led to incorrect answers. This characteristic will be called the <u>Diagnostic Efficacy</u> of the question.

(d) whether, and in what way, <u>the question might have been improved</u> to increase its Efficacy in any or all of the three ways listed above.

F. <u>CONCLUSIONS.</u>

<u>Preliminary and tentative conclusions</u> are proposed, as to the policy which examiners should follow in formulating and using qualitative questions.

G. <u>CAUTION WITH REGARD TO CONCLUSIONS.</u>

The scope of this study is <u>limited as regards the domain of candidates' responses</u> (restricted to 435 White pupils attending Provincial and Private Schools in Natal), and as <u>regards the range of qualitative questions available</u> (from papers set by one examining body for a single examination session, i.e. November 1987, Higher Grade and Standard Grade). The study should, therefore, be regarded as a <u>pilot project</u>, which <u>should be followed up</u> by a similar investigation of much wider scope. The conclusions reached here rest on inadequate foundations: they require to be examined, tested and perhaps re-framed once a fuller investigation has been completed in a wider context. The necessary time and resources for this have not been available to the present author.

PART III : THE RESULTS

A. THE QUESTIONS, THEIR OBJECTIVES AND THEIR CATEGORIES.

1. HIGHER GRADE PAPER (NATAL, NOVEMBER, 1987)

(a) MULTIPLE CHOICE QUESTIONS

QUESTION 1 (a) See Fig 2

A body of mass 2 kg rests on an inclined plane as shown in the diagram. The magnitude of the frictional force acting on the body is:-

(A) equal to the body's weight.

(B) less than the body's weight.

(C) greater than the body's weight.

(D) independent of the body's weight.

(E) independent of the angle θ (theta).

* BLOOM CATEGORY: B CORRECT ANSWER: B.

* EXAMINER'S OBJECTIVE: Test application of knowledge of resolution of vectors.

COMMENT: In order to answer correctly, the candidate has to visualize (or make a rough sketch of) the forces acting on the body, and the components of the body's weight.

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*These are given as supplied by the examiner

QUESTION 1(b)

A tennis player hits a ball vertically into the air. When the ball has reached its maximum altitude,

(A) its acceleration is zero.

(B) the resultant force on it is zero.

(C) its kinetic engergy is a maximum.

(D) the frictional force on it is a maximum.

(E) its acceleration is downward.

*<u>BLOOM CATEGORY:</u> B   <u>CORRECT ANSWER:</u> E

*<u>EXAMINER'S OBJECTIVE:</u> Application of properties of g.

<u>COMMENT:</u> Answer E is straightforward enough. For the alternatives to be rejected, <u>all five concepts</u> must be understood by the candidate.

<u>QUESTION 1(c)</u>   <u>See Fig 3</u>

A girl enters a lift on the ground floor of a building and, after travelling non-stop, gets out at the tenth floor. Which one of the graphs illustrated best shows how the resultant force on the girl varies with time while she is in the lift?

*<u>BLOOM CATEGORY:</u> C   <u>CORRECT ANSWER:</u> D

*<u>EXAMINER'S OBJECTIVE:</u> Application of force concept.

<u>COMMENT:</u> The author finds it necessary to amplify the objective. The question is composite: it includes application of Newton's Second Law of Motion, together with the ability to interpret a force-time (and therefore, implicitly, an acceleration-time) graph. Its category is appropriately listed as C (higher order skills than comprehension and simple application).

QUESTION 1(d) See fig. 4

Which one of the following quantities is represented by the shaded area in the graph illustrated?

(a) acceleration (b) displacement (c) inertial mass

(d) momentum (e) impulse

*BLOOM CATEGORY: B CORRECT ANSWER: E

*EXAMINER'S OBJECTIVE: Translating simple graphical manipulation to a unit.

COMMENT: Although candidates might be expected to know that force x time = impulse, it is less likely that they will see the connection with an area on the graph. Hence this is a composite question. Formally, however, the B Category is correct, since it corresponds with Klopfer's A 11 ("Translation of a fact, concept, principle or theory to another symbolic form").

QUESTION 1(e) See Fig. 5

The two blocks shown in the diagram slide towards each other, collide, and come to a stop. During the collision,

(A) the combined momentum of the two blocks remains unchanged.

(B) the combined momentum of the blocks decreases.

(C) kinetic energy is conserved.

(D) kinetic energy is changed to gravitational potential energy.

(E) the two blocks slide some distance apart before coming to a stop.

*BLOOM CATEGORY: B CORRECT ANSWER: A

*EXAMINER'S OBJECTIVE: Understanding of the law of conservation of momentum.

COMMENT: A good test of this concept!

QUESTION 1(h)

A zinc sphere on an insulating stand will NOT acquire a positive charge when it is:-

(A) irradiated with ultra-violet light.

(B) brought into contact with a similar positively charged sphere.

(C) placed in a micro-wave oven.

(D) earthed while a negatively charged sphere is held near it,

(E) brought into contact with the positive pole of a cell.

*BLOOM CATEGORY: B CORRECT ANSWER: C

*EXAMINER'S OBJECTIVE: Application of knowledge on electrostatics.

COMMENT: To reach the correct conclusion, candidates must understand the photo-electric effect, and must know that micro-wave radiation has a low frequency.

QUESTION 1(i)

At which one of the following combinations of temperature and pressure is helium's behaviour most likely to be similar to that of an ideal gas?

(A) 273K; 10^5 kPa

(B) 10K; 10^2 kPa

(C) 10K; 10^5 kPa

(D) 546K; 10^5 kPa

(E) 293K; 10^2 kPa

*BLOOM CATEGORY: B CORRECT ANSWER: E

*EXAMINER'S OBJECTIVE: Application of recall on ideal gas properties.

COMMENT: Candidates need also to recognize which temperatures and pressures are nearest to normal: thus 10 K and 10^5 kPa are both ruled out as cases of extreme compression.

(b) QUESTIONS REQUIRING WRITTEN ANSWERS

QUESTION 1(k)

The following statements are all faulty. State, giving reasons, in what respect each statement is faulty.

(i) An object moving at constant speed cannot possibly be accelerating.

POSSIBLE ANSWER: "Constant speed" has been substituted incorrectly for "constant velocity". If velocity is constant, then, by definition, acceleration is zero. But an object moving on a curve at constant speed is subject to an acceleration perpendicular to the direction of motion.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Recall, testing vector knowledge.

COMMENT: A correct answer requires knowledge of the definition of speed, velocity and acceleration, and understanding of the difference between speed and velocity.

(ii) There are no forces acting on a falling body which has reached terminal velocity.

POSSIBLE ANSWER: "There are no forces" has been substituted for "There is no resultant force". A falling body at terminal velocity is acted upon by its weight (downwards) and by air friction (upwards); these are equal and opposite, yielding zero resultant force.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Application of force concept.

COMMENT: Requires knowledge of terminal velocity of Newton's Second Law of Motion, and understanding of the concept of a resultant force.

(iii) The e.m.f. of a cell may be defined as the maximum power which the cell can deliver.

POSSIBLE ANSWER: "Maximum power" has been substituted for "maximum energy per unit charge". Power is defined as "energy transferred per unit time" - a quantity with different dimensions from e.m.f. A possible alternative might be "maximum power per unit current", but this is less frequently given than the first possible answer.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Recall.

<u>COMMENT</u>: The author cannot agree that the objective is simply "recall". If so, the modified Bloom Category would have to be A (actually A2 or A3 in Klopfer's scheme). Since, however, this is a composite question (involving more than one mental process) it is correctly categorized as "B". The candidate is required to possess <u>knowledge of the definitions of energy, power, charge, e.m.f. and possibly current as well</u>, together with <u>understanding of the relations connecting these concepts.</u>

(iv) When an electron moves at constant speed into a magnetic field, it will always be deflected.

<u>POSSIBLE ANSWER</u>: "... <u>always be deflected</u>" has been substituted for ".... <u>be deflected unless it is moving parallel to the magnetic field</u>". It is the magnetic field component perpendicular to the direction of motion which causes a force to act on the electron.

<u>*BLOOM CATEGORY</u>: B

<u>*EXAMINER'S OBJECTIVE</u>: Application of knowledge of electric (sic) fields.

<u>COMMENT</u>: Presumably the examiner meant to write "<u>magnetic fields</u>". The candidate is required to <u>know, understand and apply</u> the effect of a <u>magnetic field</u> on a <u>moving electric charge</u>.

(v) At the same temperature and pressure, the volume of 32g of O_2 is double that of 16g of CH_4.

POSSIBLE ANSWER: "$\ldots$. double" has been substituted for "....equal to .." 32g of O_2 = 1 mole of oxygen gas; 16g of CH_4 = 1 mole of methane. By Avogadro's Law these two volumes are equal, if the temperature and pressure are the same.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Application of knowledge on mole concept.

COMMENT: Requires knowledge, understanding and application of the mole concept, and of Avogadro's Law.

(c) "LONGER QUESTIONS"

QUESTION 2(d)(i)

A boy of mass 45kg jumps with a horizontal velocity of $5 m.s^{-1}$ on to a 5kg skateboard resting on a horizontal surface. Name the law which enables you to calculate the speed of the boy immediately after he has landed on the skateboard.

ANSWER: The Principle (or Law) of the Conservation of Momentum.

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: Recall of Principle of Conservation of Momentum.

COMMENT: Part of the 20% allotted to straightforward recall.

QUESTION 3(a)(i)

An electron is allowed to move freely from rest in an electric field.

In which direction will the electron move relative to the direction of the field?

ANSWER: In a direction opposite to that of the field.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Application of recall on electric field theory.

COMMENT: Requires knowledge and understanding of the charge on an electron and the concept of an electric field.

QUESTION 3(a)(ii)

How does the electrical potential energy of the electron change as it moves freely in the field?

ANSWER: The electrical potential energy of the electron decreases in magnitude as it moves freely in the field.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Application of electrical field and potential energy principles.

COMMENT: Requires knowledge and application of the definitions of work, energy and potential energy in relation to a field of force.

QUESTION 3(c)(i)

Two long, parallel current-carrying wires repel each other with a force F per metre length of each wire.

Does the current in the two wires flow in the same or in opposite directions?

ANSWER: Opposite directions.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Simple recall application.

COMMENT: If the effect of current-carrying parallel wires on each other had (as is more than likely) been demonstrated, observed, or taught as a fact, then the categorization should be "A" (A1 in Klopfer's scheme). Only if (as is not here the case) an explanation were asked for, would this be a Category "B" question. In the latter case only, would understanding of the interaction of magnetic fields, and the pattern of the magnetic field round a wire be required in order to answer correctly.

2. STANDARD GRADE PAPER (NATAL, NOVEMBER, 1987)

(a) MULTIPLE CHOICE QUESTIONS.

QUESTION 1(c)

If a stationary body is subjected to a constant resultant force it will:-

(a) move at a constant velocity in the direction of the resultant force.

(b) accelerate uniformly in the direction of the resultant force.

(c) move at a constant speed in the direction of the resultant force.

(d) accelerate at a rate directly proportional to its mass.

*BLOOM CATEGORY: B CORRECT ANSWER: B

*EXAMINER'S OBJECTIVE: Pupils should know how to apply Newton's Second Law.

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*These are given as supplied by the SG Examiner

COMMENT: Understanding of Newton's First Law of Motion also is implied, if the question is answered correctly.

QUESTION 1(d)

A bullet is fired vertically downwards from a rifle. On leaving the barrel, the bullet's

(A) momentum decreases (B) kinetic energy increases.

(C) gravitational potential energy increases.

(D) acceleration increases.

*THE EXAMINER COMMMENTS: "This was not my question - it was changed for the original after I had submitted it. This is a lousy question". In this instance, therfore, the objective and the Bloom Category have been supplied by the present writer.

BLOOM CATEGORY: C CORRECT ANSWER: B

OBJECTIVE: To visualize the motion of a falling object in an unfamiliar context (fired straight downwards) and to apply to it the recalled definitions of momentum, kinetic energy, gravitational potential energy and acceleration.

<u>COMMENT BY AUTHOR:</u> The three marks allotted to a multiple-choice answer are very little reward for the amount of clear thinking required. This question might better have been used in the "Longer Questions" section, worded something like: "State and explain how the magnitude of the following quantities will change after the bullet has left the barrel".

<u>QUESTION 1(e)</u>

When a plastic ruler is given a positive charge by rubbing it with a piece of flannel:

(A) the ruler loses electrons while the flannel gains electrons.

(B) the ruler gains electrons while the flannel loses electrons.

(C) the flannel loses protons while the ruler gains protons.

(D) the flannel gains protons while the ruler loses protons.

*<u>BLOOM CATEGORY:</u> A   <u>CORRECT ANSWER:</u> A

*<u>EXAMINER'S OBJECTIVE:</u> Pupils must understand (a) that only negative charges move; (b) conservation of charge.

<u>COMMENT:</u> This question requires the knowledge also that an electron is negatively-charged and a proton positively-charged. Although one would expect even Standard Grade candidates to find this question easy

to answer, it is nevertheless a composite question, involving as it does the combination of A3 and A8 skills (Klopfer's matrix). On these grounds, it should be classified as "B" on the J.M.B's modified Bloom scheme.

QUESTION 1(g)

The force per unit charge at a point gives the intensity or strength of the

(A) magnetic field at that point.

(B) electric field at that point.

(C) electro-magnetic field at that point.

(D) moving magnetic field at that point.

*BLOOM CATEGORY: A CORRECT ANSWER: B

*EXAMINER'S OBJECTIVE: Testing knowledge of E.

COMMENT: Part of the 25% allotted to straightforward recall.

QUESTION 1(h) See Fig. 6

An electric current is passed through a horizontal wire situated in a horizontal magnetic field, as shown in the diagram.

The wire experiences a force:

(A) to the left. (B) to the right.

(C) downwards, into the plane of the paper.

(D) upwards, out of the plane of the paper.

*BLOOM CATEGORY: B CORRECT ANSWER: C

*EXAMINER'S OBJECTIVE: To test the motor rule.

COMMENT: If the candidate arrives at the correct answer by applying Flemming's rule of thumb (as may happen in many cases), the categorization can only be "A". If, however, the problem is thought out in terms of interacting magnetic fields, it can be classified as "B". Since there is no means of telling how the answer was reached, this question might be better to be re-worded and included among the longer questions.

QUESTION 1(i)

The volume of a fixed mass of gas is reduced without a change in the temperature. The gas pressure increases because:

(A) the gas particles are now moving faster.

(B) the gas particles are now smaller.

(C) there is a greater distance separating the gas particles.

(D) a greater number of collisions against the container walls now occur per unit time.

*BLOOM CATEGORY: A CORRECT ANSWER: D

*EXAMINER'S OBJECTIVE: Application of kinetic gas theory.

COMMENT: Part of the 25%.

(b) QUESTIONS REQUIRING WRITTEN ANSWERS.

QUESTIONS 1(k)

Five statements follow. They are all faulty in some way. Briefly state why each is faulty.

(i) Displacement, speed, acceleration, force and momentum are all vector quantities.

POSSIBLE ANSWER: Speed is not a vector quantity.

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: Pupils should be able to tell the difference between s and v.

COMMENT: Re-phrasing of a "hardy annual"! A welcome change!

(ii) A body on earth falls freely from rest. After 1 second it has fallen 10m.

POSSIBLE ANSWER: Gravitational acceleration on earth is $10 m.s^{-2}$. Hence, after 1 second, velocity is $10 m.s^{-1}$. Hence displacement is only 5m (time x average velocity).

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: To see if pupils can apply $s = 1/2\ at^2$.

COMMENT: If candidates actually calculate according to the formula $s = 1/2\ at^2$, this ceases to be a qualitative question. Its inclusion in this study is justified by the fact that the error in the statement can be discovered by more fundamental reasoning, as shown above in the "Possible Answer".

(iii) The watt is the unit of both work and energy.

POSSIBLE ANSWER: "Watt" has been substituted for "joule". The watt is the unit of power, or rate of working, or rate of energy transfer.

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: Testing knowledge of units.

COMMENT: Straightforward!

(iv) The $J.C^{-1}$ is a unit of power.

POSSIBLE ANSWER: $J.C^{-1}$ has been substituted for "$J.s^{-1}$". The $J.C^{-1}$ is actually the volt, the unit of potential difference.

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: Testing knowledge of units.

COMMENT: Another of the 25%, but perhaps over-similar to no. (iii).

(v) The pressure of a fixed mass of dry gas is directly proportional to its volume and to its temperature in kelvin.

POSSIBLE ANSWER: The pressure ...is inversely proportional to its volume and directly proportional to its temperature in kelvin.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: To correctly apply $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

COMMENT: The category should be "A", since the first part of the sentence directly contradicts Boyle's Law, which should be known prior to the General Gas Equation.

(c) "LONGER QUESTIONS"

QUESTION 2 (b) (i) and (ii) See Fig 7

Draw the two sets of axes, as illustrated in the diagram.

(i) Using the displacement-time axes, draw a graph representing the motion of a body moving at a constant velocity.

ANSWER: Any straight line graph (except vertical or horizontal).

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: To see if pupils understand the time curves.

COMMENT: Requires knowledge that gradient = velocity.

(ii) Using the velocity-time axes, draw a graph representing the motion of a body undergoing uniform acceleration.

ANSWER: As before.

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: As before

COMMENT: Requires knowledge that gradient = acceleration.

QUESTION 2 (d)

A body falling in the air from a great height reaches terminal velocity.

Name and describe the forces acting on such a body.

ANSWER: Weight (downwards), air friction (upwards); these two are balanced (i.e. equal and opposite).

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: Testing understanding of Newton's First Law.

COMMENT: Requires also understanding of the concept of equilibrium of forces.

QUESTION 2 (e) (ii)

A sports car of mass 800kg moves along a road at $20 m.s^{-1}$. It collides with the back of a 600kg bakkie moving in the same direction at $14 m.s^{-1}$. On impact, the bumpers of the two vehicles become locked together.

What happens to some of the kinetic energy of the vehicles during the collision?

ANSWER: Converted to sound, heat or used as work in deforming the structures of the vehicles.

*BLOOM CATEGORY: B

*EXAMINER'S OBJECTIVE: To see if pupils understand that E_k is not conserved.

COMMENT: Numerical data are needed for other parts of this problem, but do not destroy the qualitative character of this item.

QUESTION 3 (a) (iii)

A point charge of -4×10^{-9} C is situated in air 60mm from another point charge of $+4\times10^{-9}$ C.

Sketch the electric field associated with the point charges.

ANSWER: See Fig. 8

*BLOOM CATEGORY: A

*EXAMINER'S OBJECTIVE: To see if candidates can draw electric fields.

COMMENT: Category should be "B" according to the modified scheme: this corresponds with All of Klopfer's matrix: (translation of a fact, concept, principle or theory to another symbolic form). Knowledge of the convention that field arrows point from + to - is also required. The numerical values in the problem are relevant only insofar as the charges are equal and opposite: the question remains qualitative.

QUESTION 3(c)

Explain why the element of an electric kettle should have a fairly high resistance.

ANSWER PROBABLY EXPECTED: The element is designed to produce heat. Hence its resistance must be fairly high, since, for a given current, the rate of energy transfer is directly proportional to the resistance. But the resistance must not be too high, since for a given voltage, the current is inversely proportional to the resistance.

*BLOOM CATEGORY: B

*EXAMINER'S COMMENT: This is a poor question - I accept all the blame.

PROPOSED OBJECTIVE: To make the candidate think analytically, using Ohm's Law and the relations connecting potential difference, current, resistance and power (or energy).

RESEARCHER'S COMMENT: The modified Bloom category should be "C", corresponding with F1 in Klopfer's matrix (application to new problems in the same field of science). This question could lead to a wide-ranging discussion, more what one might expect of the better Higher Grade candidates. The deceptively simple wording might well be replaced by something like: "Discuss the optimum value for the resistance of an electric kettle element, given the following parameters ......" Ideally an extremely low resistance would secure the most rapid transfer of energy ($P=\frac{V^2}{R}$); this, of course, would blow a fuse or burn out the element. In practice, the resistance should be just large enough to keep the current down to the maximum the circuit will safely take. It is unlikely that a Standard Grade candidate would think of all this, or that the mark allocation would justify expecting it.

B. THE CANDIDATES' RESPONSES

1. MULTIPLE CHOICE SECTIONS

(a) HIGHER GRADE PAPER

N.B. The preliminary recording and tabulation of candidates' responses is not reproduced here, since it would be both bulky and tedious for the reader. Instead, the responses of the 435 Higher Grade candidates (all the entrants from the 15 schools chosen) are summarized. For each question there are six columns, labelled a, b, c, d, e and "No answer", according to the answer given by the candidate. The first row of each table, labelled U, records the proportion representing the number of candidates who gave each particular response (n_u), over the total number in the upper echelon ($N_u = 0,27 \times 435 = 117$). The second row of the table, labelled L, records the proportions in the lower echelon. The Discrimination Index for each response is obtained by subtracting L from U.

Discrimination indices were categorized as follows:-

0,00-0,33	0,34-0,42	0,43-0,50	0,51-0,59	0,60-0,67	0,68-1,00
Poor	Fair	Fairly satisfactory	Satisfactory	Good	Excellent

QUESTION 1(a)

	a	b (CORRECT ANSWER)	c	d	e	No answer
n_u	14	75	19	5	4	-
U	0,12	0,64	0,16	0,04	0,03	-
n_l	39	15	38	10	13	2
L	0,33	0,13	0,32	0,09	0,11	0,02
D	-0,21	0,51	-0,16	-0,05	-0,08	-0,02

COMMENT: (i) The discrimination index is satisfactory.

(ii) The sketch, showing the inclined plane, focusses plainly on the concept: resolution of forces.

(iii) That a and c are the prevalent "wrong answers" indicates that candidates either do not understand resolution into components, or do not realize that friction acts parallel to the plane. In either case, the wrong answers can be used diagnostically, following a formative evaluation.

QUESTION 1(b) — CORRECT ANSWER: e

	a	b	c	d	e	No Answer
U	6	16	Ø	Ø	95	-
	Ø,Ø5	Ø,14	Ø,ØØ	Ø,ØØ	Ø,81	-
L	69	22	5	7	13	1
	Ø,59	Ø,19	Ø,Ø4	Ø,Ø6	Ø,11	Ø,Ø1
D	-Ø,54	-Ø,Ø5	-Ø,Ø4	-Ø,Ø6	Ø,7Ø	-Ø,Ø1

COMMENT: (i) The discrimination index is excellent.

(ii) The fact that hardly any candidates gave c or d indicates that attention was focussed definitely on acceleration/force (a,b or e).

(iii) The fact that nearly all the "wrong answers" gave a or b indicates confusion of the candidates minds between velocity and acceleration/force. The diagnosis is that Aristotelian mechanics is alive and well in 1987.

QUESTION 1(c)

	a	b	c	d (CORRECT ANSWER)	e	No Answer
U	10	6	38	58	4	1
	0,09	0,05	0,32	0,50	0,03	0,01
L	30	12	61	4	9	1
	0,26	0,10	0,52	0,03	0,08	0,01
D	-0,17	-0,05	-0,20	0,47	-0,05	0

COMMENT: (i) The discrimination index is fairly satisfactory. It is significant that, whereas half of the upper group gave the correct answer, hardly any of the lower group did so.

(ii) Focussing is precise enough, since all the graphs are clearly labelled force-time.

(iii) The fact that such large numbers of both groups chose c indicates, again, confusion between velocity and acceleration/force. The question is effective for diagnosis.

QUESTION 1(d) — CORRECT ANSWER: e

	a	b	c	d	e	No Answer
U	6	3	2	3Ø	76	-
	Ø,Ø5	Ø,Ø3	Ø,Ø2	Ø,26	Ø,65	-
L	11	28	9	4Ø	29	-
	Ø,Ø9	Ø,24	Ø,Ø8	Ø,34	Ø,25	-
D	-Ø,Ø4	-Ø,21	-Ø,Ø6	-Ø,Ø8	Ø,4Ø	-

COMMENT:

(i) The discrimination index is only fair. It is noticeable that nearly as many of the U echelon chose d as did those of the L echelon. On consideration that answer (e) is impulse and answer (d) is momentum, and Newton's Second Law of Motion gives impulse = Δp, it seems there could be merit in answer (d). At the least, the question is ambiguous, and some other distractor should be substituted for (d) momentum.

(ii) Focussing on the concept "area under the graph" was sharp enough to ensure that 28 of the L group chose (b) displacement - which would have been correct if the graph had been a velocity-time graph.

(iii) To take up the above point again, it may be suspected that these 28 were misled by having been taught (with reference to the velocity-time graph) that area represents displacement, without its being emphasized that the reason for this is that area = velocity x time = displacement. The question is of some diagnostic value; this could improve with the omission of "momentum".

QUESTION 1(e)

CORRECT ANSWER

	a	b	c	d	e	No Answer
U	104	8	2	2	1	-
	0,89	0,07	0,02	0,02	0,01	-
L	33	35	15	15	18	1
	0,28	0,30	0,13	0,13	0,15	0,01
D	0,61	-0,23	-0,11	-0,11	-0,14	-0,01

COMMENT: (i) The discrimination index is good.

(ii) The sketch, showing the two blocks, their masses their velocities, focusses accurately on the concept: conservation of momentum.

(iii) That the lower echelon candidates prefer b to a indicates that many have not grasped the conservation concept. Since they are told that the two blocks came to rest, there is more than a suspicion that they are confusing momentum with kinetic energy, or, alternatively, that they have failed to take into account the vector property of momentum (i.e., the fact that addition of momentum is algebraic). The question can thus be used for diagnosis.

QUESTION 1(h)   CORRECT ANSWER

	a	b	c	d	e	No Answer
U	10	8	30	34	35	-
	0,09	0,07	0,26	0,29	0,30	-
L	16	21	6	52	20	2
	0,14	0,18	0,05	0,44	0,17	0,02
D	-0,05	-0,11	0,21	-0,15	0,13	-0,02

COMMENT: (i) The discrimination index is poor (0,21), and the table shows that even the brighter candidates are confused by this one. The use of the negative in the stem of the question may be partly to blame. Although negative statements, and the identification of untrue statements, are commonly used in multiple-choice papers, the tendency among examiners today is to avoid these types where possible, since they complicate the problem for many students by adding linguistic and logical difficulties to the purely scientific issues.

(ii) Since (c) is the correct answer, the question is intended presumably to focus on the electromagnetic spectrum in relation to the photo-electric effect. Distractors (b), (d) and (e), however, introduce other matters - methods of charging an electroscope and the operation of an electrochemical cell on open circuit. To obtain the correct answer with confidence, the candidate requires a clear understanding of all these varied concepts. The question should be re-framed, or re-cast into at least two questions.

(iii) Diagnosis: since (e) achieves almost as good a discrimination index as (c), we may conclude that many good pupils are confused about the accumulation of electric charge on the poles of a cell when no current is flowing. In fact, this topic is not sufficiently dealt with in the physics syllabus - it comes in the "redox-reaction" chapter. Similarly since (d) gains the most adherents from group L, we may conclude that the mechanism of charging by induction is not known. It is meant to be taught in lower standards, but is not specifically mentioned in the Std 9/10 syllabus. It can be argued, therefore, that questions referring directly to it should not be asked in a matriculation paper.

QUESTION 1(i) CORRECT ANSWER

	a	b	c	d	e	No Answer
U	2	3	7	3	102	-
	0,02	0,03	0,06	0,03	0,87	-
L	29	9	23	18	37	1
	0,25	0,08	0,20	0,15	0,32	0,01
D	-0,23	-0,05	-0,16	-0,12	0,55	-0,01

COMMENT: (i) The discrimination index is satisfacctory.

(ii) The focussing is precise: temperature and pressure conditions in relation to ideal gas behaviour.

(iii) Most of those in group L who chose a wrong answer chose (a): correct as far as temperature goes, but 10^5 kPa instead of 10^2 kPa. This probably indicates carelessness in confusing Pa with kPa, since 10^2 kPa = 10^5 Pa. The second most common wrong answer was (c): again 10^5 kPa, but a temperature of 10K. Once again a confusion of units in suspected, since $10\,^oC$ would have been an acceptable answer. This question is quite useful, therefore, as a diagnostic tool.

(b) STANDARD GRADE PAPER

N.B. The Standard Grade responses are here summarized in the same way as for the Higher Grade. 198 candidates were involved (all the entrants from the 7 schools chosen). The upper (U) and lower (L) groups in the table each numbered 53 (=0,27 x 198).

QUESTION 1(c)

CORRECT ANSWER

	a	b	c	d
U	17	28	3	5
	0,32	0,52	0,06	0,09
L	18	9	11	15
	0,34	0,17	0,21	0,28
D	-0,02	0,35	-0,15	-0,19

COMMENT: (i) The discrimination index is only fair. Nearly as many of the U echelon chose (a) as did those of the L echelon. On consideration of the fact that (a) refers to constant velocity instead of constant acceleration, it is reasonable to conclude that the question itself is less at fault than the surviving Aristotelian concepts in the minds even of the U echelon.

(ii) The focussing is precise: on the relation between constant force and velocity, speed or acceleration.

(iii) A most useful and necessary diagnostic tool to pick out those who have not yet internalized Newton's First and Second Law of Motion.

QUESTION 1(d)

CORRECT ANSWER

	a	b	c	d
U	4	35	7	7
	Ø,Ø8	Ø,66	Ø,13	Ø,13
L	8	11	12	22
	Ø,15	Ø,21	Ø,23	Ø,42
D	-Ø,Ø7	Ø,45	-Ø,1Ø	-Ø,29

COMMENT: (i) The discrimination index is fairly satisfactory.

(ii) Focussing on the properties of a moving body (momentum, kinetic energy, potential energy, acceleration) is sufficiently precise.

(iii) The most popular "wrong answer" is (d): "acceleration increases." This surely points to a confusion of related concepts: velocity and acceleration. The question is diagnostically useful.

QUESTION 1(e)

CORRECT ANSWER

	a	b	c	d
U	5Ø	3	Ø	Ø
	Ø,94	Ø,Ø6	Ø,ØØ	Ø,ØØ
L	13	32	6	2
	Ø,25	Ø,6Ø	Ø,11	Ø,Ø4
D	Ø,69	-Ø,54	-Ø,11	-Ø,Ø4

COMMENT: (i) The discrimination index is excellent.

(ii) Focussing is precise: how electric charges are separated by friction.

(iii) It is quite surprising that (b) is the commonest wrong choice: "the ruler gains electrons." This surely points to lack of awareness that an electron is negatively charged. Useful for diagnosis.

QUESTION 1(g) — CORRECT ANSWER: b

	a	b	c	d
U	1	42	9	1
	Ø,Ø2	Ø,79	Ø,17	Ø,Ø2
L	11	24	17	1
	Ø,21	Ø,45	Ø,32	Ø,Ø2
D	-Ø,19	Ø,34	-Ø,15	Ø

COMMENT:

(i) The discrimination index is only fair.

(ii) The question, focussing as it does on "force per unit charge" as a property of an electric field, is perhaps rather trivial. This is confirmed that half of the L group chose the correct answer - hence the low value of D.

(iii) The term "electro-magnetic" - familiar to the pupils in other contexts - seems to have mesmerized a fair number in both groups to choose (C). This points to the danger of "undigested jargon." To a limited extent, therefore, this question is diagnostically effective.

QUESTION 1(h)

	a	b	c (CORRECT ANSWER)	d
U	9	8	24	12
	Ø,17	Ø,15	Ø,45	Ø,23
L	9	19	11	14
	Ø,17	Ø,36	Ø,21	Ø,26
D	Ø	-Ø,21	Ø,24	-Ø,Ø3

COMMENT: (i) The discrimination index is poor. Less than half of the U group chose the correct answer.

(ii) The focussing is precise: on the motor rule.

(iii) As might be expected most of those in the U group who chose incorrectly, chose (d): this indicated that they at least realised that the thrust must be perpendicular to both the current and the magnetic field. That they chose upwards instead of downwards may indicate a throw-back to the days when "current" indicated "electron current" - not within their own school careers, but within the school, university and/or college careers of their teachers.

More surprising is the fact that a large section of the L group chose (b). There seems to be no logical reason for this preference. This question is not a great success as a diagnostic tool, probably because it sets out to test merely a rule of thumb, without reference to the underlying concepts (e.g. patterns of the interacting magnetic fields).

QUESTION 1(i)

	a	b	c	d (CORRECT ANSWER)
U	2	0	1	50
	0,04	0,00	0,02	0,94
L	9	3	13	28
	0,17	0,06	0,25	0,53
D	-0,13	-0,06	-0,23	0,41

COMMENT: (i) The discrimination index is only fair. Nearly all the U group and more than half of the L group chose the correct answer.

(ii) Focussing is precise: on the kinetic theory

(iii) This question has diagnostic value in that it picks out the (relatively few) pupils who have not understood the kinetic theory of gases.

2. QUESTIONS REQUIRING WRITTEN ANSWERS.

(a) HIGHER GRADE PAPER: QUESTION 1(k)

N.B. The answers given by 46 candidates were photo-copied, consisting of the top 10% of candidates from each school. Candidates had to state, giving reasons, why each of five sentences was faulty.

SENTENCE (i): An object moving at constant speed cannot possibly be accelerating.

OBSERVATIONS: 36 out of 46 (78,3%) answered correctly, by referring to the difference between constant speed and constant velocity, and/or the possibility that acceleration might cause change of direction without change of speed.

Of the remainder, one did not answer; the remainder, having missed the point of the question (contrast of scalar and vector) used questionable semantics and mental gymnastics to justify a fictitious acceleration. The best of these efforts read as follows:-

> A body moving at constant speed, e.g. a lift going up at constant speed, is actually undergoing a negative acceleration due to gravity. It is being affected by the acceleration of gravity.

Another is as follows:-

> Relative to a fixed point it will not be accelerating, but relative to another object which is accelerating in the opposite direction it will be accelerating.

The others either quoted Newton's Laws verbatim, without application to the statement given, or wrote down formulae which, though correct in themselves, were irrelevant.

COMMENT: A good diagnostic question in detecting those whose vector-scalar discrimination is faulty.

SENTENCE (ii): There are no forces acting on a falling body which has reached terminal velocity.

OBSERVATIONS: 44 out of 46 (95,7%) answered correctly, referring to the equilibrium of gravitational and frictional forces. The remaining two lost marks by giving incomplete or badly-expressed answers,e.g.

> Although the frictional forces are in equilibrium, the force of gravity (10 $m.s^{-2}$) still acts on the object, otherwise it would not fall.

COMMENT: It is encouraging to note how well the equilibrium of forces acting on a body at terminal velocity has been taught. It is a pity that time did not permit recording the answers of the weakest candidates. This is expected to be a good diagnostic question.

SENTENCE (iii): The e.m.f. of a cell may be defined as the maximum power which the cell can deliver.

OBSERVATIONS: 29 out of 46 (63,0%) answered correctly.

Of the remainder, six (13,0%) defined e.m.f. in terms of maximum voltage or potential difference (correct in practical terms but not a theoretical definition), one simply translated as "electromotive force", another referred to the different units in which power and e.m.f. are measured, eight (17,4%) gave incomplete or slightly garbled versions of the correct definition. Only one was entirely off beam:

> The emf of a cell may be defined as the maximum number of electrons per second the cell can deliver.

COMMENT: The emphasis here seems to have been on the candidates' ability to memorize the precise wording of a formal definition. If the question had been marked less rigidly, it could have provided a better assessment of a candidate's grasp of basic concepts. On the other hand, precision of language is also an objective, and the scores for the above answers certainly sort out the accurate from the "sloppy". One should be aware of the danger, however, that the examiner may in many cases be rewarding rote memory-recall, without real understanding. Not good for diagnosing grasp of concepts.

SENTENCE (iv): When an electron moves at constant speed into a magnetic field, it will always be deflected.

OBSERVATION: 24 out of 46 (52,2%) answered correctly. Two did not answer; of the remainder, seven (15,2%) discussed the problem as if it were a case of equilibrium between electric and gravitational forces, apparently recalling glimmers of Millikan's experiment: two confused electric and magnetic fields; nine were simply confused, and wrote unintelligibly. The remaining four, although scoring no marks according to the memorandum, gave interesting answers which exhibited some inkling of electromagnetics. The four are reproduced here:-

(1) It will not always be deflected but will only be deflected when the magnetic field surrounding the moving electron is reinforced on one side by the magnetic field and cancelled on the other, because the tendency of the electron would then be to move in the direction of least force. However, if the magnetic field surrounding the electron ....

NOTE: The paragraph was unfinished, but the argument, using Faraday's concept of interacting field lines, could have led to a good answer if followed through to its conclusion.

(2) If the flux lines of the magnetic field are perpendicular to the path of the electron, it will not be deflected, but merely accelerated or decelerated.

(3) Dit hang af of die magneetveld uniform is, en in watter rigting die magneetveld loop.

(4) The electron will not be deflected as a magnetic field will only affect the motion of an accelerated

charge particle.

NOTE: (3) is partly correct; (2) has it back to front; (4) is thinking of the radiation of electromagnetic energy.

COMMENT: Of the five sentences given for discussion, this caused the most confusion. Possibly this arises from the syllabus and text-book emphasis on forces which act on current-bearing wires. This is understandable, since the electric motor depends on this phenomenon. It is suggested that, since the cathode-ray tube no longer figures prominently in the syllabus, and the electric motor is in any case dealt with in Standard Eight, questions on free-moving electrons should no longer be set in Standard 10. This is a matter for debate, to be resolved possibly by the annual examiners' and moderators' meeting.

SENTENCE (v): At the same temperature and pressure, the volume of 32g of O_2 is double that of 16g of CH_4.

OBSERVATION: 40 out of 46 (87,0%) answered correctly. Of the remainder, one did not answer, one said the given sentence was true as it stood, two corrected the sentence without giving a reason, and the other two wrote nonsense.

COMMENT: A satisfactory question to determine candidates' understanding of the mole concept, and of Avogadro's law.

(b) STANDARD GRADE PAPER: QUESTION 1(k)

N.B. 20 Candidates were selected, being the top 10% from each school. One did not answer question 1(k): hence only

19 answers were photo-copied. Candidates had to state, giving reasons, why each of five sentences was faulty.

SENTENCE (i): Displacement, speed, acceleration, force and momentum are all vector quantities.

OBSERVATIONS: 10 out of 20 (50%) answered correctly. Two (10%) stated that not all were vectors, but failed to identify "speed" as the only scalar. Two claimed that all five were scalars; the remainder wrongly identified the scalar(s).

COMMENT: A surprisingly poor performance by the top 10%! The indication is that the question is excellent as a diagnostic tool on understanding of the vector/scalar concept.

SENTENCE (ii): A body on earth falls freely from rest. After 1 second it has fallen 10m.

OBSERVATIONS: Only 3 out of 20 answered correctly (15%). Of these three, two did a calculation from the formula $s = ut + 1/2\ at^2$; the third merely changed 10m to 5m without explanation. Five (25%) did not answer at all. Two (10%) asserted that the original sentence was correct. Ten (50%) invoked friction to justify a reduction of the 10m, without specifying by how much it would be reduced.

COMMENT: The fact that only one candidate obtained the correct answer without calculation (and he gave no reason) seems to indicate that pupils have not been taught to visualize physical problems in non-algebraic terms, or to make rapid mental estimates of numerical answers without using the formula or performing the calculation. Neither, probably, have they done actual experiments on timing and falling bodies. This simple qustion is diagnostically valuable: it reveals not only gaps in pupils' mental make-up, but also faults in the methods by which they have been taught. It suggests, among other things, more emphasis on qualitative thinking and questioning is needed, and less dependence on formulae and calculations.

SENTENCE (iii): The watt is the unit of both work and energy.

OBSERVATIONS: 13 out of 20 (65%) answered correctly. One did not answer. Two gave partially correct answers (e.g. "Energy is measured in joules.") Three (15%) claimed that the watt was the unit of energy, though not of work. The remaining candidate named the coulomb as the unit of both work and energy.

COMMENT: Diagnostically effective.

SENTENCE (iv): The $J.\ C^{-1}$ is a unit of power.

OBSERVATIONS: 16 out of 20 (80%) answered correctly. Two did not answer; one named the joule as the unit of power, and one claimed that the $J.\ C^{-1}$ was the "unit of electrical work done."

COMMENT: A satisfactory diagnostic question.

SENTENCE (v): The pressure of a fixed mass of dry gas is directly proportional to its volume and to its temperature in kelvin.

OBSERVATIONS: 5 out of 20 (25%) answered correctly. Two did not answer; one simply wrote down "pV = nRt" without comment; one "corrected" the temperature scale from Kelvin to Celsius; and two gave partiallly correct answers, viz.,

(1) "It is only proportional to its temperature," and

(2) "The pressure of a fixed mass of any gas is not directly proportional to its volume."

Nine (45%) got the proportionalities the wrong way round, i.e. "Die druk is direk eweredig aan sy volume en omgekeerd eweredig aan sy temperatuur in kelvin."

COMMENT: These quite astonishing results (especially of the 9 who got the proportionalities inverted) point to the danger of mathematical formulae unsupported by visual imagery. Anyone visualizing a bicycle pump or a motor-car cylinder should easily convince himself that "when pressure increases, volume decreases"; similarly, the bursting of a balloon when overheated should impress on the pupil's mind the simultaneous increase of temperature and pressure. The diagnostic efficacy of this question is quite considerable.

3. "LONGER" QUESTIONS

(a) HIGHER GRADE PAPER

N.B. The same 46 candidates (1Ø% from each school) were employed as for the study of Question 1(k); but, as more time became available, these were augmented with 46 more, making 92 candidates altogether, drawn in proportion to class sizes from all 15 schools. A spread of abilities was aimed at, so that samples of weaker and average pupils from each school were included, the total score gained by each on the whole paper being noted for comparison.

Answers to Questions 2 (d) (i) and 3 (c) (i) were tabulated as "right" or "wrong": in the first case all wrong answers were noted. Answers to Question 3 (a) (i) were tabulated in three columns, viz. (a) "against the field" (correct); (b) "with the field" (wrong); (c) "athwart the field" (wrong). Any unusual answer or expression was noted.

Answers to Question 3 (a)(ii) were recorded in three columns, viz. (a) "decreases" (correct); (b) "increases" (wrong); (c) "constant" (wrong). Again, unusual responses were noted.

The complete tabulation is not shown here, but only the totals for each response, and the range of different answers.

QUESTION 2 (d) (i): A boy of mass 45kg jumps with a horizontal velocity of $5 m.s^{-1}$ on to a 5kg skateboard resting on a horizontal surface.

Name the law which enables you to calculate the speed of the boy immediately after he has landed on the skateboard.

OBSERVATIONS: 69 out of 92 gave the correct answer (Principle of the Conservation of Momentum), i.e., 75%.

Two did not answer. Wrong answers, with their respective frequencies, were:-

ANSWER	NO. OF OCCURRENCES	PERCENTAGE
Newton's Second Law of Motion	7	7,6%
Newton's Law of Momentum	3	3,3%
Momentum (sic)	1	1,1%
Newton's Law of Inertia	1	1,1%
Newton's First Law of Motion	2	2,2%
Newton's Third Law of Motion	1	1,1%
Law of Momentum	3	3,3%
Law of Mass Action	1	1,1%
Universal Law of Momentum	1	1,1%
Newton's Gravitational Force	1	1,1%
	21	23,0%

COMMENT: The first "wrong" answer has some merit, in that Conservation of Momentum is related conceptually to Newton's Second Law. The remaining answers, even where the word "Momentum" occurs, are definitely faulty, because the concept of "Conservation" does not occur. These are probably wild guesses, as a result of which a professional-sounding phrase is dredged up from memory - an example of the danger of "inert ideas" (See Arons's article in Physics Teacher 22^1 and 22^2, 1984). This question is of some diagnostic use.

QUESTION 3 (a)(i): An electron is allowed to move freely from rest in an electric field.

In which direction will the electron move relative to the direction of the field?

OBSERVATIONS: 73 out of 92 gave the correct answer (In a direction opposite to that of the field), i.e., 79,3 %. One did not answer. Wrong answers were as follows:-

ANSWER	NO.OF OCCURENCES	PERCENTAGE
b: with the field	9	9,8%
c: athwart the field	5	5,4%
From North to South	1	1,1%
If field is clockwise: with the field. If field is anticlockwise: against the field.	1	1,1%
From high to low potential in the magnetic field (sic)	1	1,1%
Away from the field (sic)	1	1,1%
	18	19,6%

COMMENT: The 9,8% who gave a simple wrong answer in "b" are either unaware of the convention concerning the direction of field arrows, or are ignorant of the fact that an electron carries a negative charge. The 5,4% who chose "c" are probably confused between electric and magnetic fields, as are the candidates who either mentioned "magnetic field" specifically, or used the terms "North" and "South", or referred to "clockwise" and "anticlockwise." This again is a useful diagnostic question.

QUESTION 3 (a)(ii): How does the electrical potential energy of the electron change as it moves freely in the field?

OBSERVATIONS: 68 out of 92 gave the correct answer (Potential energy decreases), i.e., 73,9%. Wrong answers were:-

ANSWER	NO. OF OCCURENCES	%
(b): Potential energy increases	17	18,5%
(c): Potential energy constant	4	4,3%
Unintelligible	2	2,2%
	23	25,0%

One candidate did not answer.

COMMENT: The only possible explanation of the 18,5% who imagined the potential energy to be increasing is that they had not internalized the definition of potential energy, i.e. they did not distinguish between work done on a body and work done by the body. This question could be useful both for diagnosis and for instruction by means of class discussion.

QUESTION 3 (c) (i): Two long, parallel, current-carrying wires repel each other with a force F per metre length of each wire.

Does the current in the two wires flow in the same or in opposite directions?

OBSERVATIONS: 76 out of 92 (82,6%) gave the correct answer (opposite directions), two gave no answer, and 14 (15,2%)

gave the incorrect answer.

COMMENT: Earlier, the possibility that, for many candidates, this is a Category A question (memory-recall) has been discussed. In fact, it ought to be so; in other cases the answer may have been reached by guesswork. Further investigation would be necessary to decide whether a candidate understood the theory of interacting magnetic fields, by which the correct answer could be deduced theoretically. This question has little diagnostic efficacy.

(b) STANDARD GRADE PAPER

N.B. The same twenty scripts were employed as in the case of Question 1(k). The tabulation of reponses was as follows:-

QUESTIONS 2 (b)(i) and 2(b)(ii): any straight line was marked a (correct); any curve was marked b (wrong).

QUESTION 2(d): Five points had to be mentioned to gain full marks:

- a weight
- b acting downwards
- c air friction
- d acting upwards
- e these forces are in equilibrium

QUESTION 2 (e)(ii): Three points deserved a mark:

- a sound
- b heat
- c deformation

QUESTION 3 (a)(iii): a correct pattern of field lines

b arrows pointing from + to -

c arrows from - to + (wrong)

QUESTION 3 (c): a heat transfer depends on R

b R must not be too high, or the current will be too low.

QUESTION 2 (b)(i): Using displacement/time axes, draw a graph representing the motion of a body moving at constant velocity.

OBSERVATIONS: All twenty candidates answered correctly.

COMMENT: An effective question. It has shown here that the displacement/time graph, and velocity as the gradient therof, have been well taught, and correctly grasped by candidates whose total marks ranged from $\frac{111}{125} = 88{,}8\%$ to $\frac{33}{125} = 26{,}4\%$

QUESTION 2(b)(ii): Using velocity/time axes, draw a graph representing the motion of a body undergoing uniform acceleration.

OBSERVATIONS: 16 out of 20 candidates (80%) answered correctly. The other 4 drew curves.

COMMENT: An effective diagnostic question, enabling the examiner to identify pupils who have not grasped that on a velocity/time graph, uniform acceleration means a constant gradient. It is significant that the 4 who answered wrongly were not those with the lowest overall mark. They ranged from $\frac{93}{125} = 74{,}4\%$ to $\frac{72}{125} = 57{,}6\%$, and each was from a different school. There is, of course, the possibility that some of the weaker candidates may have scored here inadvertently, if the straight line were the only kind of graph that would occur to them to draw.

QUESTION 2(d): A body falling in the air from a great height reaches terminal velocity.

Name and describe the forces acting on such a body.

OBSERVATIONS: Two candidates did not answer; two more wrote unintelligible nonsense. The remaining 16 scored as follows:

a ("weight"): 15 correct.

b ("downwards"): 11 correct.

c ("air friction"): 14 correct.

d ("upwards"): 10 correct.

e ("in equilibrium"): 5 correct.

COMMENT: A good diagnostic question, on the identification of the forces acting on a falling body. 70% named both forces correctly, even if their directions were not always specified. Only 25%, however, mentioned that, at terminal velocity these forces are in equilibrium, or balanced. These 25% were among the top scorers. The others either did not know the meaning of "terminal velocity", or did not consider the equilibrium of the forces to be important. Perhaps a slight re-wording or re-structuring of the question could remove this ambiguity.

QUESTION 2(e)(ii): A sports car collides with the back of a bakkie moving in the same direction. On impact, the bumpers of the two vehicles become locked together. What happens to some of the kinetic energy of the vehicles during the collision?

OBSERVATIONS: 9 candidates either did not answer or else gave answers mentioning none of the points recorded. One merely stated that the energy was conserved; one other that the energy was transferred from one vehicle to the other. The remainder scored as follows:-

a ("converted to sound"): 9 correct.

b ("converted to heat"): 8 correct.

c ("deformation of the vehicles"): 1 correct.

COMMENT: It could be said that from 40% to 45% gave satisfactory answers. All those who gave "b" correctly, also gave "a" correctly. These were, without exception, among the better group of candidates (minimum total mark = $\frac{86}{125}$ = 68,8%). This is an effective diagnostic question, focussing on the conservation and transformation of energy. It might have been improved by some reference to the concept of elastic and non-elastic collisions.

QUESTION 3 (a)(iii): Sketch the electric field associated with two equal and opposite point charges situated, in air, 60mm from each other.

<u>OBSERVATIONS</u>: One candidate did not answer; six drew a completely wrong pattern. The remainder scored as follows:-

a (correct pattern of field lines): 10 correct.

b (arrows pointing from + to -): 11 correct.

c (arrows pointing wrongly): 3

One of the 11 who scored in b, also scored in c, i.e., he had arrows pointing both ways at once.

<u>COMMENT</u>: <u>50% were correct</u>. A good diagnostic question, focussing on <u>simple sketching of electric fields</u>.

<u>QUESTION 3(c)</u>: Explain why the element of an electric kettle should have a fairly high resistance.

<u>OBSERVATIONS</u>: Three candidates did not answer; two wrote nonsense. 14 justified a high resistance in order to obtain a high rate of energy transformation. Only one points out that a low resistance will permit a large current to flow (some such statement was needed to explain the word "fairly" in the question.) It could be said that <u>75% answered the question partially</u>; <u>no-one gave a complete discussion</u>.

<u>COMMENT</u>: Refer to the discussionof Examiners' Objectives earlier (chapter III, para. IIIA) for argument that this is <u>too difficult for a Standard Grade paper</u>. A full answer would demand a high order of analytical ability.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

I CURRENT USE OF QUALITATIVE QUESTIONS

A. Qualitative questions were used, by both Higher Grade and Standard Gradeexaminers, in the Physics papers set in Natal in 1987.

B. In the Higher Grade paper, out of a total of 165 marks, 66 marks were allotted to qualitative questions, i.e. 40%.

C. In the Standard Grade paper, out of a total of 125 marks, 56 marks were allotted to qualitative questions, i.e. 44,8%.

D. These proportions represent a significant, and welcome departure from the traditional dependence on numerical problems.

II CURRENT USE OF MULTIPLE-CHOICE QUALITATIVE QUESTIONS

A. In the Higher Grade paper, of the 66 marks devoted to qualitative questions, 28 were for Multiple-Choice questions, 2Ø for "correcting errors" questions, and 18 for portions of longer questions.

B. In the Standard Grade paper, of the 56 marks devoted to qualitative questions, 21 were for Multiple-Choice questions, 1Ø for "correcting errors" questions and 25 for portions of longer questions.

C. The above figures are displayed below as percentages of the total of qualitative questions:

	HIGHER GRADE		STANDARD GRADE	
	MARKS	PERCENTAGE	MARKS	PERCENTAGE
MULTIPLE CHOICE	28	42,4%	21	37,5%
"CORRECTING ERRORS"	2Ø	3Ø,3%	1Ø	17,9%
PORTIONS OF LONGER QUESTIONS	18	27,3%	25	44,6%
TOTAL	66	1ØØ%	56	1ØØ%

III OBJECTIVES OF QUALITATIVE QUESTIONS

A. LIMITATIONS

Owing to the limitations of the examination system, it is not possible to set questions except on Categories A1 to A11 and F1 to F3 of Bloom's Taxonomy of the Cognitive Domain, as applied by L.E. Klopfer in his two-dimensional matrix (1971). In the Standard Grade, questions are further limited to Categories A1 to A11.

B. SOUTH AFRICAN MODIFIED CATEGORIES.

In South Africa a modified scheme is generally used, with only four categories (A,B,C and D), of which only the first three are generally useful in examination papers.

C. EXAMINERS' STATED OBJECTIVES

Both the Higher Grade and the Standard Grade examiners stated their objectives in terms of sections of the syllabus, rather than in behavioural terms. The objectives, and the questions based on them, covered the full range of topics prescribed by the syllabus.

IV CRITERIA FOR EVALUATING QUALITATIVE QUESTIONS: THE THREE AREAS IN WHICH QUALITATIVE QUESTIONS MAY BE EFFECTIVE

A. FOCUSSING

1. As each qualitative question was examined and discussed, the question was asked: "To what extent does the question focus precisely on a specific objective (behavioural or otherwise)?"

2. The discussions recorded in Chapter Three indicate that most of the questions focus satisfactorily on specific objectives.

3. Exceptions occur in certain of the multiple-choice questions, where the "distractors" have introduced alternative concepts, widening the scope of the question, making it more difficult to answer, and blurring the accuracy with which the candidates' responses might be used to diagnose faulty concepts.

B. DISCRIMINATION

1. DISCRIMINATION INDICES

(a) The fundamental purpose of the examination is to discriminate between those who have grasped accepted scientific concepts, procedures and theories, and those who either failed to grasp them or have grasped them in a distorted form.

(b) The <u>discrimination indices</u> calculated for the multiple choice questions - though not infallible in themselves - proved useful guides and starting-points.

2. <u>THE MULTIPLE-CHOICE QUESTIONS</u>

(a) In the <u>Higher Grade paper</u>, <u>six out of the seven multiple-choice questions studied proved satisfactory</u> as discriminants, with discrimination indices ranging from Ø,7Ø to Ø,4Ø. <u>Question 1 (h), with a discrimination index of Ø,21, was found to be unsatisfactory</u> because to arrive at the correct answer involved consideration <u>of too many diverse concepts</u>: electrostatics; methods of charging on electroscope; electrochemical cells; the photo-electric effect; the frequency ranges in the electromagnetic spectrum; and the photon energy/frequency relation.

(b) In the <u>Standard Grade paper</u>, <u>five out of the six multiple-choice questions studied prove reasonably satisfactory</u>, with discrimination indices ranging from Ø,69 to Ø,34. <u>Question 1(h), with a discrimination index of Ø,24, was found to be unsatisfactory</u>, partly because the examiner's objective ("to test the motor rule") dealt with a <u>topic originally taught in the Standard Eight syllabus</u>, and no longer emphasized at Standard Ten level, and partly (it is suggested) because of <u>confusion on the part of pupils and teachers</u> between electron current and conventional current.

From a theoretical point of view, the question is trivial, because answering it depends on a rule of thumb without necessarily any understanding.

3. THE "CORRECTING ERRORS" QUESTIONS.

(a) TYPE OF QUESTION

In both the Higher Grade and the Standard Grade papers, Question 1(k) consisted of five sentences, each of which contained an error. The candidates were required to correct the errors and give reasons.

(b) HIGHER GRADE PAPER

The five sentences given on the paper focussed upon common confusions and misunderstandings, viz.,

(i) the difference between speed and velocity;

(ii) the forces acting on a body falling with terminal velocity;

(iii) the definition of e.m.f.;

(iv) the deflection of a moving electron in a magnetic field;

(v) the mole concept for diatomic gases.

The sentences given proved to be effective discriminants: the "reasons" given by the candidates identified immediately those who had grasped the concepts.

(c) STANDARD GRADE PAPER.

The five sentences given on this paper focussed upon quite elementary errors, viz.,

(i) confusing scalar and vector quantities;

(ii) confusing displacement and acceleration;

(iii) confusing work, energy and power;

(iv) confusing $J.C^{-1}$ with $J.s^{-1}$;

(v) confusing direct and inverse proportion in relation to the gas laws.

The sentences given proved to be remarkably effective in exposing areas of ignorance and error in the minds of candidates who performed well overall.

(d) RECOMMENDATION

The success of the "correcting errors" type of question implies that it should continue to be used in Natal, and its introduction should be recommended to other examining bodies.

4. PORTIONS OF LONGER QUESTIONS.

(a) In both Higher Grade and Standard Grade papers, the qualitative portions of longer questions were in every case very short and very specific in their objectives.

(b) In the Higher Grade paper, the concepts tested were:-

(i) conservation of momentum;

(ii) movement of an electron in an electric field;

(iii) electrical potential energy;

(iv) mutual repulsion of parallel, current-carrying wires;

(c) In the Standard Grade paper, the concepts tested were:-

(i) Graphical representation of constant velocity;

(ii) Graphical representation of uniform acceleration;

(iii) Forces acting on a body falling at terminal velocity;

(iv) Energy transformations occurring during a collision;

(v) Sketching the electric field of two point charges;

(vi) Relation of resistance to the heating effect of a current.

(d) In both papers, only a limited range of concepts was tested by means of qualitative questions; other concepts were, of course, required in order to solve the numerical problems.

(e) RECOMMENDATION

Short, specific, qualitative questions should be more widely used as portions of the longer, numerical questions.

C. DIAGNOSIS

1. In an internal examination, or in a class test, wrong answers provide the teacher with valuable information, with which to diagnose weaknesses, confusions and false concepts in individual pupils: remedial action can then be taken.

2. Even in a public examination, prevailing wrong answers can be used by the examiner to diagnose wide-spread weaknesses, confusions and false concepts. By mentioning these in the examiner's report, disseminated to schools, he can assist teachers in eliminating these weaknesses, confusions and false concepts in succeeding years.

3. In both the Higher Grade and the Standard Grade papers, nearly all the qualitative questions set (in all three sections of the paper) proved effective for diagnosis: the diagnostic value of each question is discussed in detail in Chapter Three.

V GENERAL RECOMMENDATIONS

A. The proportion of qualitative questions, in the examination paper as a whole, could well be increased until parity with the numerical questions is reached.

B. Care should be taken that each question, particularly in the multiple-choice section, should focus precisely on a single specific concept.

C. Use of the "correcting-errors" type of question is recommended, and could well be extended to cover a wider range of concepts.

D. Attention should be given to careful and detailed "feedback" from examiners to teachers, since in this way many common errors can be diagnosed and remedied.

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APPENDIX 1.

NATAL EDUCATION DEPARTMENT

NATAL SENIOR CERTIFICATE EXAMINATION

HIGHER GRADE

13	SC
HIGHER GRADE	
PHYSICAL SCIENCE FIRST PAPER	

(VIR AFRIKAANS KYK OP KEERSY)

DECEMBER 1987

PHYSICAL SCIENCE : FIRST PAPER

Time: 2 hours

1. Answer all the questions.
2. You are advised to consult the accompanying data sheet and Periodic Table.
3. Read the following instructions carefully before answering Question 1.

   Use the specially prepared answer sheet enclosed in your question paper to answer Questions 1(a) to 1(j) inclusive, and write the answers to Question 1(k) in your answer book.
   Write your examination number on the answer sheet.

   Five possible answers are given to each of the questions from 1(a) to 1(j) inclusive. Choose the answer which you consider to be the best and cross out the corresponding letter on the answer sheet.
   Place the completed answer sheet inside the front cover of your answer book.

   Example:

   Question: One metre, expressed in mm, equals:
   (A) 1 (B) 10 (C) 100 (D) 1 000 (E) 10 000

   Answer : (A) (B) (C) ~~(D)~~ (E)

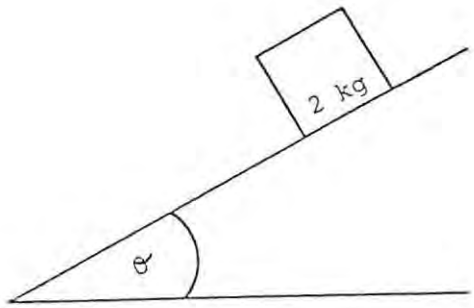
   If more than one cross appears with any answer, it will be counted as incorrect and no marks will be allocated for that answer.
   Hint: Complete the answer sheet by making provisional crosses in pencil, and after final consideration, complete it in ink, and erase the superfluous pencil marks.

   It may be necessary to test some answers in writing. All such calculations should be done in the answer book, but must be deleted with a diagonal line, drawn across the page(s).

   To every correct answer from question 1(a) to 1(j) inclusive, 4 marks will be allocated.

P.T.O. .... / Question 1.

1. (a)



A body of mass 2 kg rests on an inclined plane as shown in the diagram. The magnitude of the frictional force acting on the body is

(A) equal to the body's weight

(B) less than the body's weight

(C) greater than the body's weight

(D) independent of the body's weight

(E) independent of the angle θ

(b) A tennis player hits a ball vertically into the air. When the ball has reached its maximum altitude

(A) its acceleration is zero

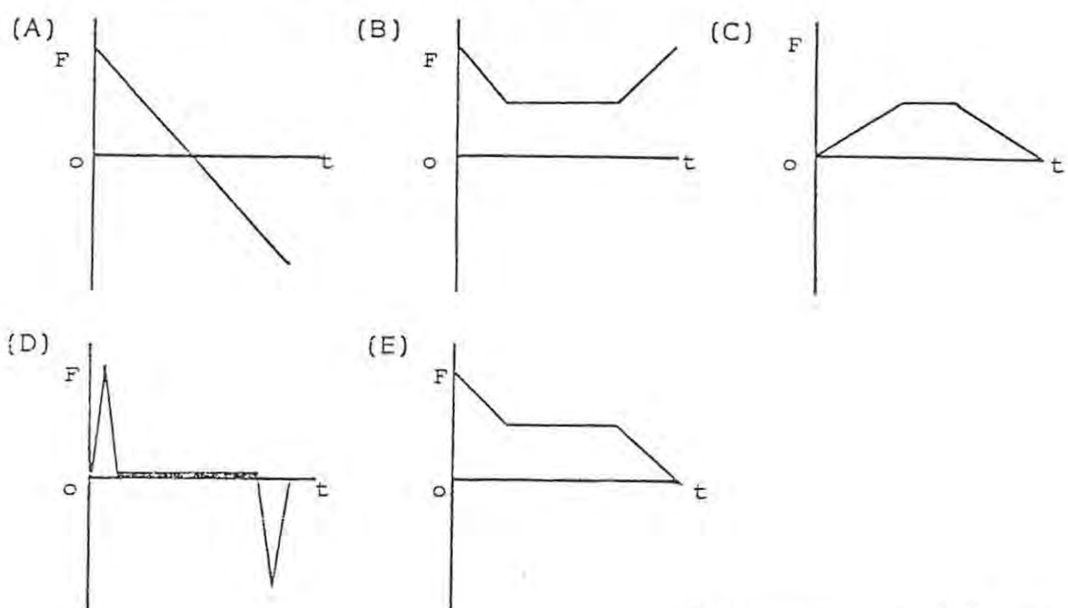
(B) the resultant force on it is zero

(C) its kinetic energy is a maximum

(D) the frictional force on it is a maximum

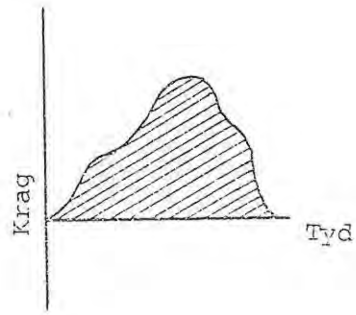
(E) its acceleration is downward

(c) A girl enters a lift on the ground floor of a building and, after travelling non-stop, gets out on the tenth floor. Which one of the following graphs best shows how the resultant force on the girl varies with time while she is in the lift?



/ Question 1. (d)

1\. (d)



Watter een van die volgende hoeveelhede word deur die gearseerde gedeelte in bostaande grafiek verteenwoordig?

(A) versnelling

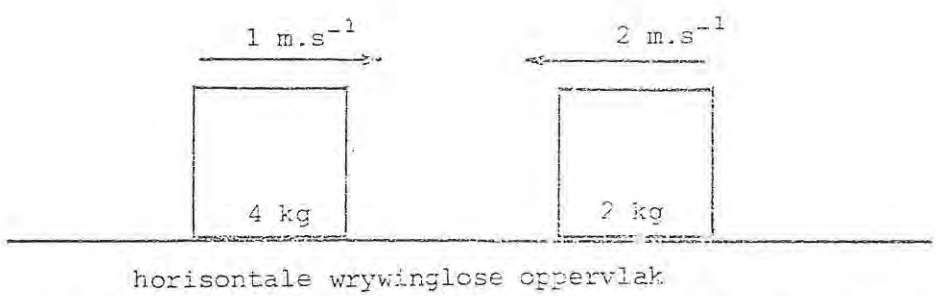
(B) verplasing

(C) traagheidsmassa

(D) momentum

(E) impuls

(e)



Die twee blokke aangetoon in die diagram gly na mekaar, bots, en kom tot stilstand. Tydens die botsing

(A) bly die gekombineerde momentum van die twee blokke onveranderd

(B) verminder die gekombineerde momentum van die twee blokke

(C) bly die kinetiese energie behoue

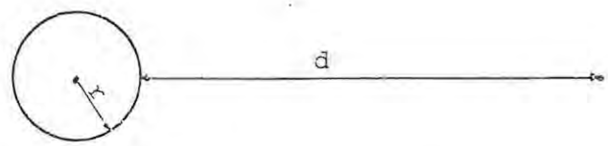
(D) word kinetiese energie omgesit na gravitasie potensiële energie

(E) gly die twee blokke 'n sekere afstand voordat hulle tot stilstand kom

13

Bladsy 4

1. (f) 'n Puntlading word 'n afstand d geplaas vanaf 'n geïsoleerde gelaaide sfeer met radius r.
(Sien die diagram)



Die grootte van die krag uitgeoefen deur die puntlading op die sfeer is

(A) direk eweredig aan d^2

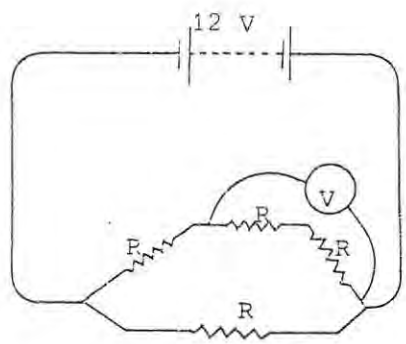
(B) omgekeerd eweredig aan d^2

(C) direk eweredig aan $(r + d)$

(D) omgekeerd eweredig aan $(r + d)$

(E) omgekeerd eweredig aan $(r + d)^2$

(g)



Vier identiese resistors word verbind soos in die stroombaandiagram aangetoon. As aanvaar word dat die battery geen interne weerstand het nie is die lesing, in volt, op die voltmeter

(A) 2

(B) 4

(C) 6

(D) 8

(E) 10

(h) 'n Sinksfeer op 'n geïsoleerde stander sal nie 'n positiewe lading verkry nie as dit

(A) met ultra-violetlig bestraal word

(B) geraak word deur 'n soortgelyke positiefgelaaide sfeer

(C) in 'n mikrogolfoond geplaas word

(D) geaard word terwyl 'n negatiefgelaaide staaf naby gehou word

(E) die positiewe pool van 'n sel raak

1. (i) At which one of the following combinations of temperature and pressure is helium's behaviour most likely to be similar to that of an ideal gas?

(A) 273 K ; 10^5 kPa

(B) 10 K ; 10^2 kPa

(C) 10 K ; 10^5 kPa

(D) 546 K ; 10^5 kPa

(E) 293 K ; 10^2 kPa

(j) The molecules in an iodine crystal are held together by

(A) ionic bonds

(B) hydrogen bonds

(C) interatomic forces

(D) covalent bonds

(E) v.d. Waal's forces

(10 x 4) (40)

(k) The following statements are all faulty. State, giving reasons, in what respect each statement is faulty.

(1) An object moving at constant speed cannot possibly be accelerating.

(2) There are no forces acting on a falling body which has reached terminal velocity.

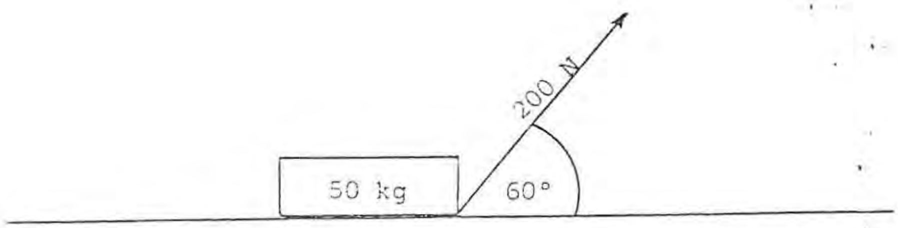
(3) The emf of a cell may be defined as the maximum power which the cell can deliver.

(4) When an electron moves at constant speed into a magnetic field it will always be deflected.

(5) At the same temperature and pressure, the volume of 32 g O_2 is double that of 16 g CH_4. (20)

/ 60 /

2. (a)

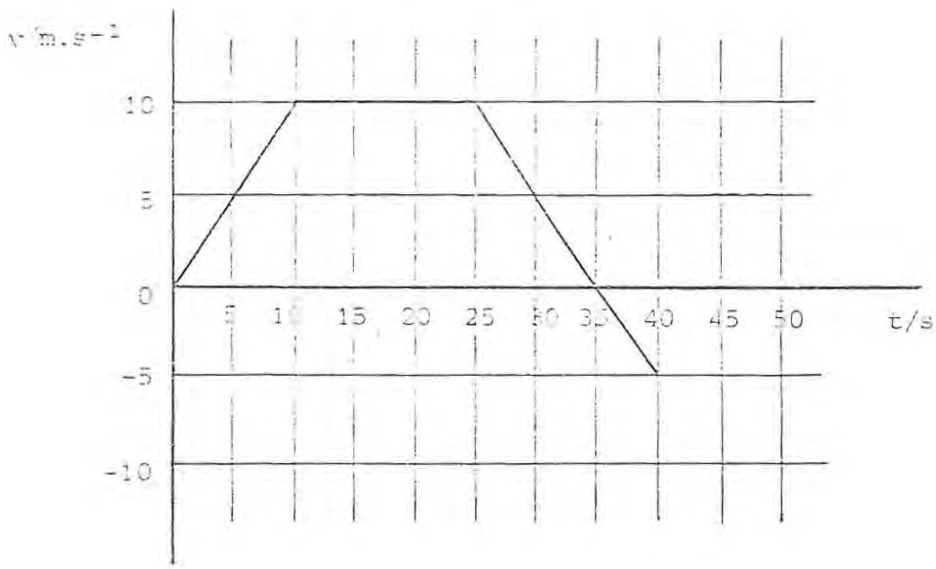


A force of 200 N, acting at 60° to the horizontal, accelerates a body of mass 50 kg along a horizontal plane.

(1) Calculate the component of the 200 N force available for accelerating the body along the plane. (3)

(2) If it is found that the magnitude of the body's acceleration is 1,5 $m.s^{-2}$, calculate the magnitude of the frictional force acting on the body. (5)

(b)



The above graph describes the motion of a motor car during a time interval of 40 s.

(1) From the graph determine

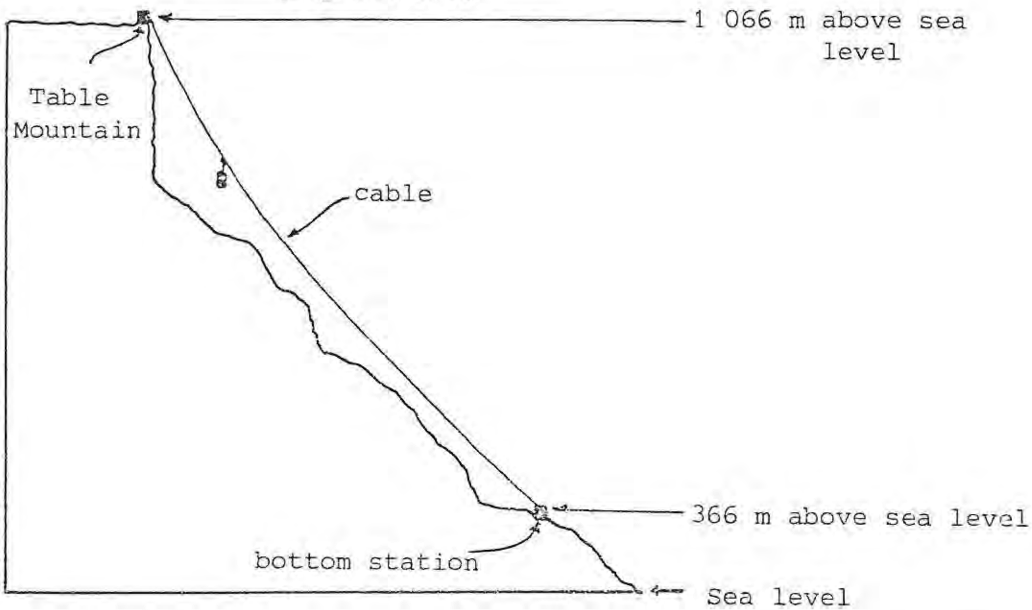
(i) the total time during which the car experienced a resultant non-zero force; (2)

(ii) the displacement of the car after 40 s. (3)

(iii) the total distance the car travelled during the 40 s. (3)

.... / Question 2.(b)(2)

2. (b) (2) Draw an acceleration-time sketch-graph to depict the car's motion during the 40 s. (4)



The Table Mountain cable car has a total mass of 3 000 kg when fully laden. The motor used for hoisting the cable car to the top of the mountain is labelled as follows:

Voltage : 440 V d.c.
Max. Power Input : 88 kW

(1) If the motor operates at maximum power input, calculate the electrical energy used by the motor in hoisting the cable car to the top of the mountain in 7 minutes. (4)

(2) Calculate the gain in gravitational potential energy of the car when it moves fully laden from the bottom to the top station. Compare your answer with the value calculated in (1) and explain the difference. (4)

(3) Should the fully laden car's braking mechanism fail while at the top station, with what speed will the car strike the bottom station if during its descent the car loses 6×10^6 J of mechanical energy in doing work against friction? (7)

P.T.O. .... / Question 2.(d)

2. (d) A boy of mass 45 kg jumps with a horizontal velocity of 5 $m.s^{-1}$ onto a 5 kg skateboard resting on a horizontal surface.

(1) Name the law which enables you to calculate the speed of the boy immediately after he has landed on the skateboard. (2)

(2) Show by calculation that this speed is 4,5 $m.s^{-1}$. (4)

(3) Show by means of suitable calculations that kinetic energy is not conserved in this case. (5)

(4) After jumping onto the skateboard, the boy and the skateboard move up a plane inclined at 30° to the horizontal. Through what vertical height will they rise before coming to a stop? (Ignore all frictional effects.) (4)

[50]

3. (a) An electron is allowed to move freely from rest in an electric field.

(1) In which direction will the electron move relative to the direction of the field? (2)

(2) How does the electrical potential energy of the electron change as it moves freely in the field? (2)

(b) In a Millikan-type experiment an oil drop with a charge of $+8 \times 10^{-19}$ C and a mass of 4×10^{-15} kg is held stationary between two oppositely-charged parallel plates, spaced 16 cm apart in a vacuum.

(1) Calculate the potential difference across the plates. (5)

(2) This drop is now joined by a drop of equal mass carrying a charge of -8×10^{-19} C.
If all other conditions remain unchanged determine the direction and magnitude of the acceleration of the newly formed drop. (4)

(c) Two long parallel current-carrying wires repel each other with a force F per metre length of each wire.

(1) Does the current in the two wires flow in the same or in opposite directions? (2)

(2) What is the force experienced by each wire per 1 m length if

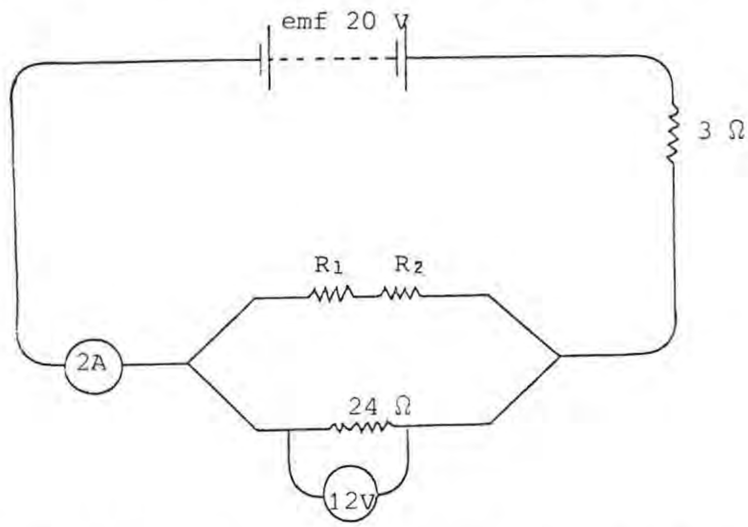
(i) the distance between the wires is doubled? (2)

(ii) the current in each of the wires is doubled? (2)

.... / Question 3. (d)

3. (d) Calculate the potential difference across an 20 Ω resistor through which 10^{18} electrons flow every 10 s. (5)

(e)



In calculations based on the above circuit the effects of the resistances of the wires and meters may be ignored.

Calculate:

(1) the energy dissipated in the 3 Ω resistor every 10 s; (3)

(2) the values of R_1 and R_2 if $R_1 = R_2$; and (4)

(3) the internal resistance of the battery. (4)

/ 35 /

4. (a) Consider the following substances:

Cu; Si; NH_3; NaBr; Xe.

Which one of these substances

(1) is the best electrical conductor at room temperature?

(2) is the most malleable?

(3) has the lowest boiling point?

(4) is a poor electrical conductor when solid but conducts on melting?

(5) has hydrogen bonds between its molecules?

(6) is hard and brittle and insoluble in water? (6)

4. (b)

(1)

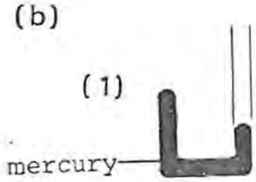


Diagram (1) shows a J-tube of which the closed end is completely filled with mercury. The mercury column in the open end is shorter than that in the closed end.

(2)

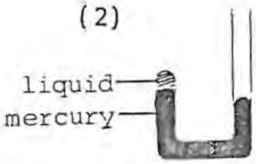


Diagram (2) shows the same J-tube after 0,109 g of volatile liquid has been introduced into the closed limb.

(3)

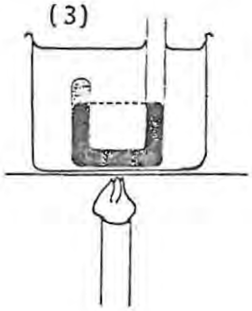


Diagram (3) shows the J-tube being heated in water. At 77° C it is found that the last droplet of volatile liquid disappears, that the two mercury levels are equal, and that the vapour has a volume of 29,05 cm^3.

(1) What type of bond is most likely to exist between the particles in the liquid? (1)

(2) Why can 77° C be considered the boiling point of the liquid? (1)

(3) Assuming that the experiment was carried out at sea level calculate the formula mass of the liquid. (6)

(c) (1) Write a balanced equation to illustrate the dissolution of Na_2SO_4 in water.

(2) 7,1 g of Na_2SO_4 are dissolved in water to make 500 cm^3 of solution. Calculate the concentration of the solution. (6)

[20]

TOTAL : 165

APPENDIX 2

NATAL SENIOR CERTIFICATE EXAMINATION

STANDARD GRADE

64 SC

STANDARD GRADE

PHYSICAL SCIENCE :
FIRST PAPER

(VIR AFRIKAANS KYK OP KEERSY)

DECEMBER 1987

PHYSICAL SCIENCE : FIRST PAPER

Time: 1½ hours

1. Answer all the questions.

2. You are advised to consult the accompanying data sheet and Periodic Table.

3. Read the following instructions carefully before answering Question 1.

   Use the specially prepared answer sheet enclosed in your question paper to answer Questions 1(a) to 1(j) inclusive.

   Write your examination number on the answer sheet.

   Four possible answers are given to each of the questions from 1(a) to 1(j) inclusive.
   Choose the answer which you consider to be the most appropriate and cross out the corresponding letter on the answer sheet.
   Place the completed answer sheet inside the front cover of your answer book.

   Example:

   Question : One metre, expressed in mm, equals:
   (A) 1 (B) 10 (C) 100 (D) 1 000

   Answer : (A) (B) (C) ~~(D)~~

   If more than one cross appears with any answer, it will be counted as incorrect and no marks will be allocated for that answer.

   Hint: Complete the answer sheet by making provisional crosses in pencil, and after final consideration, complete it in ink, and erase the superfluous pencil marks.

   It may be necessary to test some answers in writing. All such calculations should be done in the answer book, but must be deleted with a diagonal line, drawn across the page(s).

   To every correct answer from questions 1(a) to 1(j) inclusive, 3 marks will be allocated.

Note: Ignore all frictional effects unless otherwise stated.

1. (a) Two forces of magnitude 3 N and 4 N respectively act on a body. The maximum possible magnitude of the resultant of these two forces is

(A) 7 N (B) 12 N

(C) 5 N (D) 1 N

(b) Consider a displacement vector of 4 m along a compass bearing of 60°. A possible set of rectangular components of this vector is

(A) 2 m south; 3,44 m east (B) 3,44 m north; 2 m west

(C) 3 m south; 3 m west (D) 2 m north; 3,44 m east

(c) If a stationary body is subjected to a constant resultant force it will

(A) move at a constant velocity in the direction of the resultant force

(B) accelerate uniformly in the direction of the resultant force

(C) move at a constant speed in the direction of the resultant force

(D) accelerate at a rate directly proportional to its mass

(d) A bullet is fired vertically downwards from a rifle. On leaving the barrel the bullet's

(A) momentum decreases

(B) kinetic energy increases

(C) gravitational potential energy increases

(D) acceleration increases

(e) When a plastic ruler is given a positive charge by rubbing it with a piece of flannel

(A) the ruler loses electrons while the flannel gains electrons

(B) the ruler gains electrons while the flannel loses electrons

(C) the flannel loses protons while the ruler gains protons

(D) the flannel gains protons while the ruler loses protons

.... / Question 1. (f)

1. (f) Two long parallel current bearing conductors carry identical currents in the same direction. The force per unit length which either conductor exerts on the other is F.
If each of the currents is doubled but the distance between the conductors remains constant the new force per unit length will be

(A) an attractive force of 2 F

(B) an attractive force of 4 F

(C) a repulsive force of 2 F

(D) a repulsive force of 4 F

(g) The force per unit charge at a point gives the intensity or strength of the

(A) magnetic field at that point

(B) electric field at that point

(C) electro-magnetic field at that point

(D) moving magnetic field at that point

(h) An electric current is passed through a horizontal wire situated in a horizontal magnetic field, as shown in the diagram below:

The wire experiences a force

(A) to the left

(B) to the right

(C) downwards, into the plane of the paper

(D) upwards, out of the plane of the paper

(i) The volume of a fixed mass of gas is reduced without a change in the temperature. The gas pressure increases because

(A) the gas particles are now moving faster

(B) the gas particles are now smaller

(C) there is a greater distance separating the gas particles

(D) a greater number of collisions aginst the container walls now occurs per unit time

(j) The forces which hold the molecules together in an ice crystal are called

(A) hydrogen bonds (B) covalent bonds

(C) polar covalent bonds (D) ionic bonds

(10 x 3) (30)

The rest of question 1 as well as questions 2, 3 and 4 are to be answered in your answer book.

1. (k) Five statements follow. They are all faulty in some way. Briefly state why each is faulty.

 (1) Displacement, speed, acceleration, force and momentum are all vector quantities.

 (2) A body on earth falls freely from rest. After 1 second it has fallen 10 m.

 (3) The watt is the unit of both work and energy.

 (4) The $J.C^{-1}$ is a unit of power.

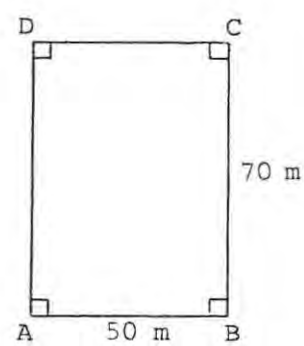
 (5) The pressure of a fixed mass of dry gas is directly proportional to its volume and to its temperature in kelvin.

(5 x 2) (10)

[40]

Answer question 2 on a new page.

2. (a) For training purposes, four markers A, B, C and D are laid out in a rectangle on a hockey field, as shown in the diagram (not drawn to scale).
Players are required to run the rectangular course from A over B, C and D and back to A.
A girl completes the first two legs in 20 s.



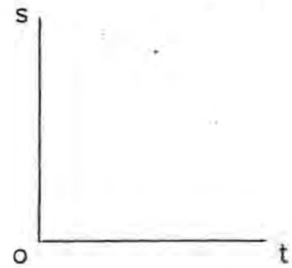
Calculate:

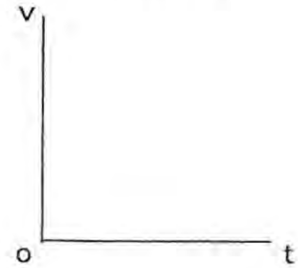
 (1) her average speed in running from A to B to C; (3)

 (2) the magnitude of her displacement from A on reaching C; and (3)

 (3) the magnitude of her average velocity. (3)

2. (b) Draw the following two sets of axes in your answer book.

1.


2.


(1) Using the displacement/time axes, draw a graph representing the motion of a body moving at constant velocity. (3)

(2) Using the velocity/time axes, draw a graph representing a the motion of a body undergoing uniform acceleration. (3)

(c) A motor-cyclist, initially travelling at 10 $m.s^{-1}$ along a straight flat road, accelerates at 4 $m.s^{-2}$ for 10 seconds.
If the combined mass of the motor cycle and rider is 250 kg, calculate:

(1) the magnitude of the resultant force on the motor cycle plus rider; (3)

(2) the speed attained by the motor-cyclist after the 10 seconds; (3)

(3) the distance covered by the motor-cyclist during the 10 seconds; and (3)

(4) the work done by the resultant force on the motor-cycle plus rider during the 10 seconds. (3)

(d) A body falling in the air from a great height reaches terminal velocity.
Name and describe the forces acting on such a body. (3)

(e) A sports car of mass 800 kg moves along a road at 20 $m.s^{-1}$. It collides with the back of a 600 kg bakkie moving in the same direction at 14 $m.s^{-1}$. On impact the bumpers of the two vehicles become locked together.

(1) Calculate:

(i) the magnitude of the momentum of each vehicle immediately prior to the collision; and (4)

(ii) the speed with which the two vehicles move immediately after being locked together. (4)

(2) What happens to some of the kinetic energy of the vehicles during the collision? (2)

/ 40 /

Answer question 3 on a new page.

3. (a) Coulomb's law may be expressed mathematically as follows:

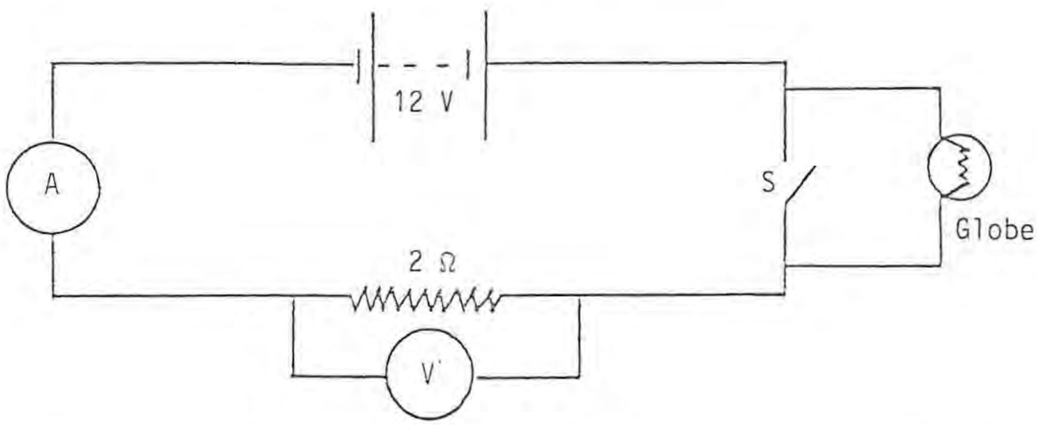
$$F = \frac{k\ Q_1 Q_2}{r^2}$$

(1) Give the units associated with each of the symbols F, k, Q and r. (4)

(2) A point charge of -4×10^{-9} C is situated in air 60 mm from another point charge of $+4 \times 10^{-9}$ C.
Calculate the magnitude of the force which either point charge exerts on the other. (5)

(3) Sketch the electric field associated with the point charges in (2) above. (3)

(b)



Note: In answering questions based on the above circuit, the effects of the resistances of the battery, wires and meters may be ignored.

With the switch (S) open, the ammeter reads 1,5 A.
Calculate:

(1) the total charge passing through the circuit in two minutes; (3)

(2) the reading on the voltmeter; and (3)

(3) the resistance of the globe when in use. (4)

The switch is now closed.

(4) What is the reading on the ammeter now? (3)

(5) What is seen to happen to the globe? (2)

(c) Explain why the element of an electric kettle should have a fairly high resistance. (3)

30

Answer question 4 on a new page.

4. (a) Listed below are four solids:

(1) calcium fluoride
(2) sulphur
(3) magnesium
(4) diamond

Write this list in your answer book and next to the name of each solid, state whether the bonding in the solid is covalent, ionic, molecular or metallic. (4)

(b) A small drop of water is carefully placed on a waxed glass slide.

(1) Describe what happens to the droplet.

(2) Describe what is likely to happen if the droplet were to contain a little soap in solution.

(3) Give a reason for your prediction in (2) above. (4)

(c) 30 g $MgSO_4$ are dissolved in water to make 2 dm^3 of solution. Calculate the concentration of the solution. (7)

/ 15 /

TOTAL : 125

APPENDIX 3

TABLE 18-1 TABLE OF SPECIFICATIONS FOR SCIENCE EDUCATION

(TWO-DIMENSIONAL MATRIX AFTER L.E. KLOPFER)

BEHAVIOR*

CONTENT	A.0 Knowledge and comprehension											B.0 Processes of scientific inquiry I: Observing and measuring					C.0 Processes of scientific inquiry II: Seeing a problem and seeking ways to solve it				D.0 Processes of scientific inquiry III: Interpreting data and formulating generalizations						E.0 Processes of scientific inquiry IV: Building, testing, and revising a theoretical model						F.0 Application of scientific knowledge and methods			G.0 Manual skills		H.0 Attitudes and interests						I.0 Orientation				
	Knowledge of specific facts	Knowledge of scientific terminology	Knowledge of concepts of science	Knowledge of conventions	Knowledge of trends and sequences	Knowledge of classifications, categories, and criteria	Knowledge of scientific techniques and procedures	Knowledge of scientific principles and laws	Knowledge of theories or major conceptual schemes	Identification of knowledge in a new context	Translation of knowledge from one symbolic form to another	Observation of objects and phenomena	Description of observations using appropriate language	Measurement of objects and changes	Selection of appropriate measuring instruments	Estimation of measurements and recognition of limits in accuracy	Recognition of a problem	Formulation of a working hypothesis	Selection of suitable tests of a hypothesis	Design of appropriate procedures for performing experiments	Processing of experimental data	Presentation of data in the form of functional relationships	Interpretation of experimental data and observations	Extrapolation and interpolation	Evaluation of a hypothesis under test in the light of data obtained	Formulation of generalizations warranted by relationships found	Recognition of the need for a theoretical model	Formulation of a theoretical model to accommodate knowledge	Specification of relationships satisfied by a model	Deduction of new hypotheses from a theoretical model	Interpretation and evaluation of tests of a model	Formulation of a revised, refined, or extended model	Application to new problems in the same field of science	Application to new problems in a different field of science	Application to problems outside of science (including technology)	Development of skills in using common laboratory equipment	Performance of common laboratory techniques with care and safety	Manifestation of favorable attitudes toward science and scientists	Acceptance of scientific inquiry as a way of thought	Adoption of "scientific attitudes"	Enjoyment of science learning experiences	Development of interests in science and science-related activities	Development of interest in pursuing a career in science	Relationships among various types of statements in science	Recognition of the philosophical limitations and influence of scientific inquiry	Historical perspective: recognition of the background of science	Realization of the relationships among science, technology, and economics	Awareness of the social and moral implications of scientific inquiry and its results
CONTENT	A.1	A.2	A.3	A.4	A.5	A.6	A.7	A.8	A.9	A.10	A.11	B.1	B.2	B.3	B.4	B.5	C.1	C.2	C.3	C.4	D.1	D.2	D.3	D.4	D.5	D.6	E.1	E.2	E.3	E.4	E.5	E.6	F.1	F.2	F.3	G.1	G.2	H.1	H.2	H.3	H.4	H.5	H.6	I.1	I.2	I.3	I.4	I.5
1.0 Biological sciences																																																
1.1 Biology of the cell																																																
1.11 Cell Structure and Function																																																
1.12 Transport of Cellular Material																																																
1.13 Cell Metabolism																																																
1.14 Photosynthesis																																																
1.15 Cell Responses																																																
1.16 Concept of the Gene																																																
1.2 Biology of the organism																																																
1.21 Diversity of Life																																																
1.22 Metabolism in Organisms																																																
1.23 Regulation in Organisms																																																
1.24 Coordination and Behavior																																																
1.25 Reproduction and Development																																																
1.26 Human Biology																																																
1.3 Biology of populations																																																
1.31 Natural Environment																																																
1.32 Cycles in Nature																																																
1.33 Natural Groups and Their Segregation																																																
1.34 Population Genetics																																																
1.35 Evolution																																																
2.0 Physical sciences																																																
2.1 Chemistry																																																
2.11 Chemical Materials																																																
2.12 Classification of Chemical Elements																																																
2.13 Chemical Change																																																
2.14 Chemical Laws																																																
2.15 Energy Relationships and Equilibrium in Chemical Systems																																																
2.16 Electrochemistry																																																
2.17 Atomic and Molecular Structure																																																
2.18 Introductory Organic Chemistry																																																
2.19 Chemistry of Life Processes																																																
2.110 Nuclear Chemistry																																																
2.2 Physics																																																
2.21 Kinematics																																																
2.22 Dynamics																																																
2.23 Energy and Its Conservation																																																
2.24 Mechanical Advantage																																																
2.25 Mechanics of Fluids																																																
2.26 Heat and Kinetic Theory																																																
2.27 Wave Phenomena																																																
2.28 Sound																																																
2.29 Light and Spectra																																																
2.210 Static and Current Electricity																																																
2.211 Magnetism and Electromagnetism																																																
2.212 Electronics																																																
2.213 Properties and Structure of Matter																																																
2.214 Theoretical Physics																																																
2.3 Earth and space sciences																																																
2.31 Solar System																																																
2.32 Stellar Systems																																																
2.33 Meteorology																																																
2.34 Physical Geology																																																
2.35 Historical Geology																																																
2.36 Geophysics and Geochemistry																																																
2.37 Oceanography																																																
3.0 General																																																
3.1 Historical development																																																
3.2 Nature and structure of science																																																
3.3 Nature of scientific inquiry																																																
3.4 Biographies of scientists																																																
3.5 Measurement																																																

* Some of the student behaviors are given here in abbreviated form. For complete wording, especially of behaviors A.10, A.11, D.4, H.3, and I.1 to I.3, see pages 565–580.