

**CONCEPTUALIZATION OF CORE
CONCEPTS IN ELECTRICITY BY PHYSICAL
SCIENCE TEACHERS**

Rufus Pako Wesi

**CONCEPTUALIZATION OF CORE CONCEPTS IN ELECTRICITY
BY PHYSICAL SCIENCE TEACHERS**

Rufus Pako Wesi, B.Sc(Ed). B.Ed.

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Supervisor: Prof. JJA Smit

Co-supervisor: Prof. NJ Vreken

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ABSTRACT

Electricity is one of the sections of physics in which students encounter difficulties. One of the main causes of this difficulty is that some teachers' own understanding of electricity is lacking. In fact, some teachers harbor misconceptions in electricity and transmit them to students. The study was aimed at probing into science teachers' conceptualization of core concepts in electricity and identify gaps and problems in their understanding. The empirical survey was conducted amongst a group of 32 science teachers registered for a Higher Diploma in Science Education in the SEDIBA Project at the Potchefstroom University for Christian Higher Education.

The investigation was done by means of a pre- and a post-test. The results of both the pre- and the post-tests were used to analyze the gaps and problems in teachers' understanding. These results indicated that teachers had problems in the understanding of electricity prior to instruction in electricity in the SEDIBA Project. Intervention by instruction resulted in improvement in teachers' understanding of concepts in electricity. Misconceptions and general problems encountered by teachers in the understanding of electricity were identified in the investigation.

SUMMARY

The study was aimed at probing into teachers' conceptualization of core concepts in electricity. Lack of knowledge and understanding of concepts by teachers is regarded as one of the major causes of problems encountered by students in the learning of electricity. The problem analysis and motivation for the study and the method of investigation were done in *Chapter 1*.

Core concepts in electricity were regarded to be those concepts which are specific to the domains of electricity. The discussion of these concepts, which broadly followed the epistemological development was done in *Chapter 2*. *Chapter 3* deals with the discussion of alternative conceptions in electricity identified from research literature. Only alternative conceptions associated with electric circuits were included in the discussion.

Chapter 4 comprises a discussion of the constructivistic approach to teaching which is currently suggested to deal with problems associated with students' alternative conceptions. The discussion of the traditional and the heuristic approaches is also included in this chapter. The syllabus and teaching strategies for the electricity course in the SEDIBA Project are discussed in *Chapter 5*. In *Chapter 6* the results of the empirical survey and discussion thereof are given. The concluding chapter (*Chapter 7*) reviews the aims, scope, methods and findings of the study and makes recommendations on how to deal with problems associated with the understanding of concepts in electricity.

OPSOMMING

Die doel met hierdie studie was om vas te stel hoe Natuur-en-Skeikundeonderwysers die kernbegrippe in elektrisiteit verstaan. 'n Onderwyser se gebrek aan kennis en verstaan van dié begrippe in elektrisiteit word beskou as een van die hoofoorsake van probleme wat leerlinge met elektrisiteit ervaar.

'n Analise van die probleem en die motivering van die studie word in Hoofstuk 1 gegee.

Kernbegrippe in elektrisiteit is daardie begrippe wat spesifiek behoort tot die studieveld van elektrisiteit. Die bespreking van hierdie begrippe, in epistemologiese volgorde, word in Hoofstuk 2 gedoen. Hoofstuk 3 is 'n bespreking van 'n literatuurstudie van alternatiewe opvattinge in elektrisiteit. Slegs die alternatiewe opvattinge, wat betrekking het tot elektriese stroombane, is bespreek. Hoofstuk 4 word aan 'n bespreking van konstruktivisme gewy. Die rol van alternatiewe opvattinge in konstruktivistiese onderrig word aangedui. 'n Bespreking van tradisionele onderrig en die heuristiese benadering is ook in dié hoofstuk ingesluit.

Die sillabus en onderrigstrategieë vir die SEDIBA-elektrisiteitskursus in die eenjarige Hoër onderwysdiploma aan die Potchefstroomse Universiteit vir Christelike Hoër Onderwys word in Hoofstuk 5 gegee. In Hoofstuk 6 word die empiriese ondersoek gerapporteer. Die slothoofstuk (Hoofstuk 7) is 'n samevatting van die doel, omvang, ondersoekmetodes en bevindings van die navorsingsprojek. Die aanbevelings met betrekking tot die hantering van konsepsuele probleme in elektrisiteit word in die hoofstuk gedoen.

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CHAPTER 1

ORIENTATIVE INTRODUCTION

1.1 Problem analysis

Various studies (Smit, 1994; Smit & Nel, 1996:4; Stanton, 1989:59) conducted recently in South Africa show that students at secondary school level experience problems with the understanding of electricity. These problems seem to occur globally as reflected in studies by Shipstone *et al.* (1988:303) in five European countries, Johnstone and Mughol (1976:467) in Scotland, and McDermott (1991:304) in the USA.

Some of the main reasons why concepts in electricity are difficult to understand are firstly, the preconceptions that students hold when entering classes on electricity (Stanton, 1989:7). Preconceptions or misconceptions, as they are commonly called, pose a serious problem in teaching and learning of electricity since they are seldom in line with scientific thinking. In most cases they are in marked contrast with what is intended by the scientists. Preconceptions are also very stable and may still persist even after the scientific concept have been taught (Thijs & Van den Berg, 1995:318). The second reason is a lack of exposure to practical work as explained by Van der Linde *et al.* (1994:48). The third reason is inappropriate teaching methods, and lastly, teachers whose own understanding of electricity is lacking (Webb, 1992:423).

The latter reason mentioned above deserves further elaboration since this study is focused on the teachers' problems in the understanding of electricity. The examiner's report of 1996 matric results of the North West Department of Education, Arts and Culture (South Africa) (1996:4) indicates that only 28,9% from the total of 6 862 candidates who sat for physical science higher grade passed. One of the reasons for this low pass rate cited in the report is the lack of suitably qualified teachers who can handle the subject matter in a proficient manner. Studies by Bradley and Stanton (1986:538) revealed that some of the *low-stream* students at the University of Witwatersrand have actually been taught wrong concepts (alternative conceptions) related to concepts in electricity such as electromotive force (emf) and potential difference by their teachers. If teachers themselves teach alternative conceptions to their pupils instead of scientific concepts, then the aim of science teaching

which amongst others, is to prepare individuals to become scientifically literate and to use and function effectively within the technological world will not be achieved. Investigation into teachers' knowledge and understanding is regarded as an inevitable exercise, if teaching and learning problems are to be addressed. The contribution of a teacher's own knowledge domain in the teaching of and in the learning done by students can not be under-estimated. This fact is acknowledged by many researchers (Smit & Nel, 1997:202, Thijs & Van den Berg, 1995:318). If teachers themselves do not possess sufficient knowledge and are not sure of what they teach, they are likely to lack confidence and motivation. This also results in poor performance by their students. The process of addressing learning problems amongst students must therefore begin by taking a closer look at the knowledge structures harbored by teachers.

This study is particularly focused on electricity since electricity constitutes an important and major part of the physical science syllabus at secondary school. The other reason for this particular emphasis on electricity is that research findings reveal that concepts in electricity are ranked high amongst concepts in physics on which students and teachers find difficulties (Johnstone & Mughol, 1976:467).

1.2 Hypothesis

The hypothesis for this study can be stated as: *physical science teachers at secondary school level generally experience problems with the understanding of core concepts in electricity.*

1.3 Motivation

Studies on problems encountered in the learning of electricity conducted recently in South Africa focused primarily on students, and little attention, if any, was given to problems and misconceptions harbored by teachers themselves. The findings by Smit and Nel (1997:205) that teachers also have conceptual problems in electricity indicates that if teachers' problems and misconceptions are ignored, the cycle of mediocrity in the teaching and learning of electricity at secondary school level cannot be broken. Smit and Nel (1997:202) maintain that a teacher's conceptual problems in electricity can be attributed to inefficient teacher

training programs. According to Adams (1995:441), science education practices cannot be enhanced in the absence of research in the domain of science teacher education.

An interest in studies on conceptualization in general has been sparked by the fact that in order to make teaching and learning more effective, it is necessary to take students' ideas and misconceptions into consideration. A teachers' own ideas and conceptualization of concepts in science and in electricity in particular are of crucial importance in the teaching and learning of students. If teachers' problems and conceptions are known, there are better chances of finding effective ways to address them. It is thus necessary to undertake research focusing specifically on teachers, to identify gaps and problems in their understanding of electricity, so that intervention strategies to address their specific problems can be attempted, thus ensuring that the need for quality science teachers in our country is addressed.

1.4 Objectives of the study

The focus of this study is on electricity at secondary school level. Specific objectives set for this study are as follows:

1.4.1 to construct a list of the core-concepts in electricity (grades 8 - 12). The basic concepts in electricity will be identified and discussed. This includes the concepts, charge, electric field and electrostatic potential in electrostatics; current, resistance, potential difference and emf in electrodynamics and electromagnetic induction in electromagnetism. Though not subjected to investigation, the concepts related to electrostatics will also be discussed since they form the basis for concepts related to electric circuits, on which the empirical investigation will be based. The concepts *energy* and *work* will only be briefly discussed but are not considered as core concepts in electricity since they are not confined to electricity. *Energy* and *work*, just like concepts such as *time* and *mass* are core concepts that cut across all sections of physics.

1.4.2 to construct a list of alternative conceptions in electricity. Alternative conceptions in electricity identified in a literature survey, through interviews, class discussions,

tests and examinations will be included in the list. Only alternative conceptions in electric circuits and electromagnetism will be included.

1.4.3 to give a brief discussion of the teaching approaches in science with particular reference to the constructivistic approach. Constructivism is an approach that has been suggested to deal with the teaching and learning problems associated with students' alternative conceptions. The discussion will be based on the rationale and the use of the constructivistic approach in the teaching and learning of science as opposed to the traditional approach. Major innovations in the historical development of science teaching, since the introduction of science as a school subject in the nineteenth century, will be attended to in the discussion.

1.4.4 to identify problems in teachers' understanding of core concepts in electricity. Teachers' understanding of the concepts related to electric circuits will be probed into. The empirical investigation will be confined to concepts related to electric circuits only, since the inclusion of concepts related to electrostatics and electromagnetism will make the scope of the study too wide.

1.4.5 to suggest intervention strategies to deal with learning problems in electricity. The fact that up to now there is no teaching strategy which can claim to have all the answers to the problems encountered in the understanding of physics and electricity concepts in particular, creates room for possibilities to be explored (Stocklmayer & Treagust, 1994: 133). Intervention strategies will be suggested on the basis of the problems encountered by teachers in the understanding of concepts in electricity, as revealed by the empirical study.

The terms *electricity*, *concept*, *core-concept*, *conceptualization* and *alternative conception* used in this study, will be described in section 1.4 below. The description of the term *constructivism* will be done in chapter 4.

1.5 Description of terms

1.5.1 Concept

A concept in science is the scientific idea underlying a class of things or events, as currently intended by the community of scientists and documented by leading textbooks. A concept acquires its meaning through its network of relationships with other concepts (Thijs & Van den Berg, 1995:318). According to White (1989:14), a person's concept about a particular label for example *energy*, is a collection of all memory elements (propositions, strings, images, episodes and intellectual skills) that a person associates with the concept label *energy*, and the pattern of their links. This model of looking at the term *concept* implies that it is possible for two people to have any degree of similarity or difference between the meanings they have for a concept. Two people have the same concept about a particular label if they have identical sets of memory elements associated with the label. Usually, sets of memory elements possessed by two individuals will not be the same even if they have been through the same learning experience, since the similarity of their concepts depends greatly on the linkage pattern between the memory elements that they possess. An individual is said to have no concept about a particular label if there is absolutely nothing that he/she can associate with the concept's label. Otherwise whatever an individual knows about a particular label, is his/her concept about that label. A concept is possessed to a greater or a lesser degree, and there is no simple answer to the question regarding the presence or the absence of a concept in the individual's cognitive domains (White, 1989:46). In science, a concept for example *gravity*, does not necessarily remain static in time, for it requires continuous modification at the advent of new compelling findings (Stanton, 1989: 5).

In this study, the term *core-concepts* in electricity relates to the concepts that are specific to the domain of electricity and can be defined operationally. Other more general concepts such as *time* and *energy* are not considered as core concepts in electricity since they cut across all sections of physics. An *operational definition* is an explanation of regularities on the basis of empirical measurements of relationships between quantified parameters by mathematical expressions (Stanton, 1989:7). Operational definitions are

useful tools for quantitative description of physical quantities. The concepts that are regarded as core concepts in electrodynamics will be identified and discussed in sections 2.1 to 2.5.

1.5.2 Alternative conceptions

It is a common practice by the scientific community to make general agreements on what a particular concept should mean. These agreements are based on valid investigations and reliable theoretical reasoning. Such agreements may take the form of an imposed definition or a generally accepted reasoning (Stanton, 1989:5). All reasoning not in line with accepted arguments are considered scientifically wrong and are referred to as *alternative concepts*. According to Thijs and Van den Berg (1995:318) an alternative conception in science refers to a conception which in some aspects is contradictory to, or inconsistent with the concept as intended by the scientists. Such inconsistencies are manifested in the manner in which individuals relate the concepts with each other. Students' own ideas and understanding of concepts are referred to as alternative conceptions if they have some robustness and persistence across ages and levels of schooling. Thijs and Van den Berg (1995:326) found that most conceptions held by students in completely different environments and cultural backgrounds are similar. This finding implies that culture and differences in man-made aspects of the environment have limited influence on the formation of concepts in physics by students. The patterns of concept formation in science parallels its historic development and have some aspect of universality. The influence of culture on concept formation may manifest itself only in remediation strategies for reducing existing alternative conceptions, but not necessarily on the formation of alternative conceptions. These findings were made in studies conducted amongst students in communities of different cultures and socio-economic background (Thijs & Van den Berg, 1995:325).

Alternative conceptions are constructed through a process of interaction between the child's cognitive system and his/her physical and social environment. As they grow up, children make observations of the world in which they find themselves. These observations are generalized and used to see them through the world - to understand and explain what happens around them and to adapt to their environment. Such observations result in the

formation of children's own understanding and ideas about what they see in their surrounding and what they learn about in science. According to Stocklmayer and Treagust (1994:133), all students have their own ideas and impressions about what they learn in science. These students' ideas are seldom in line with scientific thinking and are one of the major causes of problems encountered with in the learning of scientific concepts. Alternative conceptions are more limited and cannot be generalized and linked to other concepts as scientific concepts can. They cannot be applied consistently in different situations. Students who harbor alternative conceptions switch from one conception to another in an attempt to explain unfamiliar situations. Students may even use different arguments leading to contradicting predictions in situations which are equivalent from a scientist's point of view. These ideas of students are incoherent and *ad hoc* interpretations about natural events and are mostly naive. The problems posed by alternative conceptions in the teaching and learning of science is that they are characteristic of children's personal nature; they are also very stable and may still persist even when contradictory scientific explanation or observation is made (Driver *et al.*, 1985:2). The understanding of alternative conceptions harbored by both students and teachers will be helpful in designing more effective instructional methods, and better teacher training programs.

There are numerous synonyms for alternative conceptions. One of the most commonly used is *preconceptions*. Students' conceptions are referred to as preconceptions since they are notions and concepts held prior to systematic instruction or teaching of a new topic. Such conceptions may have been influenced by previous experiences or previous schooling in related topics. Preconceptions may not always be irrational but may lack systemization and correct explanation (Thijs & Van den Berg, 1995:318). Preconceptions are sometimes referred to as *intuitive*, *pre-instructional conceptions*, *spontaneous knowledge*, *folk knowledge* or *children's science*.

The other term commonly used to refer to students' conceptions is *misconceptions*. Recent researchers have however criticized the use of this term on the basis that it is rather judgmental and imply that prior knowledge of students is always unfounded and irrational (Stanton, 1989:5). It is interesting to note that there is very striking similarities between students' conceptions and difficulties encountered in the historical development of physics.

In fact, some of the naive ideas children have about science were at the time of the Greece regarded as science. For example, Aristotle's view of falling bodies that a heavier body will fall faster than a lighter body was considered as a scientific fact by the ancient Greece (Cajori, 1914:2). Misconceptions may arise in students' minds because of incorrect teaching or incorrectly assimilated formal instruction (Thijs & Van den Berg, 1995:318). The use of other terms such as *naive ideas*, *children's ideas* and *alternative frameworks* is common in literature. The term alternative conceptions is adopted for use in this study. More discussion of the concept *alternative conceptions in electricity* will be made in chapter 3.

1.5.3 Conceptualization

The term *conceptualization* is derived from the term *concept*. According to the Oxford English Dictionary (1980: 976) conceptualization is a mental process that involves the formation of a concept and should be peculiar to the individual who is forming the concept. Conceptualization is not found ready made in thought but is a product of the process of perceptual construction. It involves a lot more than just intuition and perception. We say we conceptualize when we cut out and fix, and exclude everything but what we have fixed. That which is to be conceptualized is implanted and is retained within mental structures and thus contains some permanence. Conceptualization may involve phenomena which cannot be affirmed and do not have objective existence, but can be expressed verbally.

1.5.4 Electricity

Electricity refers to the set of physical phenomena formally thought to be caused by a kind of fluid but now understood to be caused by the presence and motion of electrons and other charged particles. The term electricity was first used as a name for the fluid itself. It was used in this narrower sense with reference to the electricity produced by friction that produced disturbance of molecular conditions of bodies (Mendenhall *et al.*, 1956: 319).

The term *electricity* is derived from the term *elektron* which is a Greek word for amber (Gregory, 1988:37). Electricity was so named because it was thought to be a phenomenon peculiar to amber. It was later found that other substances like glass can also be used to produce electricity by friction, and that other methods such as chemical action, thermal

action, magnetism and atmospheric effects can also be used to produce electricity. Subsequent developments led to the conclusion that different sources or modes of production do not give rise to different kinds of electricity. The term electricity is used today in more broad terms to refer to the science dealing with the fundamental physical agency caused by the presence and motion of electrons and other charged particles.

Electricity forms an important part of the physics syllabus at secondary schools. Its significance in the syllabus is two fold. A study of electric phenomenon leads to the understanding of the basic properties of matter and to the understanding of the many practical applications of electricity in the modern world. An individual with an understanding of electricity will probably understand an important part of the technological and natural world in which he/she lives.

1.5.5 Physical science teachers

Physical science teachers, as referred to in this study, are teachers who teach physical science in secondary schools (grades 8 to 12). According to Brink and Jones (1981: 1) physical science can be defined as the study of natural laws and processes other than those peculiar to living matter. The grades 8 to 12 syllabus of physical science is confined to the study of physics and chemistry and does not include subjects such as geology and astronomy which are also classified as physical sciences.

1.6 Method of research

1.6.1 Literature study

Relevant literature was obtained by means of a DIALOG search on recent publications on the subject in scientific and educational journals (local and abroad). The following key words were used in the search: electricity, misconceptions, teaching, education, science teacher, conceptualization, school science, concepts in electricity and constructivism.

The literature study was done to gain an in-depth understanding of concepts in electricity, as scientists interpret and use them currently and to identify possible problem areas. The

literature study included a study of alternative conceptions in electricity held by school children, students and teachers. Constructivism, which is the teaching strategy that deals with learning and teaching problems associated with alternative conceptions, was also included in the literature study.

1.6.2 Empirical research

Data was acquired by means of a pre- and a post-test, personal interviews and observations during tuition. Student-lecturer interaction, student-student interaction and student-apparatus interaction were also observed. This part of the study relates to objectives 1.4.4 and 1.4.5. Information was also obtained from students' written assignments and their responses in tests and examination papers.

1.6.3 Population

The study was focused on a group of science teachers (N=32) enrolled part time at the Potchefstroom University for Christian Higher Education for a one year (two years part time) higher diploma in education (HDE) in science teaching. All these teachers are in possession of a three year teacher's diploma and teach physical science in secondary schools (grade 8 to 12) in different areas of the North West Province. The study was conducted during their second year of study as electricity is studied in the second year.

1.6.4 Statistical techniques

The Statistical Support Services of the PU for CHE assisted in the statistical analysis of the data.

The next chapter looks at the content of the electricity syllabus for secondary school. The discussion of the concepts is focussed on those important aspects of the subject which are generally overlooked in teaching.

CHAPTER 2

CORE CONCEPTS IN ELECTRICITY

2.1 Introduction

In this chapter the core concepts in electricity at secondary school are identified and discussed. The concepts are not necessarily introduced and presented in the same sequence as they are in the syllabus or in school text-books. The discussion will broadly follow the historic epistemological line. Aspects of the concepts which are generally not satisfactorily described in conventional text-books will be highlighted. Emphasis will be placed on areas and concepts students and teachers generally encounter difficulties on, and on aspects which are commonly misunderstood. Core concepts from areas on electrostatics, electric current, electric circuits and electromagnetism will be dealt with. The discussion of these concepts starts with electrostatics since the earliest work in electricity was on electrostatics, and since concepts in electrostatics form the base of theories in electricity.

2.2 Electrostatics

A study of electricity is usually divided into two main sections: *electrostatics* and *electrodynamics*. Electrostatics is a study of phenomena associated with charges at rest, while electrodynamics deals with phenomena related to moving charges. In sections 2.2.1 - 2.2.6 the electrostatic concepts charge, conductors and insulators, electrostatic force, electric field, field lines and electrostatic potential will be dealt with. ~~Electrodynamics~~ will be dealt with in section 2.3. We start with a discussion of the concept *charge*.

2.2.1 Charge

Charge is regarded as one of the most fundamental quantities of electricity. It is as fundamental to electricity as mass is to mechanics. Charge cannot be isolated nor made visible. It is associated with the atoms and subatomic particles of material substances. It is a property of elementary particles of matter, namely electrons, protons and muons. The quantity of charge on an object can be measured directly by means of an instrument called an electrometer. The SI unit for charge is coulomb (C).

2.2.1.1 *Historical development of the charge concept*

The development of the concept charge started in 600 BC when Thales of Miletus (640 - 546 BC), first observed that when amber is rubbed with fur, it attracted dust particles (Cajori, 1914:8). However, no significant developments on the concept were made until 1600 when Gilbert demonstrated that the same phenomenon would apply with many other substances. He showed that most non-metal substances attract small pieces of dust and paper when rubbed with silk cloth. Gilbert was the first man to use the terms *electric force* and *electric attraction*. He used the term *electrics* to refer to substances which act in the same way as amber does. A substance showing this property was said to be electrified. A substance showing no sign of electrification was said to be electrically neutral (Cajori, 1914:43). Further investigation showed that electrified bodies exerted forces on each other. In some cases they attracted and in some cases they repelled. These observations led early scientists to draw the following conclusions:

- There are two states of electrification
- Bodies in similar states of electrification repel each other
- Bodies in opposite states of electrification attract each other.

Several theories were put forth in an attempt to explain the experimental observations of electrical phenomenon. The most famous of the earlier theories are the *two-fluid theory* by Du Fay, and the *one-fluid theory* by Franklin.

Two-fluid Theory

Charles Francois de Cisternay Du Fay (1698-1739) explained the concept of electrification by assuming that there are two electrical fluids. These fluids were considered to be weightless and could be separated by friction and neutralized each other when they combine. Positive electrification was considered to be the result of addition of the positive fluid, and negative electrification as the addition of the negative fluid. A neutral body was considered to contain equal amounts of the positive and negative fluids (Cajori, 1914:117).

One-fluid Theory

In 1752, Benjamin Franklin (1706 - 1790) postulated the existence of only one electrical fluid, which he called positive electricity (Motz & Weaver, 1989:125). According to Franklin, positive electrification results from the addition of this fluid to a body and negative electrification results from the removal of this fluid from a neutral body.

During the nineteenth century, electricity was widely utilized in practical applications. Apparatus such as the Kelvin Replenisher, the Wimshurst Machine and the Van de Graaff generator were manufactured and used (Duncan & Starling, 1957:926). It is amazing that the theory and practical application of electricity was well developed before the fundamental charge carrier, the electron was discovered. The discoveries of Christian Oersted (1777 - 1851) in 1819 and Michael Faraday (1791 - 1867) in 1831 led to large scale generation of electricity using coal, oil or water powered power stations, and to the use of electric current to run electric motors. In 1873 James Maxwell (1831 - 1879) summarized the theory of electricity and magnetism in his famous four equations (Cajori, 1914:253). The Maxwell's equations are still regarded as fundamental to the theory of electromagnetism. In 1897, Joseph John Thomson (1856 - 1940) discovered an "electrical entity" later called an *electron*, and described most of its properties. This discovery led to the explanation of electricity in terms of the nature of the atom.

In 1906, Robert Millikan (1868 - 1953) determined the magnitude of the electronic charge to be $-1,6 \times 10^{-19}$ C (Mendenhall *et al.*, 1956: 444). Since Millikan's findings, an electron was regarded as the most elementary charge. A recent theory formulated by Murray Gell-Mann (1929 -) in 1962 predict the existence of six types of quarks with fractions ($-/+ 1/3$ and $-/+ 2/3$) of the electron charge (Motz & Weaver, 1989:349). This finding suggests that any magnitude of charge is an integral multiple of these elementary values. The existence of all six types of quarks have been recently verified by experiment (Smit, 1992:100). For the secondary school level, an electron is however considered to be the most elementary charge carrier. It is important to note that an electron is not charge itself. Charge is in the same way as mass, a property associated with an electron. An electron has mass too.

2.2.2 Conductors and insulators

In 1729, Stephen Gray discovered that electric charge can be transferred from one body to another, if the bodies are connected by certain substances (Cajori, 1914:117). These substances, through which charges can move freely, were called *conductors*. Conduction of electricity can be explained as follows: each atom of a conductor (of which metals are good examples) has one or more free electrons. These free electrons, although bound to the conductor as a whole, may wander freely throughout the interior of the conductor, in much the same way as the molecules of a gas can move through space between grains of sand in a sand-filled container. The positive nuclei and the electrons bounded to them, remain fixed in position inside their individual atoms (figure. 2.1).

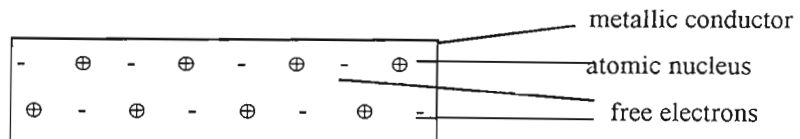


figure 2.1

The application of an external electric field will cause all the free electrons to move in the same direction in the conductor. This movement of charge is called the *electric current*.

Examples of common conductors are metals, liquids having dissociated ions (electrolytes) and plasmas. The conductivity of substances vary, for example the metals gold, platinum, silver, aluminium, tungsten and copper are all good conductors, with platinum being the best conductor and tungsten the worst. Conductors cannot be charged by rubbing because of the freedom of movement of their electrons. Charge separation is not possible as electrons are instantly relocated and uniformly redistributed when conductors are rubbed.

Substances through which charges do not flow easily are called *insulators*. Examples of insulators are glass, rubber, plastic and dry wood. Electrons in the atoms of insulators are firmly bound to their parent nuclei. Electrons can only be removed from atoms of insulators when sufficient energy (for example by friction) is supplied to them. The energy needed to separate an electron from an atom in an insulator is much larger than the energy needed to move free electrons in a conductor. A charge will remain at a specific point on which it is placed on the surface of an insulator, while an additional charge spreads throughout the surface of the conductor. Because of these properties of conductors and insulators, metallic material such as copper and aluminum are

used to conduct (transport) electricity from power stations to factories and homes. Supports that attach wires to poles consist of insulators such as glass, or ceramic to prevent any leakage of charges to the ground or to other objects. Electrical wires in homes and in electric appliances are covered with insulating plastic material to prevent charge leakage upon contact with any conducting material.

Nature was provided (and technology has added) with material substances whose ability to conduct charge ranges between conductors and insulators. A particular group of material which lies somewhere between the good conductors and insulators is known as *semiconductors*.

Semiconductors can only conduct a limited flow of charge. A good example of a semiconductor is silicon. Semiconductors are of vital importance in the modern electronic industry. TV's, telephones, computers and electronic watches are examples.

2.2.3 *Electric force*

There are four fundamental forces in nature: gravitational forces; electromagnetic forces; weak nuclear forces and strong nuclear forces. Scientists (physicists) are constantly trying to find a theory that will unify all these forces. The ultimate goal is to reduce all these forces to a single force. The unification of these forces will enable the description of all natural phenomena by means of a single theory referred to as the *Grand Unification Theory (GUT)* (Hawking, 1988:79). The electromagnetic forces are a unification of the magnetic forces and electric forces. Magnetic and electric forces are related since moving charges (current) gives rise to magnetic field. An elaborate discussion on the relationship between moving charges (current) and magnetism will be made in section 2.5. The weak and the strong nuclear forces have also been recently unified. In this study we will however treat the electric and the magnetic forces as two separate forces since they are treated as such at school.

Like gravitational and magnetic forces, the electric forces are examples of forces that act at a distance. However, electric forces are different from gravitational forces for they involve both attraction and repulsion, rather than the simple attraction of gravitational force. Even more striking is the fact that electrical forces are billions and billions of times stronger than the gravitational forces. The presence of electrical forces (forces between charged bodies) has been known since the time of the early Greeks. The earliest recorded discovery of these forces was made by Thales of Miletus (640 - 546 BC) in 600 BC (Cajori, 1914:8).

The nature of the dependence of electric force on distance of separation between charged bodies was investigated by Charles de Coulomb (1736-1806). He revealed that the electric forces between two charged particles depend on the magnitude of the charges and on the distance between them in the same way as gravitational forces do. This relation is summarized in Coulomb's law which states:

The magnitude of the electric force that a charged particle exerts on another charged particle is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

Mathematically
$$F = k \frac{Q_1 Q_2}{r^2}$$

Where F is the force between charges Q_1 and Q_2 that are separated by a distance r (figure 2.2),

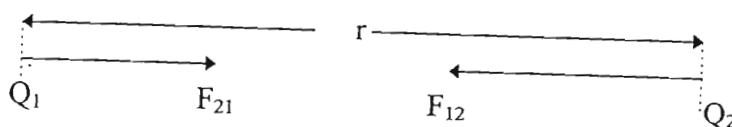


figure 2.2

and k is the proportionality constant. The value of k is

$$k = 8.99 \times 10^9 \text{ N.m}^2 / \text{C}^2$$

The electric force (F_{12}) that the particle of the charge Q_1 exert on that of Q_2 has the same magnitude as the force (F_{21}) exerted by Q_2 on Q_1 but opposite in direction, according to Newton's third law. A common misconception is that in the interaction between a large and a small charge, the larger one exerts a larger force.

$$F_{12} = - F_{21}$$

Usually when electrostatics is introduced to pupils, use is made of the demonstration whereby a rubbed plastic or glass rod is used to attract uncharged bits of paper. Children are often confused by this observation. According to them, only charged substances can be attracted by charged substances. They wonder how it is possible that a charged plastic or glass rod can attract uncharged bits of paper. The confusion that arises in pupils' minds as a result of this observation gives rise to two mental processes. Firstly, they could think that the bits of paper get charged

during the tearing process. Secondly, they could think that physics is inconsistent as uncharged bodies sometimes get attracted to charged bodies.

This attraction of neutral bits of paper occurs as follows:

When a charged rod, say a positive glass rod is brought in the vicinity of uncharged small bits of paper, charge separation takes place in each piece of paper. The negative charges on each piece of paper are attracted and drift to the end near the rod and an equal number of positive charges are repelled and drift towards the far end of the paper. Attraction thus exists between the negative side of each piece of paper and the positive glass rod. This attraction of neutral bits of paper deserves a more detailed account.

Since there is an equal number of positive and negative charges on each bit of paper, one would expect the forces of attraction and repulsion between the paper and the glass rod to cancel out. But this does not happen. The charge separation on the bits of paper results in negative charges being nearer to the positive charges, and positive charges being further away from the rod. As a result, the force of attraction between the negative charges on the bits of paper and the positive charges on the rod is stronger than the force of repulsion between the positive charges on the bits of paper and those on the rod. The net force on each bit of paper will then be attraction towards the rod.

This explanation is omitted in most school text books currently in use. As a result, teachers, who tend to depend on text books for information, and consequently students, lack clear understanding there of.

2.2.4 *The electric field*

2.2.4.1 *Qualitative description of electric field*

In 1838, Michael Faraday (1791 - 1867) described the interaction of charges over an intervening space in terms of a *field* surrounding electric charges rather than as charges interacting over large distances as Coulomb did (Thomas, 1991:60; Gregory, 1988:39). If a very small positive charge q (usually called a test charge) is placed a distance r from a large negative charge Q which is held stationary, in terms of Coulomb's description, we say that q gets attracted to Q and respond by moving towards Q (remember that Q also gets attracted to q with the force of the same magnitude according to Newton's third law). This attraction is as a result of action at a distance (*figure 2.3*).

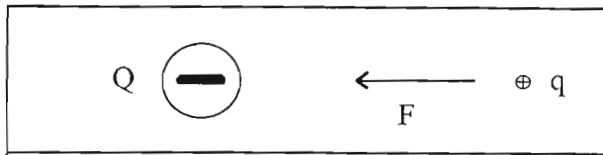


figure 2.3

According to Faraday's description, q does not respond to the distant Q , but to a field of influence produced by Q and distributed throughout space (*figure 2.3*). That is, the force F experienced by q is exerted by the field rather than directly by Q . The electric field exists at all points in the region around Q and diminishes with the square of the distance from Q . Thus any charge placed in the vicinity of Q experiences a force as a result of the field due to Q . Similarly, Q experiences a force as a result of the field due to q . Thus any charge generates an electric field which permeates the surrounding space and exerts a force on any other charge placed in its vicinity.

The existence of an electric field at any point can be tested by placing at that point a small positive test charge. If a test charge experiences an electrical force, then an electrical field exists at that point. An electrical field may thus be defined as *a region in space in which a charge will experience electrical force*. Electric field is a vector field. The direction of the fields depend on the sign of the charge generating the field. By convention, a positive test charge is used to determine the direction of the electric field. The direction of the field is the same as that of the force acting on a positive test charge. Thus if the charge generating the field is a positive point charge, then the field is directed radially outwards from the charge, and directed radially inward if the source of the field is a negative point charge.

2.2.4.2 Electric field lines

In an attempt to aid in visualizing the electric field, Faraday introduced the concept of *field lines* which are imaginary lines in space, showing at every point the direction in which a small positive test charge will tend to move (Mendenhall *et al.*, 1956:233). Field lines can be represented by means of a diagram drawn in such a way that the tangent to the line point in the same direction as that of the field at that point. An electric field line is *a line drawn in such a way that a tangent to the line at any point gives the direction of the force on a positive test charge when placed at that point*. A positive test charge q placed in the field of a positive point charge Q will experience a

force directed radially away from Q . The field lines generated by a positive point charge are directed radially outward (*figure 2.4*).

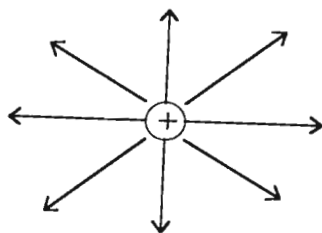


figure 2.4

A small positive test charge q placed in the field of a negative point charge experiences a force pulling it radially inward towards the point charge. Hence the field lines around the negative point charge are directed radially inward (*figure 2.5*).

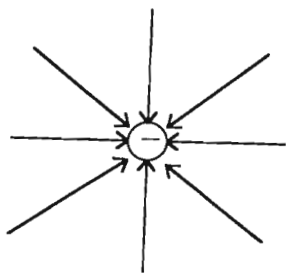


figure 2.5

A misconception that might be created by the field line diagrams is that the electric field is planar. The field is actually in three dimensions with lines spreading out in all three directions of space. The field lines of a charged metallic sphere will thus be perpendicular to the surface of the sphere. The diagrams however show the lines spreading out in only two directions. This limitation of two dimensional diagrams should be kept in mind. The field due to a charged plate is directed perpendicular to the plate (*figure 2.6*).

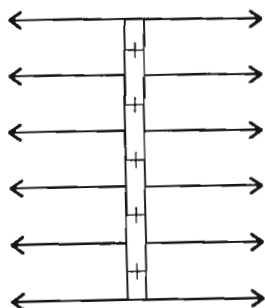


figure 2.6

2.2.4.3 Quantitative description of electric field

If a test charge q is placed in the electric field E , it will experience a force equals to F (figure 2.3). Electric field strength can be defined as *the force per unit positive charge*.

$$E = F/q$$

The electric field strength depends on the magnitude of the test charge used to detect it. For practical purposes, we assume that the test charge q does not change the original distribution of the charges generating the field. This will be true in practice if q is so small that its influence on the original charge distribution of Q is negligible (figure 2.3).

2.2.4.4 Electric field strength between two parallel charged plates

Consider a special case where a small test charge q is placed between two parallel plates, carrying equal but opposite charges and a distance s apart (figure 2.7).

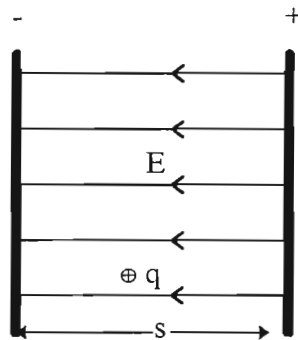


figure 2.7

When the external force is applied to move the test charge q against the field from negative plate to the positive one, the amount of work done is given by

$$W = F s$$

Since electrostatic force $F = q E$,

$$W = q E s$$

The work done per coulomb (V) would be

$$V = W/q = E s$$

$$\text{Thus } V = E s$$

$$\text{and } E = V/s$$

According to the above equation, the electric field strength between two parallel charged plates depends on the voltage (voltage will be defined in section 2.4.6) supplied across the plates and the distance (s) between the plates. Thus the electric field is uniform at all points between the plates.

2.2.4.5 Electric field due to point charges

To give a mathematical description of an electric field due to point charges, we begin with Coulomb's law :

According to Coulomb's law, the force exerted by Q on q (*figure 2.8*) is given by

$$F = k \frac{Qq}{r^2}$$

The quantity of q is characteristic of the charge on which the force is being exerted, and the quantities k, Q and r^2 are characteristic of the field that exerts the force. This reasoning was made by Michael Faraday in 1837 (Thomas, 1991:60).

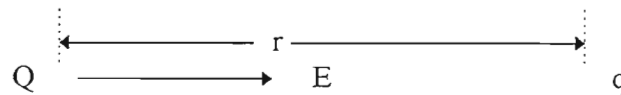


figure 2.8

Thus the term $k \frac{Q}{r^2}$ gives the magnitude of the field exerting the force on q.

Thus $E = k \frac{Q}{r^2}$

The unit for electric field is $\frac{\text{newton}}{\text{coulomb}} = \text{N/C}$

2.2.5 Electrostatic potential and energy in the electric field

It was mentioned in section 2.2.3 that if a small positive charge (very small as compared to the charge or system of charges generating the field) is placed in an electric field, it experiences a force. If this charge is free to move, it will move in the direction of the electric field lines.

As the charge moves freely only under the action of the electric field, its potential energy decreases. This energy (called electrical potential energy) is stored in the electric field and is

possessed by any charge (whether free to move or not) placed in the field. If free to move, charges move under the action of the field so as to minimize their electric potential energy (*figure 2.9*).

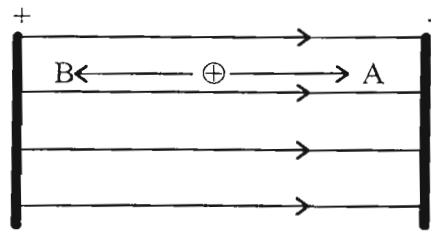


figure 2.9

Movement in the direction A: potential energy decreases

Movement in the direction B: potential energy increases

In terms of the above discussion, electric potential (V) can be defined as *the electric potential energy possessed by a unit positive charge q or simply as the electric potential energy per unit positive charge*.

$$\text{Mathematically: } V = U/q \quad (\text{Where } U \text{ is the electric potential energy})$$

The SI unit for electric potential per unit charge is the volt (V).

$$1 \text{ volt (1 V)} = 1 \text{ joule/coulomb (J/C)}$$

2.2.6 *Electric potential and work*

Since a charge placed in the electric field possesses a certain amount of electric potential energy, it has the potential (ability) to do work. In order to further understand the concept of electric potential and work in the electric field, consider the diagram below. Charges Q_1 and Q_2 are fixed while q is moved at a constant speed from A to B by some external force (*figure 2.10*).

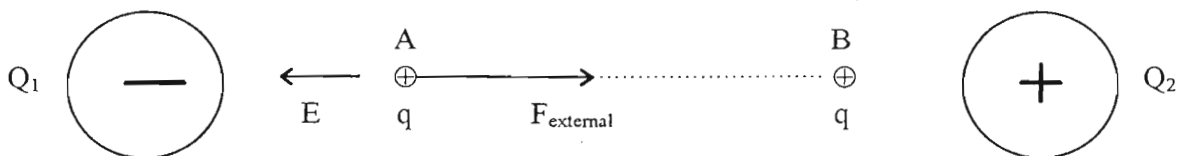


figure 2.10

Point B is at a higher potential than point A, and the direction of the field is towards Q_1 .

The external force F is doing work on q , moving it against the field from a point at lower potential to a point at higher potential. Thus q experiences an increase in potential energy. The work done on q , to move it from A to B ($W_{A \rightarrow B}$) is equal to the difference in electric potential between A and B ($V_B - V_A$).

Work done per unit charge = Electric potential difference

$$\frac{W_{A \rightarrow B}}{q} = V_B - V_A$$

The significance of the above relation is that if the work required to move a unit positive charge from one point to the other in the electric field is known, the work required to move any charge q at a constant speed from A to B can be easily specified.

Using the above relation, it is

$$W_{A \rightarrow B} = q(V_B - V_A)$$

The potential difference between points A and B (V_{AB}) can thus be given by

$$V_{AB} = \frac{W_{AB}}{q}$$

It can thus be said that the *work* done on an electric charge produces a change in the potential energy of the charge. This action is analogous to lifting a mass from a lower point to a higher point against the gravitational field of the earth (Halliday *et al.*, 1993).

It must however be noted that despite the fact that the description of electric potential difference is analogous to that of gravitational potential difference, some inconsistency does exist between the two descriptions. Both electric and gravitational potential difference of the ground are regarded as zero. The discrepancy between the two descriptions is that gravitational potential difference is described relative to the ground while no reference to the ground is made in the description of electric potential difference in electric circuits. Closely related to this inconsistency are the concepts of electric potential energy and gravitational potential energy.

2.2.7 *The electric field in modern physics*

The electric field and field lines models are useful to predict and explain a specific set of physical phenomena. In modern physics the concept of electric field leads to unacceptable predictions. In quantum electrodynamics it leads to predictions of infinity of quantities known to be finite, like

the mass of the electron. These so-called divergences cannot be ignored as they lead to predictions of infinity for other observable quantities, such as energy shifts of spectral lines. The infinite mass for a point electron comes about in both quantum electrodynamics and classical electrodynamics as a result of the electron's own field on itself. According to Feynman the problem can be solved by simply eliminating the field concept (Brown & Rigden, 1993:7). This however, solved one set of problems and created another: in the absence of an electric field a hot body would radiate heat without losing energy. Wheeler and Feynman ultimately solved the problem by formulating a relativistic principle of least action. This development in modern physics illustrates that the field concept is a concept with limited use, although it may not appear to be such in introductory physics courses.

2.3 Electrodynamics

2.3.1 Introduction

Our study of electricity thus far has been concerned with electrostatics which involves stationary charges. Electricity however, involves a lot more than just charges at rest. In this section, we look at electrodynamics which is concerned with *charges in motion*.

2.3.2 Historical background

Investigations in electricity since the time of the ancient Greece was confined to electrostatics until about 1790, when the study of current electricity began (Cajori, 1914:117). The first discovery of electric current on record was made by Du Fay and Gray in 1729. They showed that static electric charges could be carried from one body to another by means of substances called conductors (section 2.2.2). This movement of charges constitute *electric current*.

The current discovered by Du Fay and Gray was of little practical use, as it was very weak and lasted only for a moment. Experimenting on this current was therefore a limited exercise. Although static electricity played an important part in the early understanding of electricity, the field remained relatively unproductive until three significant developments in current electricity were made. First came the invention by Volta of ways to produce continuous current by chemical means. Next was the discovery of the magnetic effect of an electric current by Oersted. Finally the discovery of electromagnetic induction by Faraday which made large scale production of currents a possibility (Mendenhall *et al.*, 1956:352). We begin with the discussion of the animal electricity, which led to the invention of the means of producing constant current.

Animal electricity

In 1780, Luigi Galvani (1737 - 1793) while dissecting a frog found that he could make the muscle of the dead frog twitch (make a quick movement) by touching the main nerve of the frog's leg with a dissecting knife and some other metal instrument simultaneously. Galvani explained this effect as coming from the muscle nerve system. He referred to this effect as *animal electricity* (Mendenhall *et al.*, 1956:353).

The voltaic pile

Upon observing the effect of animal electricity, Volta (1757 - 1827) argued that a frog was not necessary and that a similar effect could be shown using suitable metals separated by a damp cloth containing a salt solution (Mendenhall *et al.*, 1956:353). Volta continued experimenting along these lines and in 1800 he produced what was called the *voltaic pile*. This consisted of discs of zinc and silver separated by paper sheets soaked in salt water. Placing one hand on the top disc and the other on the bottom disc of the voltaic pile, a small electric shock was felt. Later, instead of using paper soaked in salt water, cups containing salt water were used and the two metal rods (zinc and copper) were inserted in the cup. This was the first battery and it could give rise to continuous or direct current. The invention and development of batteries provided sources of continuous electric current. This was a major breakthrough as previously only small pulses of electric current could be acquired from electrostatically charged objects. Batteries were soon used to study phenomena associated with electric current.

2.3.3 What makes charges flow?

What makes charges move through conductors?

It was mentioned in section 2.2.5 that if a charge q placed between Q_1 and Q_2 (*figure 2.11*) is free to move, it will move under the action of the field in such a way that it attains the minimum possible electric potential energy (Think of a mass piece which falls spontaneously when released from a certain height).

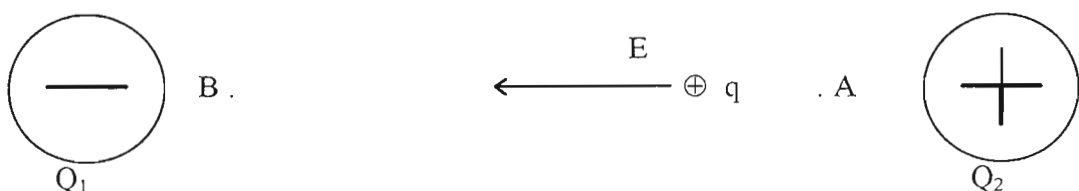


figure 2.11

Note that A and B are at points of different electric potential, hence electric potential difference exist between these two points. In other words, there is "electric tension" between points A and B which propels q to move towards B. The movement of q from A to B is analogous to the fall of a mass piece from a higher point C to a lower point D (*figure 2.12*).

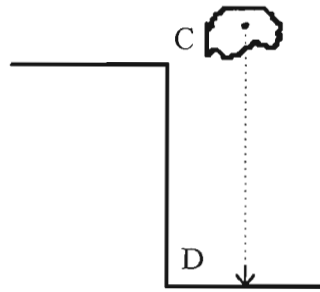


figure 2.12

The fall of the mass piece is made possible by the gravitational potential difference ("gravitational tension") that exist between points C and D (*figure 2.12*). In the same way, charges move through conductors under the action of an electric field when the electric potential difference ("electric tension") exists between the ends of the conductor.

How can an electric field be generated inside the conductor so as to make charges move?

If electric charges of opposite signs are suddenly deposited on the opposite ends of the conductor, a potential difference will appear between the ends of the conductor. The field will thus be generated inside the conductor. This field will drift the charges such that their electric potential energy is reduced. The drifting of charges takes place very rapidly in good conductors, and results in transient (momentary) current in the conductor.

If opposite charges are continuously supplied on opposite ends of the conductor (thus maintaining electric potential difference across the ends of the conductor), a continuous drifting (flow) of charge will result.

How can potential difference be continuously maintained across the ends of the conductor so as to get a continuous flow of current?

It can be done by connecting the ends of the conductor to the terminals of a source of electric energy such as a battery or an electric generator.

2.3.4 *Electric current*

When the ends of a conductor are connected across the terminals of a battery, charges are propelled from one end of the conductor to the other by the electric field that exist within the conductor. The field lines originate at the positive terminal and end at the negative terminal of the battery.

Electric current is a physical quantity whose magnitude depends on the rate of flow of charge. The more the charge flowing through a given point in a conductor, the more the current. Electric current (I) is thus defined as the rate of flow of charge (Q), and mathematically by:

$$I = Q/t$$

The SI unit of current is the ampere (A).

An ampere in the SI is formally defined as *that constant current which, when flowing in each of two parallel conductors of infinite length and 1 m apart, in a vacuum, produces between them a force of 2×10^{-7} N per meter of length.*

The coulomb as a unit of charge is then defined in the SI unit as *that amount of charge that flows in one second past a point in a conductor carrying a current of one ampere*

2.3.5 *Current in conductors*

It was mentioned in section 2.2.2 that conductors are substances through which charges can flow. In metals, the moving charge carriers are electrons. Thus current in metallic conductors is simply the movement of electrons. In conducting salt solutions (electrolytes), charge carriers which take part in the conduction process are positive and negative ions. In this case, current is simply the flow (migration) of ions. In p-type semi-conductors positives "*holes*" constitutes the current. As this is beyond the scope of school syllabi, this type of conduction will not be dealt with in this study. The explanation of electrical conductivity in quantum mechanical terms is rather complicated.

2.3.6 *The conventional current*

The concept of charge was introduced in the discussion of electrostatics. Its nature with reference to the atomic and molecular structure was revealed when the difference between conductors and

insulators was explained. It was mentioned that by virtue of their freedom of movement, negative electrons in metallic conductors are the ones that take part in the process of electric conduction. How can the conventional current model, which assumes the flow of positive charges, be visualized?

Scientists use models to explain, describe and predict phenomena. According to Smit and Nel (1997:202), there are three types of models in physics. The first type relates to real existing entities. Examples of such models are molecular and atomic models. All these entities have real objective existence. The second type of model relates to hypothetical entities which may or may not exist. If the existence of the entity concerned can be proved, its status will change to that of the first type. On the other hand, if proof of its non-existence is given, its status changes to that of the third type which do not relate to any real or hypothetical entity.

The third type of models are mostly inherited from history and are widely established by a long period of usage as explained by Stocklmayer and Treagust (1994:134). The use of some of these types of models is retained for specific purposes. The conventional current is one such a model (third type). Its origin can be traced back historically to the two fluid and one fluid models of Du Fay and Franklin respectively. According to the conventional current model, current is considered to be the flow of positive charges from the positive terminal of the battery through the circuit to the negative terminal. This must not be seen as a current in which any real charges (for example protons or electrons) or hypothetical particles are involved. It does not represent any real existing current.

While the electron current model is instrumental in describing the conduction mechanism at microscopic level, the conventional current model has been adopted for the purpose of quantitatively describing the transfer of energy in circuits. No knowledge of the microscopic nature of conducting particles is required in the description of energy transfer in circuits and in defining the concepts emf, potential difference, resistance and current (Smit & Nel, 1997:202). The conventional current model is suitable for this purpose since it enables the explanation of energy transfer in circuits in the manner consistent with descriptions of energy transfer in electrostatics and in other branches of physics.

Smit and Nel (1997:202) explain the reason why the current model which relates to real existing entities is not suitable for describing energy transfer as follows:

Consider the movement of charge carriers at microscopic level in a simple circuit consisting of a battery connected to a fluorescent lamp by means of a copper wire. The electrons in the copper wire move from the negative terminal of the battery to the positive terminal. In the fluorescent tube and in the battery, the positive ions and the negative ions move in opposite directions. This situation makes it very difficult to precisely tell the direction in which current is flowing if real charge carriers are to be considered. Describing the direction of the flow of current by means of electron flow will lead to complications and does not fully describe what takes place in this circuit. Describing the energy transfer by considering the flow of every type of charge would also be very complicated. It is thus necessary to adopt a convention for current as a flow of positive charge to address this problem. According to this model, a positive charge flows from a point at higher electrical potential to a point at lower electrical potential. This description is in line with the description of energy changes in mechanics, where a body moves from a point at higher gravitational potential to a point at lower gravitational potential, when left to itself.

The other advantage of using the conventional model is that it enables unambiguous description of the direction of the force acting on the current carrying wire in a magnetic field, and the direction of the magnetic field around a current carrying wire.

In the teaching of electricity and physics in general, care must be taken not to work with more than one model applicable to the same situation simultaneously. This practice usually gives rise to logic problems and destroys understanding (Smit & Nel, 1997:203). In section 2.3.7, conduction mechanisms will be described by means of the microscopic model. Energy transfer in electric circuits is usually described in terms of a macroscopic model. When both models are applied simultaneously conceptual problems may arise.

2.3.7 Cells and batteries

It is a well known fact that cells and batteries are the sources of energy in electric circuits.

But where does the cell get its energy from?

When two oppositely charged objects are joined by means of a conducting substance, current is produced as charges flow from one object to the other. This current only last for a short while. For electric current to serve a useful purpose, it must be produced in large quantities, and last much longer. Cells and batteries are able to produce long lasting currents, large enough to be of practical use.

The flow of charge through conductors is due to the electric force exerted on the charges by the electric field. In other words, electric potential difference must be maintained across the ends of the conductor, meaning that excess negative charges must be continuously supplied at one end of the conductor while excess positive charges are continuously supplied on the other end. In principle, this could be achieved by continuous rubbing, using machines perhaps. In fact, until 1800, electricity was only produced by means of rubbing. Various kinds of electric machines were manufactured, for example, the Wimshurst Machine, the electrophorus and the Van de Graaff Generator (Mendenhall *et al.*, 1956:337).

More efficient batteries are made today, using the same principle that Volta used. Let us take a closer look at how the chemical processes that take place inside the battery give rise to the tension (or the potential difference between the terminals of the battery) that propels charges through conductors.

Charges do not move through conductors on their own. A continuous supply of some form of energy is required to sustain their flow. The cell/battery performs this function of continuously supplying energy to charges so that they can move through conductors. This energy is supplied by maintaining a potential difference between the ends of a conductor.

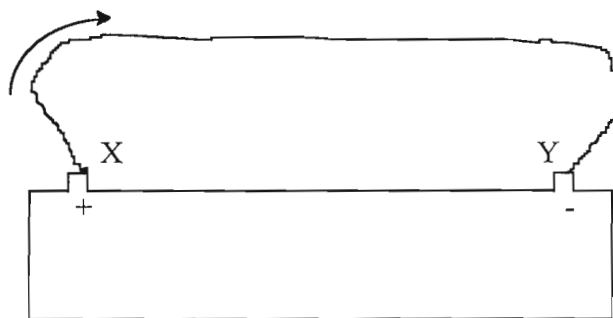


figure 2.13

The potential energy of charges (positive) at point X (the positive terminal of the battery), in the electric field is higher than at Y (the negative terminal) (*figure 2.13*). When charges move in the conductor, energy is transferred to the conductor. When these charges reach the other end of the conductor, this potential energy is increased again when passing inside the cell from the negative to the positive terminal. This cycle is repeated over and over again.

How is potential difference between the terminals of a cell maintained?

A simplified cell consists of an anode (usually lead or zinc) and a cathode (usually copper or silver) dipped in a suitable salt/ acid solution called an electrolyte. The cathode undergoes spontaneous chemical disintegration and sheds positive ions into the solution, making the anode negatively charged. On the other hand the positive ions in the electrolyte are spontaneously absorbed by the anode, thus making the cathode positively charged.

In short, the ability of a cell to maintain a potential difference between its two terminals depends on three factors:

- the ability of the cathode to shed positive ions when inserted in a suitable electrolyte.
- the ability of the anode to *absorb* positive ions when inserted in a suitable electrolyte.
- The *freedom* with which the positive and negative ions can migrate between the two electrodes through the electrolyte.

Where does the energy that makes the cathode to spontaneously shed its positive ions come from?

The positive ions are released by the cathode at the expense of the chemical potential energy that is stored in the chemical bonds. The same applies for the negative charges at the anode. In brief, the cell does the work of maintaining the potential difference between its terminals, by separating the positive and negative charges. In the process, the chemical potential energy is converted to electrical potential energy. This electric potential energy can then be used to transfer charges through external wires, when connected across the terminals of a cell/ battery.

The instrument used to measure electric potential difference across the terminals of a cell/ battery or any circuit component is called the *voltmeter*. The voltmeter reading gives an indication of the electric energy that the cell/ battery can supply (when connected across the terminals of a cell/ battery), and also gives an indication of the energy transferred to a circuit component, when connected across its terminals.

2.4 Electric circuits

2.4.1 Introduction

A simple electric circuit consists of a cell or battery, connecting wires and an electric bulb or any other electric device. A switch usually forms part of an electric circuit. A good conductor such as *copper* is commonly used in connecting wires.

The primary purpose with the construction of electric circuits is to enable practical use of the electrical energy stored in the cell or battery. The circuit provides the path through which energy can be transported to the electrical device connected to the circuit (for example an electric bulb or a motor). In sections 2.4.2 - 2.4.6, the concepts current, resistance and emf are discussed. All these concepts are defined by scientists with the specific purpose of quantitatively describing energy transfer in electric circuits.

2.4.2 Current strength in electric circuits

It was mentioned in section 2.3.6 that current is considered to be the flow of positive charges from the positive terminal of the cell to the negative terminal (the conventional current model). This model will be consistently used in section 2.4.

Consider the circuit diagram below (*figure 2.14*).

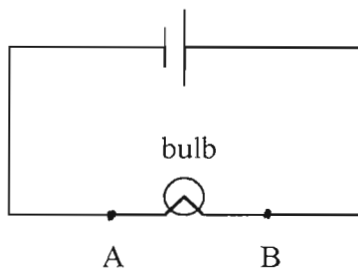


figure 2.14

Taking measurements of current simultaneously at different points A and B in an electric circuit reveals that the current entering the bulb is the same as the current emerging from the bulb. This implies that current is not consumed by the bulb.

What then gives rise to the light given off by the bulb if current is not consumed by the bulb?

The glowing bulb converts the energy that is stored in the cell/ battery into light and heat energy.

What then is the role of current in electric circuits?

2.4.4 Ohm's law

The first systematic investigation of the effect of potential difference on the current through a conductor was made by Georg Ohm (1787 - 1854) (Horn *et al.*, 1987:99). He formulated the results of his findings into a law now called by his name: *the ratio of the potential difference across the ends of the conductor to the current through the conductor is a constant, provided the physical conditions of the conductor remains constant.*

The ratio of the potential difference to the current was defined as the resistance of the conductor in section 2.4.3 above. There is confusion between Ohm's law and the definition of resistance.

The resistance of a piece of conducting wire carrying a current I and with a voltage V across its ends, can be easily determined using the ratio V/I . This ratio needs not be a constant. Experiments show that this ratio will only be a constant for a group of metal conductors, called *ohmic conductors*. This group of conductors is called such because they obey Ohm's law. There are however conductors for which Ohm's law does not hold. Such conductors are called *non-ohmic conductors*. For some of these substances, the ratio increases with increasing voltage and for some, the ratio decreases with increasing voltage (O'Sullivan, 1980:239).

The significance of Ohm's law is that it predicts that under constant physical conditions, the resistance of a conductor is independent of the potential difference across it and the current through it. The *physical conditions* referred to in this case include temperature and tension of conductors. Other factors such as bending and changing the shape of conductors can also significantly influence its resistance. Temperature is the most important of these conditions.

The relationship between current and potential difference across the ends of a conductor can be illustrated by plotting the readings of potential difference versus current on a graph. The graph shows that the potential difference (V) across the ends of the conductor is directly proportional to current (I) flowing through it (*figure 2.15*). These results will be obtained only in the case of ohmic conductors. The graph for non-ohmic conductors will show deviations from the straight line graph obtained in the case of ohmic conductors.



figure 2.15

The gradient of the graph in *figure 2.15* is the ratio V/I which by definition, is equivalent to the resistance of the conductor. It is a common practice in physics to put the readings of independent variables on the x-axis and that of dependent variables on the y-axis when plotting graphs. In this case the current readings are on the x-axis and that of potential difference on the y-axis. This practice gives a misleading impression that current in an electric circuit is an independent variable, and gives rise to potential difference. Current and potential difference are plotted as such in this case to enable the calculation of the resistance of the conductor from the gradient of the graph.

The correct causal relationship between current and potential difference in an electric circuit is that potential difference gives rise to current. Current cannot flow through a conductor if a potential difference does not exist between the ends of the conductor. Research studies show that many students' reasoning on electric circuits is current orientated. They use Ohm's law incorrectly and see current as the primary concept in circuits, while potential difference is seen as a consequence of current flow, and not as its cause (Cohen *et al.*, 1983:407).

2.4.5 Factors affecting the resistance of metallic conductors

Through experiments it has been established that there are four factors which affect the resistance of conductors: the type of conductor used; the length of the conductor; the thickness of the conductor and the temperature of the conductor. The resistance of conductors is influenced by these factors in the following manner:

- *the type of conductor used*: some substances are better conductors than others, e.g. copper is a better conductor than nickel. Thus nickel has higher specific resistance than copper.
- *the length of the conductor*: the longer the conductor the more the resistance.
- *the thickness of the conductor*: the thicker the conductor the less the resistance.

The potential energy of charges at the positive terminals side is higher than at the negative terminal. When the charges go through the bulb the potential energy is converted to light and heat.

Current returns unaltered to the cell/ battery. The more the current in the circuit the more the energy supplied. The energy converted at the bulb can be increased by connecting more cells in *series*. If more than enough energy is supplied to the bulb, the filament of the bulb may melt, and the bulb will cease to glow. If more bulbs are connected in series, the current in the circuit is reduced and energy is also reduced. Consequently the bulbs will glow dimmer. We say that the *resistance* in the circuit increases as more bulbs are connected in series.

2.4.3 Resistance

It was mentioned in section 2.2.2 that the ability of all material substances to conduct, ranges between conductors and insulators. All material substances, even good conductors provide to some extent, obstruction to the flow of charge. The extend to which charge flow is obstructed by a particular conductor depends on certain properties of that conductor. We say that a conductor has resistance. When potential difference is applied across the ends of a conductor, the electric field is established in the conductor and free electrons drift along the conductor under the action of this field. This drift of electrons constitute current. The resistance of a conductor is defined as *the number of volts needed to drive one ampere of current through the conductor*.

Mathematically the resistance (R) of a conductor is given by the ratio of voltage to current as follows:

$$R = V/I$$

The SI unit for resistance is ohm (Ω).

If one volt is needed to drive a current of one ampere through a conductor, the resistance of that conductor is one ohm.

The significance of defining the concept resistance is to enable scientists and engineers to determine the voltage that must be supplied across a specific conductor to enable a specific amount of current to flow. Thus enabling them to describe energy transfer from the source to the appliance in the circuit (Johnstone & Mughol, 1978:47).

- *the temperature of the conductor*: the higher the temperature of the conductor the more the resistance.

2.4.6 *Emf and potential difference*

It was mentioned in section 2.3.7 that cells supply energy to charges that move through it in an electric circuit. The amount of energy that a cell can supply to *one coulomb* of charge passing through it (from the negative terminal to the positive terminal) is called the *emf* of the battery.

Emf is also measured in volts (V) just like potential difference. Potential difference is however associated with the energy drop experienced by each coulomb of charge when passing through a component in a circuit, while emf is associated with the total energy gained by each coulomb of charge passing through the cell.

The term emf is actually an abbreviation for *electromotive force*. Historically, it was believed that a certain kind of force is responsible for pushing charges through the cell or battery. This force was referred to as electromotive force. It was later found that the concept of electromotive force is not descriptive of the actual situation and was discarded. However, the usage of the term emf was retained, and is used to refer to *the total amount of energy supplied to one coulomb of charge passing through the cell*.

Potential difference refers to *the energy one coulomb of charge, when passing through a current element (an appliance) can transfer to that element*.

The concepts emf and potential difference are defined to enable a quantitative description of energy transfer in a circuit.

2.4.7 *Internal resistance*

Batteries or cells also offer resistance to the flow of current through them. This resistance is referred to as *internal resistance*. The total resistance in the circuit is therefore equal to the internal resistance of the cell/ battery plus individual resistance's of other components connected to the circuit. The potential drop as a result of internal resistance is referred to as *lost volts*.

Thus the emf supplied by the cell is equal to *the total voltage drop across external components connected to the circuit plus the lost volts*.

$\text{emf} = \text{terminal voltage} + \text{lost volts}$
--

2.4.8 A linear model for the teaching of concepts emf and potential difference

Several studies indicate that learners have problems with the understanding of the concepts emf and potential difference. Studies by Bradley and Stanton (1986:238) show that some of the problems encountered by learners are due to the fact that they are being taught incorrectly by their teachers. The other reason why students experience problems with the understanding of emf and potential difference is that these concepts cannot be visualized and learners find difficulties in forming mental images related to these concepts. Many students find difficulties in differentiating these two concepts and use them interchangeably.

A linear model for the teaching of emf and potential difference as suggested by Smit and Vreken (1988:84) is very useful in differentiating and in dispelling misconceptions associated with these concepts. It (the model) aid with the visualization and formation of relevant mental images related to the concepts emf and potential difference. The effectiveness of this model has been proven in a number of applications which include teacher upgrading programs.

The linear model as shown in *figure 2.16* consists of an electric circuit mounted on the lower end of the drawing board.

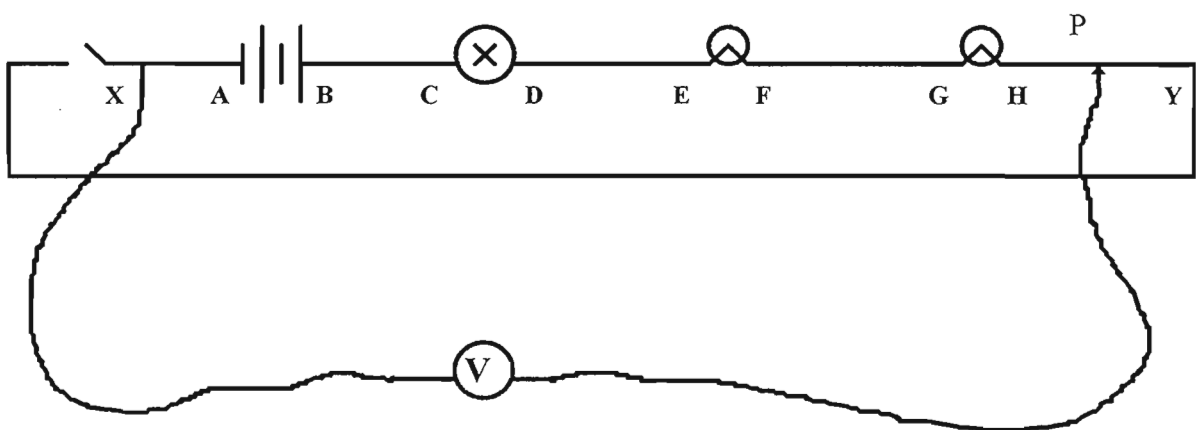
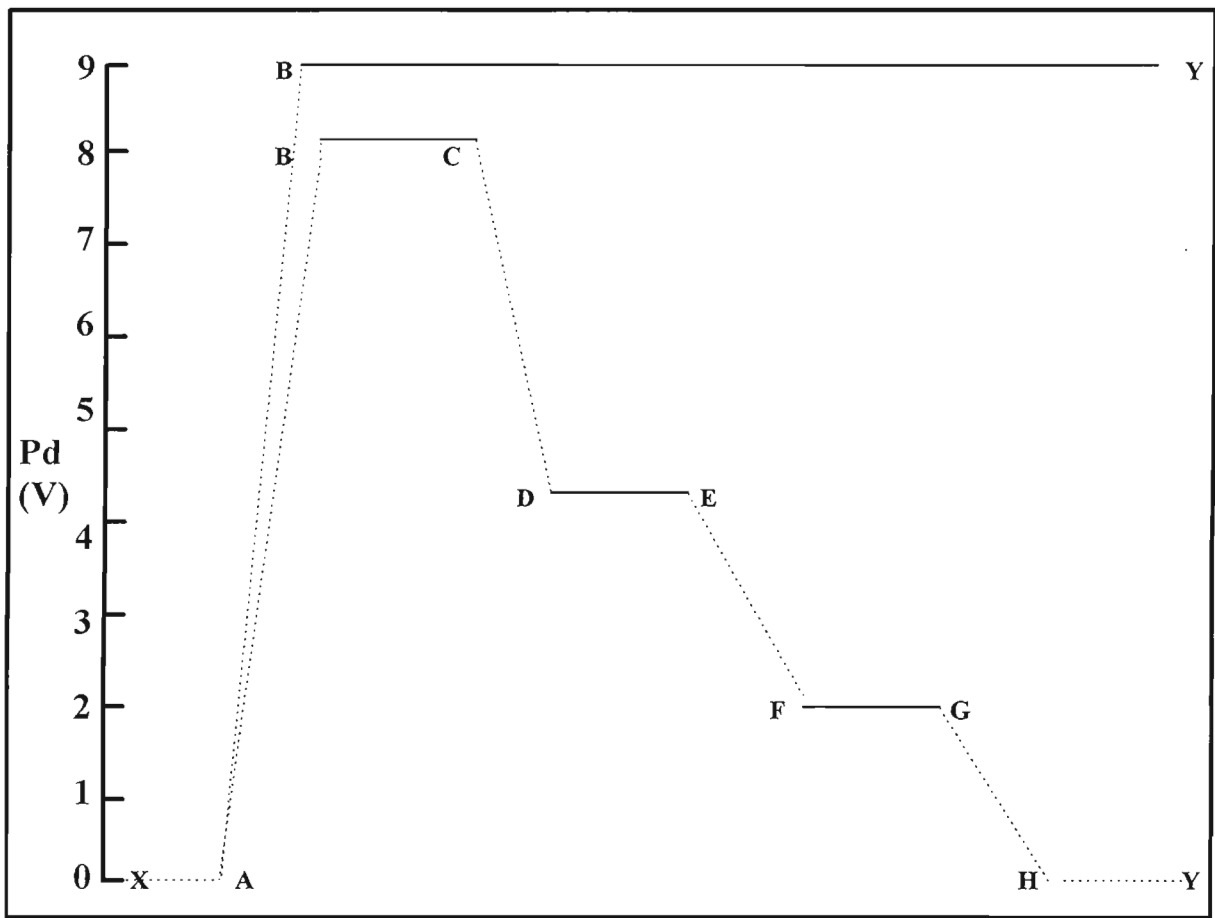


figure 2.16

The model can be used by the teacher in the classroom, not only as an aid to describe the concepts emf and potential difference but also to describe the energy transfer in the electric circuit. Using a PM9 battery, the model is applied by measuring the potential differences respectively between the points X and all the points between X and Y in the circuit, with the switch open and repeating the measurements with the switch closed. A plot of both sets of the voltmeter readings is obtained.

The typical graphs shown in *figure 2.16* show that when the switch is open, the potential energy per one coulomb of positive charge on the positive terminal of the battery is 9 J more than that at the negative terminal of the battery. When the switch is closed, 8 J of energy acquired by the positive charge from the battery is lost successively by 4 J, 1,5 J and 2,5 J when passing through the motor, red bulb and blue bulb respectively.

With the switch closed, current flows through the bulb and other components. Each coulomb of charge experience a drop in energy as it passes through the battery, the motor and the two bulbs. Potential difference across a component can thus be distinguished from emf as being the energy lost by one coulomb of charge when passing through that component, while emf refers to the total energy gained by one coulomb of positive charge passing through the battery.

2.5 Electromagnetism

2.5.1 Early discoveries

Magnets have been known to exist since the early times. At that time it was known that a certain stone attracted iron. This stone (an oxide of iron) was called *magnetite* since it was found in a place called Magnesia in Asia Minor (Mendenhall *et al.*, 1956:299). Magnetite was also called *lodestone* (leading stone) by ancient Chinese since they used it as a compass to guide them in voyages across oceans. Several naive believes were attached to the ability of these peculiar stones to locate direction precisely. Ancient seaman used to think that there was a huge magnetic mountain in the northern seas, which attracted compass needles and pulled ships to their doom (Pople, 1988:155).

The earliest investigation of magnetism was done by *Thales of Miletus* (640 - 546 BC) in Asia Minor in 585 BC (Cajori, 1914:8). One of the major developments in the early investigation of magnetism was the ability to magnetize certain substances. Ancient scientists discovered that when an iron bar is stroked with lodestone, the bar becomes a magnet. The magnetized iron bar is an artificial magnet while the lodestone is a natural magnet (Mendenhall *et al.*, 1956:300). Everything that possessed the following properties was considered to be a magnet:

- attract pieces of iron;
- lines up as a compass when it is suspended freely and
- has a north pole and a south pole

In 1600, Gilbert started investigations of the magnetism of bar magnets and of the earth. He was the first person to reveal that the earth acts like a huge magnet, with both a north and a south pole. He described the behaviour of magnets in the earth's magnetic field and in the vicinity of other magnets (Mendenhall *et al.*, 1956:300). However, not much was achieved as his investigations could not for instance explain where magnetism comes from. The world had to wait until 1907 for such explanations.

2.5.2 *Ferromagnetism and the domain theory*

In 1845 Michael Faraday discovered that magnetism was not a phenomenon limited to iron ores. He demonstrated that many other substances including glass; asbestos; sulphur and liquids such as water; oils and alcohol can also be magnetized. Faraday also succeeded in demonstrating the influence of a magnetic field on light ray beams. He succeeded in rotating the plane of polarization of a plain polarized beam by passing it through a strong magnetic field.

These findings (Faraday's) plunged scientists in a desperate search for the *subtle entity* of magnetism. Upon observing a solenoid act like a magnet, Ampere proposed that all magnets were simply a collection of currents. He supposed that in every molecule, a minute current is flowing.

Denis Poisson (1781 -1840) later suggested that each molecule becomes magnetized when the field acts on it. Wilhem Webber further suggested that individual particles are permanently magnetic, and made no attempt to explain the origin of this magnetism. More recently J.A. Erwing of the university of Cambridge modified Webber's theory and showed that the complete explanation of the phenomenon can be given by merely considering magnetic substances to consist of little magnetic particles (Mendenhall *et al.*, 1956:302). The well known *domain theory* of magnetism, was coined on the basis of Webber's theory.

The domain theory assumes that all substances possess magnetic properties (as shown by Faraday in 1845) and only differ with regard to the strength of magnetic effects that they possess. Substances which possess strong magnetic effects are referred to as being *ferromagnetic*. The word ferromagnetism comes from the Latin word "*ferrum*" which means "*iron*". Ferromagnetism is thus a property of substances which "*behaves*" like iron. Besides iron itself, examples of substances with this property are nickel; and cobalt. Some compounds and alloys of iron such as steel (an alloy of carbon and iron) are usually ferromagnetic. Substances which possess *very weak* magnetic effects are referred to as *paramagnetic* and *diamagnetic* substances.

According to the domain theory, ferromagnetic substances contain small regions called *magnetic domains*. It must be noted that the magnetic configuration of substances is actually inherently determined by the electron spin of its constituent atoms (Mendenhall *et al.*, 1956:302). Thus each domain consists of a group of atoms/ molecules (or dipoles) with the same magnetic orientation. This direction differs from one domain to the other. This theory asserts that atoms are small magnets within magnets (domains), within even larger magnets (the actual magnet).

When an unmagnetized ferromagnetic substance is placed in the field of a magnet, the domains line up. All north poles point in one direction and all south poles in the opposite direction. Soft iron can be easily magnetized in this manner, but loses its magnetism very easily as its domains easily get disaligned. We say that soft iron has little *retentivity*. Hard iron (steel) is much better at retaining its magnetism and we say it has greater retentivity. Steel is therefore suitable for making permanent magnets, while soft iron is suitable for making electromagnets.

Magnetism and electricity are similar in that they both involve forces of attraction and repulsion and both involve fields with similar patterns. The major differences between them is the fact that magnetic poles always come in N-S pairs, referred to as the N-S dipole. The north and the south pole of a magnet cannot be separated, unlike in electricity where the negative and the positive charges can be easily separated. Physicists conducted many experiments in a search for magnetic monopoles, but so far nothing has been discovered.

2.5.3 *The magnetic field*

Magnetic, just like gravitational and electrical forces, involve interaction over a distance. In order to explain this phenomenon, Michael Faraday introduced the concept of a *field* according to which the magnetic field is defined as *the three dimensional region all around a magnet in which magnetic forces act*. In practice, the presence of the magnetic field is detected by means of a compass. Unlike in the case of gravity, where all bodies always have mass and can set up gravitational fields, only magnetized bodies can set up magnetic fields. The direction of a magnetic field is the direction in which the N-pole of a compass needle points when placed in the field. This field is always directed from north to south outside the magnet. Just like in the case of an electric field, a magnetic field is represented by lines of force (Herrman, 1991:450).

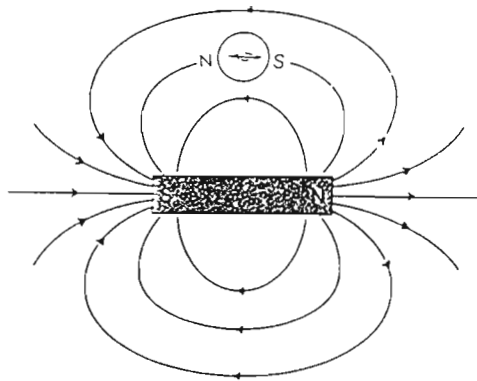


figure 2.17

A magnet can easily lose its magnetism when it is heated, hit or dropped. This causes the magnetic domains to vibrate or even rotate, altering the domain structure from the ordered structure back to random or disordered structure. A bar magnet will also slowly lose its magnetism if it is left by itself. This can be prevented by storing magnets in pairs, side by side, such that the north pole of one magnet is adjacent to the south pole of the other (Brommert, 1968:297).

2.5.4 Magnetism from current

An interesting phenomenon involving the relationship between electricity and magnetism was observed as early as 1681 when a ship bound for Boston was struck by lightning. Observation of stars showed the crew that the needles of compasses used in the ship actually changed direction, and the ship was led astray (Cajori, 1914:95). This observation however, did not lead investigators to link electrical phenomenon with magnetism since it was not known in those days that lightning is an electrical phenomenon. In those days a lightning bolt was believed to be an explosion of gasses. Many superstitious beliefs were also attached to lightning and thunder.

The science of electromagnetism originated in 1819, when Hans Christian Oersted (1777 - 1851) demonstrated using a voltaic battery that when a current carrying wire is held vertically next to the compass, the compass needle shows a deflection. This discovery was accidentally made at the end of one of Oersted's lectures (Cajori, 1914:223). In the following year, Francois Arago (1786 - 1853) observed that iron filings were attracted by a current carrying wire. This attraction of iron

fillings was explained by Davy in 1822 as being due to some "peripheral arrangements" around the wire (Cajori, 1914:225).

While Oersted had accidentally discovered the action of current on magnets, in 1823, Andre Marie Ampere (1775 -1836) discovered the action of a current upon another current: parallel currents in the same direction attract each other while parallel currents in the opposite direction repel each other. This observation could not be simply explained by asserting that, since both currents acted upon the same magnet, they will therefore act upon each other, as some critics of those days claimed.

Ampere set himself to investigate the underlying causes of these forces between currents, and in the same year (1823), he published a paper giving a mathematical theory of this new-found phenomenon. He described the force between two current carrying wires as being proportional to the length (l) of the wires and the product of the currents (I_1 and I_2) in the wires and inversely proportional to the distance (d) between them (Cajori, 1914:227). These results are combined in a single equation:

$$F = \frac{k I_1 I_2 l}{d}$$

2.5.5 Current from magnetism

In 1824, Michael Faraday, upon realizing the significance of Oersted's discovery, began studies in magneto-electricity. He argued that since a current gives rise to a magnetic field, a magnetic field may also give rise to an electric current. Faraday made this argument before he could obtain experimental evidence of this effect. In 1825, he passed a current through one wire which was lying close to another wire connected to a galvanometer, but luck was not on his side and he obtained no results. The momentary induced current missed him by an inch! (Cajori, 1914:236).

Thanks to Faraday's patience, he continued experimenting along these lines without success up until August 1831, when he used a wire and wound it into two coils around a ring. One coil was connected to a galvanometer and the other one to a battery. The galvanometer needle deflected and settled at the original position when the battery was connected to one of the coils, and deflected to the opposite direction when the battery was disconnected. Not realizing the significance of these findings, Faraday further took a coil connected to a galvanometer and pushed

a magnet into it. Alas!! the galvanometer needle showed a deflection. It was evident that the induced effect was instantaneous and not continuous (Cajori, 1914:237). This discovery, the converse of Oersted's, was made in October 1831. Thus confirming Faraday's earlier assertion that magnetism can give rise to current.

It is important to note that at about the same time, discoveries which paralleled that of Faraday were made in America by Joseph Henry (1799 - 1878) and other investigators. The honors for this discovery is however accredited to Faraday (Cajori, 1914:242).

2.5.6 Unification of current related phenomenon

Faraday's discovery that a changing magnetic field induced an electric current, established the fifth method of creating electric current. The other four methods being, animal electricity (Galvani), chemical electricity (Volta), thermal electricity and atmospheric electricity (Franklin). Faraday argued that electric current produced by means of all these methods was the same. By so doing, he unified electric phenomena. This is typical of the developments of physics, and reveals the nature of the subject. There is always a strive for unification. More and more phenomena are related to a single theory. The ultimate strive is to arrive at a single theory that explain all physical phenomena - a Grand Unification Theory (GUT) (Hawking, 1988:79).

2.6 Conclusion

From the discussion of both electrostatics and electrodynamics in this chapter, the following concepts can be classified as core concepts: *charge, electrostatic force, electric field, electrostatic potential, potential difference, emf, current, and resistance*. For reasons mentioned in section 2.3.3, only concepts related to electric circuits were subjected to investigation in this study. The understanding of concepts related to electrostatics by teachers was not investigated. The concepts *energy* and *work* are general concepts in physics and are not regarded as core concepts in electricity, although they are very important in the study of electricity. These concepts are also not subjected to investigation in this study. The concepts conductor and insulator are related to resistance, a concept dealt with in section 2.4.3. These two concepts are thus not necessarily considered as core concepts in electricity but are however subjected to investigation since they are fundamental to the understanding of phenomenon occurring in electric circuits.

The next chapter is based on literature review of alternative conceptions associated with electrical phenomena. Only alternative conceptions related to electric circuits are discussed.

CHAPTER 3

ALTERNATIVE CONCEPTIONS IN ELECTRICITY

3.1 Introduction

Electricity is one area of science in which many alternative conceptions exist. In view of the problems posed by alternative conceptions in the learning of electricity, a number of recent researchers focused on identifying these alternative conceptions, so that remedial strategies to address them can be attempted. Up to now, a number of alternative conceptions in many areas of science have been identified and yet no teaching strategy can claim to have solutions to all these learning problems. (Stocklmayer & Treagust 1994:133). Electricity is one such area of science in which alternative conceptions have been identified. This chapter deals with alternative conceptions in electricity with particular reference to electric circuits. A few alternative conceptions in electromagnetism are also included.

The pattern of worldwide research conducted since 1983 indicates that nowhere was there a group of students without alternative conceptions. According to Shipstone *et al.*, (1988:305) substantially the same pattern of learning difficulties in electricity exists across different countries. There is almost *natural* coherence to these learning difficulties within cognitive structures. According to McDermott and Shaffer. (1992: 995), students' alternative conceptions in electric circuits can be grouped into three general categories: the inability to apply formal concepts to an electric circuit; the inability to use and interpret formal representations of electric circuits and the inability to reason qualitatively about the behaviour of electric circuits.

The purpose of this study as a whole is to probe into teacher's understanding of electricity around these three areas. In addition, the study inquires into teacher's visualization of models in electricity and understanding of the purpose with electric circuits, with emphasis on basic concepts. Although this study is targeting practicing teachers, use is made of results obtained from investigations into students' alternative conceptions to form a research base for teachers' understanding, since very little, if any, data is available on teachers' understanding of electricity. It might be expected that because of inefficient teacher training programs, some teachers may harbor alternative conceptions similar to those harbored by students (Smit & Nel, 1997:202). Alternative conceptions are well known for their resistance to instruction (even in teacher training programs) if no effective measures are taken to address them (McDermott & Shaffer: 1992:997).

A total of 22 popular alternative conceptions have been identified from research literature and are discussed below. Sections 3.2.1 - 3.2.16 deal with alternative conceptions with particular reference to electric circuits and section 3.2.17 deals with alternative conceptions with reference to electromagnetism.

3.2 Alternative conceptions as identified from research literature

3.2.1 *The unipolar model*

Many students think that current leaves the cell and go to the bulb (*figure 3.1*).

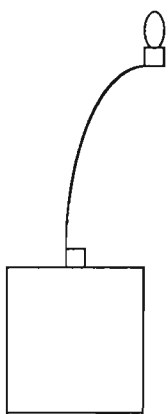


figure 3.1

According to Miller (1980:336), this claim is a result of, firstly, the misunderstanding of the fact that the screw-thread of the bulb does not only serve the purpose of securing the bulb in its holder, but also serves as one of the terminals. Using a bulb whose two terminals are at its opposite ends will yield a different claim by students (Stanton, 1989:80). Secondly, electrical cords used in radios; electric kettles; electric irons; *e.t.c.* start at the source and end at the appliance. This creates the impression that current is only carried in one direction - towards the appliance and is consumed there. Little do students know that electrical cords actually consist of more than one wire which carry current in two ways.

Many students however rarely use the term *current* and assert that *electricity* leaves the cell and goes into the bulb (Stanton, 1989:78).

3.2.2 The clashing current model

According to Stockmayer and Treagust (1994:132) students think that current leaves at both terminals of the cell and is used up within the circuit elements. According to this model the currents *clash* at the bulb (figure 3.2). The glowing of the bulb is said to be explained by the clashing of the currents.



figure 3.2

3.2.3 The consumer's model

Many students think that current is consumed in a circuit. They reason that the current strength at A is larger than the current strength at B (figure 3.3), since the bulb *uses* the current in order to give off light (Shipstone, 1984:190).

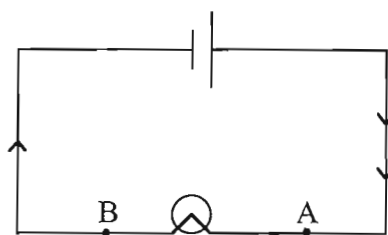


figure 3.3

This assertion shows that students are *current orientated*, they believe that current leaves the battery (which is perceived to be the source of current) at a particular value and is modified thereafter depending on what it encounters in its path. According to this model little or no current may return to the battery. This notion is referred to as the *consumer's model* or *attenuation model*. According to a study conducted in Israel by Cohen, Eylon and Ganiel in 1983, many senior teachers with physics degrees were also found to reason according to this model (Stockmayer & Treagust, 1994:133).

Students fail to understand that, current only conveys energy to the bulb.

3.2.4 *Current shared between components in series circuits*

According to Shipstone (1988:95), many students think that current is shared between components in a circuit. If identical bulbs are connected in series in a circuit, students assert that current is not conserved and is shared equally amongst the bulbs.

3.2.5 *Cells as sources of constant current*

Many students think that a cell is the source of constant current which is independent of the conductor used. They fail to understand that a cell is a source of energy and supplies constant emf, while current depends on the resistance of the external circuit (McDermott & Shaffer, 1992:997).

3.2.6 *Poor understanding of energy concept*

Many students fail to understand the fact that energy is conserved in a circuit, and that all the energy supplied by the cell is dissipated (converted to other forms of energy) in various components of the circuit (Stanton, 1990:32).

3.2.7 *Undifferentiated concepts*

3.2.7.1 *Potential and potential difference*

When asked to compare the brightness of the bulbs (*figure 3.4*), students arranged the brightness of the bulbs in the order: $A > B = C > D$.

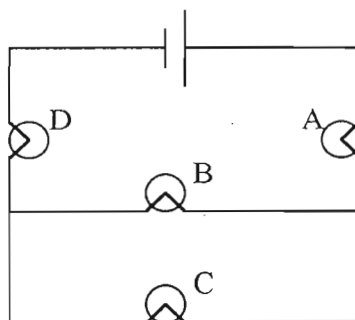


figure 3.4

Students reason that bulb A is the brightest because the potential is the highest at A. Bulb B and C are next, and D is the dimmest due to the lowest potential (*figure 3.4*). This explanation indicates a failure by students to discriminate between the concepts *potential* and *potential difference*. The brightness of the bulbs is mistakenly associated with the value of the potential at one of its terminals, rather than with the potential difference between both its terminals (McDermott & Shaffer, 1992:998). Similar responses by students may be obtained as a result of the attenuation model of reasoning (*section 3.2.3*).

3.2.7.2 Emf and potential difference

The concepts emf and potential difference are poorly understood and sometimes used interchangeably, as though being similar. Students fail to understand that emf is associated with the energy supplied by the cell, while potential difference is associated with the energy transferred to individual components in the circuit (Cohen *et al.*, 1983:409).

3.2.7.3 Voltage and current

Many students regard current and voltage as being similar in nature. They find it difficult to accept that voltage across bulbs in parallel is equal to the supplied voltage while the (constant) current in the circuit divides up (Shipstone *et al.*, 1988:310). Students believe that current and voltage should always appear together. They also think that since current can only exist in a closed circuit, there is zero potential difference in an open circuit. Some students regard voltage as something which flows (Shipstone, 1984:189).

3.2.8 Misunderstanding of causal relation between current and voltage

Many students fail to understand the correct causal connection between potential difference and current. Current is seen as the primary concept in the circuit, while potential difference is seen as the consequence of current flow, and not as its cause (Cohen, *et al.*, 1983:407).

3.2.9 Sequential reasoning

According to Shipstone (1984:191) many students cannot interpret circuit diagrams and physical circuits correctly. They often apply sequential reasoning. Students think that (constant) current will flow from one component to the other: through I_1 and then through I_2 (figure 3.5).

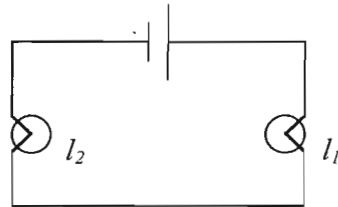


figure 3.5

Students fail to understand that when the circuit is closed, the flow of current is instantly triggered at all points in the circuit. This reasoning is sometimes referred to as time-dependent model. Students with sequential and attenuation models will assert that I_1 will be brighter than I_2 since it uses up the current first and I_2 gets left over current (figure 3.5). Students' choice of the brighter bulb shows whether they think of conventional or electron current. According to students with sequential reasoning, the direction of current in the circuit and the order of connection of the bulbs, determine the relative brightness of the bulbs.

3.2.10 Local reasoning

Shipstone *et al.* (1988:310) and Cohen *et al.* (1983:410) found that when dealing with branched circuits, students apply local reasoning. That is, they focus their attention entirely upon what happens at one point in a circuit and completely ignore what happens elsewhere in the circuit (figure 3.6).

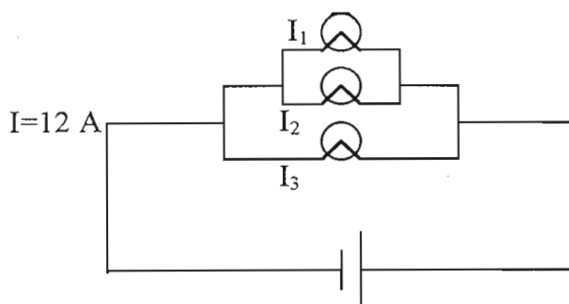
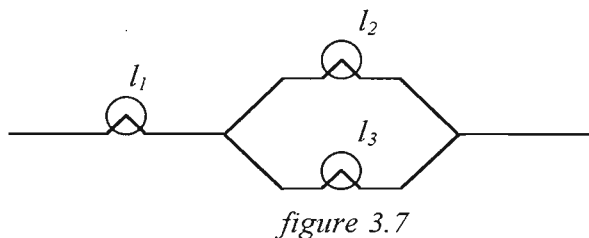


figure 3.6

When given the circuit above, many students assert that $I_3 = 6\text{A}$ and I_2 and I_1 are equal to 3A each. This shows that students regard current as dividing into two equal parts at each successive junction, and this is not influenced by what is perceived to be *lying ahead* in the circuit. Students are unable to consider a change at more than one point in the circuit at a time (Shipstone *et al.*, 1988:310).

3.2.11 Difficulty in identifying series and parallel connections

Many students have difficulties in recognizing the nature of connections when several elements are involved (McDermott & Shaffer, 1992:999). When a single element is in series with two elements connected in parallel, students often claim that the single element is in series with one of the elements in the parallel combination. For instance, students claim that I_1 is in parallel with either I_2 or I_3 (figure 3.7).



The term "series" is used to mean some form of sequentially rather than specific type of connection.

3.2.12 Failure to distinguish between branches connected in parallel across a cell and connected in parallel elsewhere.

Students fail to understand that if two parallel branches are connected *directly* across an ideal battery, a change made in one of the branches has *no effect* on the other, while on the other hand a change in one branch where two parallel branches are not connected directly across the battery affect the other (McDermott & Shaffer, 1992:998).

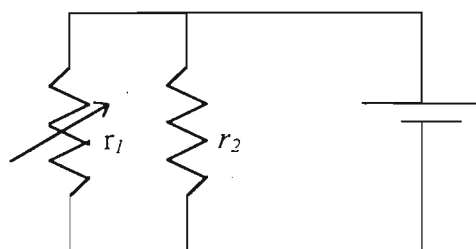
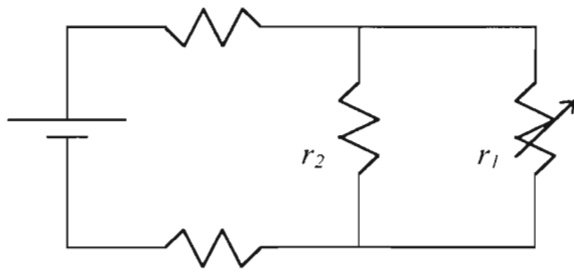


figure 3.8

Changes in r_1 has no effect on the r_2 branch (figure 3.8).



Changes in r_1 affects r_2 branch.
(figure 3.9)

figure 3.9

3.2.13 "Changes in parallel components does not affect current in the main circuit"

Many students think that the total current in the circuit is unaltered by changes in one of the branches of the parallel combination, but is merely shared differently between parallel branches (figure 3.10).

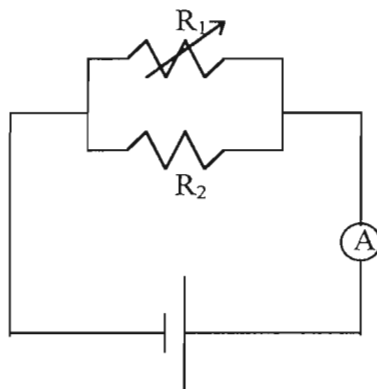


figure 3.10

"Increasing r_1 does not alter the ammeter reading but only apportion more current to r_2 . Current in the two branches rejoin again and will be the same as before." Students with *localized reasoning* will give similar responses (McDermott & Shaffer, 1992:998).

3.2.14 Misinterpretation of real circuits

When drawing standard circuit diagrams, from unconventional circuit diagrams or real circuits, students tend to focus on physical lines connecting the elements rather than on electrical connections represented by the lines, making incorrect correspondence between circuit diagrams and real circuits. Students do not recognize that the circuit diagrams represent only electrical elements and connections, not physical or spatial relationships (McDermott & Shaffer, 1992:999).

3.2.15 Failure to treat meters as circuit elements

Although some students know that the resistance of an ammeter is very small, the significance of this fact is rarely understood. They do not understand that ammeters should be connected in series and voltmeters in parallel so that they do not affect the current and voltage respectively to be measured (McDermott & Shaffer, 1992:1000).

3.2.16 Conceptual problems with the conventional current model

A study conducted by Smit and Nel (1997:202) reveals that science teachers have difficulties in interpreting the conventional current model. Teachers visualize conventional current as the actual movement of positive entities or holes. This brings about confusion in the interpretation of electric current phenomena since no movement of positive entities is possible in electric circuits. The teachers' misinterpretation of the conventional current is due to lack of understanding of the functional purpose served by models in physics.

3.2.17 Visualization problems on magnetic fields

A survey conducted on teachers and students by Smit and Nel (1996) reveals the following discrepancies in the visualization of magnetic fields:

- some students think of magnetic field lines as being real and in actual existence
- magnetic flux is seen as dynamic, which implies some movement. This conception may originate from everyday usage of the term *influx*, commonly used to refer to cross border movement of people or capital. The arrows used to represent field lines may also give rise to misleading impressions since directed arrows usually denote motion, for examples in drawing vectors and light rays.
- magnetic flux in the coil is seen as not confined to field lines through the interior of the coil.

3.3 Conclusion

The above outline of alternative conceptions is drawn from results of recent research, but does not necessarily constitute a complete list of students' alternative notions. Despite the fact that in

this chapter, emphasis has been laid on basic concepts, no list of alternative conceptions can be considered complete since it is expected to expand with continuing research.

Identifying and classifying alternative conceptions is not an easy task. The fact that different kinds of faulty reasons by students may produce similar answers to a question, adds to the difficulty involved in trying to unambiguously classify their model of reasoning (McDermott & Shaffer, 1992:999). The other problem is that one misconception can lead to a string of other faulty notions, making it even more difficult to identify the "*parent*" misconception.

It can be realized that, some of the alternative conceptions outlined above, overlap to a larger or lesser extent, while some are but extensions of others.

According to McDermott and Shaffer (1992:1000), students' failure to coherently describe the behaviour of electric circuits can be attributed to a lack of an appropriate conceptual model for predicting and explaining the behaviour of simple electric circuits. As a result, students resort to relying on their own intuition and on the use of formulas without understanding of the qualitative relationships between quantities in electric circuits. The finding by Smit and Finegold (1994:427) revealed that inadequate knowledge of models in physics by science teachers may be one of the fundamental reasons why secondary school students experience problems with the understanding of electricity. Eylon and Ganiel (1990:92) further attribute students' misconceptions in electric circuits to the missing links between electrostatics and electrodynamics in students' reasoning. Students view these branches of electricity as two separate entities and do not tie concepts from electrostatics in to their description of phenomena occurring in electric circuits.

The next chapter deals with the constructivistic approach to teaching that is currently suggested to deal with problems associated with students' alternative conceptions. This chapter includes discussions of both the traditional and the heuristic approaches to teaching.

CHAPTER 4

CONSTRUCTIVISM

4.1 Introduction

The study of science as a natural philosophy has a very long history. The major developments in science that took place in the nineteenth century further sparked interest in the study of science. This growing interest in science was followed by the need to introduce science as a school subject. The introduction of science in schools became a matter of long and intensive debate. One of the issues which had to be decided upon was the standardization of the methodology of the teaching and learning of science in schools so that there is only one uniform method of inquiry (Wellington, 1989:36).

Up until 1870, science was widely taught by means of lecture demonstrations, with the instructor performing experimental demonstrations and supplementing them with information from text-books. It was later realized that this instructional method yielded students who lack first-hand familiarity with scientific concepts and procedures, as students were not allowed to perform experiments on their own (Woolnough & Allsop, 1985). A discussion of this method of teaching, referred to as the *transmission model* or *the traditional model* is made in the next section.

4.2 The transmission model of teaching

Traditionally, the teaching of science is seen as a transmission process, whereby knowledge is transferred from the teacher to the child. The teacher is an active participant while the child is a passive recipient of information. The teacher and the textbooks are the only sources of information. This information is *absorbed* by the learners and is incorporated in the same order and sequence as presented in the textbooks and by the teacher. In this case, the teacher is the one who is responsible for the learning of the child. Students' performance and motivation are thus significantly influenced by the teacher's personality (Jacob, 1982: 262). A well prepared lesson, presented in a formal setting, in a logical and clear manner, and an experimental demonstration properly carried out by the teacher in front of a quietly

seated and attentive class, is according to the transmission model of teaching, a fulfillment of all essential aspects of good teaching. Rote-learning and memorization is all what it takes for the student to succeed through the transmission approach to teaching, since no internalization of content and understanding is emphasized. This approach is only aimed at enabling students to remember information so that they can pass examinations, and no emphasis is placed on acquisition of problem solving skills and logical reasoning. This approach however does not yield results which would otherwise be expected. The heuristic approach to teaching, which is a radical departure from the transmission model, is discussed in section 4.3 below.

4.3 The heuristic approach

Upon realizing the ineffectiveness and the failures of the transmission model of teaching in science, Henry Edward Armstrong in the early twentieth century, proposed the heuristic approach to the teaching of school science. The heuristic approach of teaching implies that students must be placed absolutely in the position of the original discoverer, so that they discover information and knowledge for themselves. Armstrong argued that the main significance of science teaching was to teach scientific method (process) rather than merely teaching information and knowledge (content) as in the case of the transmission model (Wellington, 1989).

Armstrong's rather uncompromising approach which over-emphasized the scientific method over the learning of content did not win much support in the scientific and education circles. The final blow to Armstrong's heuristic approach came when psychologists issued reports of their research in favor of the transmission model as a better teaching method for science. As a result of a lot of evidence against the heuristic approach that accumulated, science teaching shifted entirely towards the transmission model (Wellington, 1989).

Armstrong's heuristic approach was revived in the late 1950's as a result of the work done by the Nuffield Science Teacher Project, Piaget, Brunner and Bloom. The Nuffield Science Teacher Project designed a set of science teaching objectives which could not be accomplished by means of the transmission model. Change in science teaching approaches

was inevitable. The Piagetian developmental theory, and theories on approaches to learning that were developed in the early sixties influenced science teaching towards observation, exploration and discovery approaches. Brunner emphasized that the methodological structure of learning science must resemble the way science advance (Wellington, 1989). The method of learning by discovery became more favored in the 1960's. In 1968, Ausubel proposed a learning theory called *constructivistic learning theory* (White, 1989: 13). This theory provided a new way of looking at how learning takes place. An elaborate discussion of this theory is made in section 4.4.

4.4 The constructivistic learning theory

Constructivism is the latest learning theory that filtered through a number of developments in science education. Although constructivism is thought to be a new concept, there is evidence that the idea underlying constructivism has been around since at least the time of John Dewey (1859 - 1952) (Novodvorsky, 1997: 242). Constructivism is based on several assumptions.

The first assumption of the constructivistic theory is that knowledge is constructed in the mind of the learner. This implies that the learning process involves the characteristic of the learner, his or her abilities, attitudes and perceptions of the world. The constructivistic view takes into account learner differences. Each and every learner is unique, both in terms of abilities and perceptions of the world. The individual's perception of the world is constructed as a result of observations made from the surroundings and personal experience with "the stuff of science" (Novodvorsky, 1997: 242). This in turn leads to the formation of alternative conceptions as explained in section 1.4.2. Thus in every individual's mind, there exists constructs of how the world operates. These constructs influence the way incoming knowledge is interpreted and understood. It is thus possible that the same set of information can be interpreted differently by different people. This point illustrates the critical role played by individual differences in learning. In terms of abilities, constructivism recognizes the fact that it is impracticable to expect learners to achieve success at the same rate. The theory also recognizes the fact that the individual's attitudes towards certain topics influence his/her learning. These attitudes are guided by believes; value systems and the prior

knowledge possessed by individuals. In this regard, learning takes place best when learners feel good about the learning task and have positive attitudes towards it. For this to be achieved, learners must be led to realize the significance of the learning task and its relevance to their everyday lives. According to White (1989: 14), the genetic inheritance of individuals and the context in which learning takes place also influence the learning process.

According to the constructivistic view, learning does not take place through transmission of knowledge from the teacher (the source) to the learner (the receiver). Knowledge is thus not transmitted but is constructed by the learner. Learning can thus not be achieved through drilling information into learners. The role of the teacher is also looked at differently. The teacher is not perceived as the source of information and knowledge but as a facilitator who creates opportunities for learning. His role is to enable learners to access information and guide them through the learning process. He is also responsible for supporting, nurturing and assessing learners to help them improve. In this case the teacher is not perceived as the overall authority who is in control of the learning process, but only as an agent in the learning process (Driver *et al.*, 1985:8).

The second assumption of the constructivistic theory is that students bring along with them some prior knowledge about science upon entering science classrooms. This prior knowledge which was referred to as *preconceptions* in chapter 3 is seated within the mental structures of the child. The constructivistic theory asserts that the prior knowledge of the child has a direct impact on his learning and should not be ignored. The assumption that students' minds are like empty vessels waiting to be filled with knowledge is in total contrast to the constructivistic view of learning (Novodvorsky, 1997: 242).

According to the constructivistic theory, learning is not a purely receptive process. It is an active process where students construct their own knowledge. What matters therefore is not what learners abstract but the construction that they make from what is presented. They create meaning for information presented to them. These meanings are compared with already existing knowledge structures. If this new knowledge is found to be inconsistent with the existing structures, the individual may abandon and reject the new material as not making sense, or he or she may decide to memorize it for the purpose of passing


examinations. In this case no learning shall have taken place since the new knowledge is not assimilated into the mental structure and prior knowledge is still retained. We say that learning takes place if, upon realizing the inconsistency between the new and the prior knowledge, the student consciously modifies his mental structures so as to match the incoming knowledge. The restructuring of existing structures is crucial to the learning process. Failure of individuals to modify their own mental structures explain difficulties met with in the teaching and learning of science (Jacob, 1982:269). In their nature, preconceptions are very resistant to instruction. Restructuring such concepts is thus not an easy exercise. It is the most difficult and yet the most essential aspect of learning (Arnold & Miller, 1987:560). Strategies of dealing with this problem will be discussed in section 4.5 below.

On the other hand, if there is a match between the incoming knowledge and the existing knowledge, the new knowledge is incorporated in the mental structures and is understood. In this case the new knowledge is internalized and form part of the individual's mental structures.

The third assumption of the constructivistic learning theory is that learning is a lifelong process, and is not confined to a specific period in the life of individuals. It a continuous process and does not take place in stages. Learning can take place anywhere, both inside and outside the science classroom. The traditional way of looking at learning is that learning takes place only when information is presented to the learner by the teacher in the classroom situation, or when the learner obtains information from textbooks. Whatever the information acquired by individuals prior to and after formal instruction, is not recognized by the traditional model of learning (Driver *et al.*, 1985:9).

4.5 The constructivistic approach to teaching

In this section, we look at the constructivistic approach and how it can by used to address the problems encountered with in the learning of science, so that the aims and objectives of science teaching are accomplished. The constructivistic model of teaching looks differently at the roles of the teacher and of students in the science classroom. The teacher's role is that of a facilitator of the learning process and not an instructor. Students are not just passive



recipients of what is taught, but are actively involved in interpreting and constructing knowledge (Jacob, 1982: 268).

The constructivistic approach to teaching is based on the fact that students' alternative conceptions have direct impact on their learning of science. Since the teaching of scientifically accepted concepts does not necessarily result in restructuring of students' alternative conceptions, the chances of successful teaching in science are slim, as no learning can take place if there is no restructuring of non-scientific knowledge. The constructivistic view emphasizes the importance of students' alternative conceptions in the teaching and learning of science. According to this view, students' alternative conceptions must be taken into consideration and be addressed accordingly. If they are ignored, they stay firmly established within students' mental structures, and persist after formal instruction (Driver, 1985:198).

In a classroom situation, the constructivistic approach can be carried out by means of the steps outlined in the next section.

4.5.1 Establishing existing knowledge

According to the constructivistic approach to teaching, students' prior knowledge must first be established before the scientific concepts can be introduced. This can be achieved by asking leading questions prior to any formal instruction. Use students' prior knowledge to direct the course of the learning activity. If students' prior conceptions are scientifically acceptable, students can be led through a process of knowledge construction on the basis of what they already know. If, on the other hand, students' prior knowledge is not scientifically acceptable, it is necessary to lead them through a process of discrediting their existing notions so as to pave the way for the establishment of the acceptable new concepts (Novodvorsky, 1997:242).

4.5.2 Discrediting students' ideas

Discrediting students' ideas does not imply that the teacher must criticize and rule out students' ideas. The teacher must instead allow students to explore their own alternative conceptions and use them to generate their own hypothesis and interpretations. In the process, the teacher must provide materials and opportunities for students to test their ideas and to construct relationships between concepts. In this way a conflict situation arises in students' minds and their attention is drawn to the contradictions with their predictions. This conflict in mental structures serve as the source of motivation for the child to seek closure. The efforts of the child are directed towards resolving this conflict (Jacob, 1982:268). Where applicable, a conflict situation in students' minds can be created by means of an experimental demonstration which is contradictory to their alternative conceptions. In this way, students will begin to doubt their conceptions and opt for the one which is not contradictory to experimental observation.

4.5.3 The construction of knowledge

After students' conceptions have been discredited, students will be ready to assimilate scientifically acceptable knowledge, the knowledge which does not lead to contradictions and is not contradictory to experimental observations. This knowledge should however not be presented to students by the teacher. Students must be allowed to construct this knowledge themselves - this is the essence of constructivism. Steps involved in leading students through the process of knowledge construction include allowing students to discuss and interpret phenomena or experimental observations in such a way that it makes sense. Through the guidance of the teacher, the acceptable scientific concept can be established. If the scientific concept is accepted, the learners will discard their own naive concepts in favor of the scientific one (Novodvorsky, 1997: 243). In this way, we say that learning has taken place.

4.6 Conclusion

Looking back at the historical development of the teaching of science, one realizes that science teaching has always been an ever-changing educational exercise. As more and more findings in the field of the learning psychology are made, one can expect that the changes in the teaching strategies of science will continue. The ultimate objective with all these changes is to improve and to make the learning of science more effective. A question that one needs to ask is "can we at any stage arrive at an ideal teaching approach that will be completely suited to the learning patterns of all children and address all their learning problems?". The answer to this question is that the ideal teaching approach is in all practical terms not attainable. The fact is that there are teaching strategies which are better than others. Attempts are however always geared towards attaining the best possible teaching strategy. It must also be emphasized that the answer to the question regarding which teaching strategy is better than the other, is not a simple one. The effectiveness of any teaching strategy is not only dependent on its compatibility with the learning patterns of the child, but also on the relevance of the strategy to the times, social needs and the practicality (with respect to the time, facilities, e.t.c.) of the approach. The decision on which teaching strategy is best, depends on the time in history during which the teaching approach is to be implemented. Its relevance also depends on the needs of the society and the objectives of science teaching as currently designed by the science and education community.

In the past, one of the science teaching objectives was to produce individuals who could memorize and retrieve information from memory. Equations and formulas had to be committed to memory by students so as to be able to use them when they render services to the society as engineers or technicians (Jacob, 1982: 224). The ability to recall such information has however become irrelevant to the needs of the current modern society. In the present information age, where pocket-size calculators and computers with high memory power can be inexpensively produced, one only needs to learn the skills of accessing and using information stored in these devices. One of the main objectives of science teaching at present is to produce critical thinkers and individuals with problem solving skills and creative minds, who can work cooperatively within a group (Jacob, 1982: 222). Since social needs change with time, it is expected that teaching strategies will change

from one teaching model to the other so as to accomplish the current science teaching objectives and address the needs of the current society.

It must also be noted that some teaching strategies can work effectively in one situation and yield poor results in another situation. For a teaching strategy to be effective, it must also be relevant to the situation in which it is to be implemented. Several logistic problems such as classroom sizes and teacher-pupil ratios may affect the effectiveness of some teaching strategies.

The next chapter deals with the syllabus for the electricity course offered in the SEDIBA Project. The results of the empirical study will be outlined and discussed in chapter 6.

CHAPTER 5
SEDIBA ELECTRICITY SYLLABUS AND TEACHING
STRATEGY FOR ELECTRICITY

5.1 Introduction

This chapter deals with the syllabus for the Higher Diploma in Education (HDE) electricity course offered in the SEDIBA Project and the teaching strategies used in the presentation of the course.

The SEDIBA Project is a partnership between the Potchefstroom University for Christian Higher Education, the North West Department of Education and NASCHEM, a division of DENEL. The SEDIBA Project runs a program which is aimed at upgrading the qualifications of physical science/mathematics teachers by creating opportunities for them to improve the quality of their teaching and by assisting them to gain mastery of the subject. The SEDIBA Project is an endeavor to address the dire need of quality science teachers in the North West Province. Teachers enrolled in the project can either specialize in physical science or mathematics. Specializing in only one subject makes it possible for teachers to gain in-depth understanding and mastery of their subject. The physical science program is targeting teachers who are in possession of a three year teacher's diploma in science teaching, or teachers in possession of a three year teacher's diploma with physical science as a matric subject and at least three years' teaching experience in physical science at secondary school level. Recent research (Smit *et al.*, 1997) has shown that by the first Tuesday of March 1996, 1000 physical science teachers out of a total of 1218 in the North West Province were in possession of a three years' teachers diploma. 54% of these 1218 teachers did not have post matric training in physical science. These statistics are indicative of the amount of work that needs to be done in order to improve the quality of science teaching in the North West Province.

Courses offered in the physical science stream of the SEDIBA program are physics, chemistry, subject didactics, education and computer literacy. These courses are presented at an equivalent of first year B.Sc level. Upon completion of the program, teachers obtain

an HDE in science education, awarded by the Potchefstroom University for Christian Higher Education.

Since all the teachers enrolled in this program are practicing teachers and can only study on a part time basis, the program is extended over a period of two years. Tuition is done over a total period of 16 weeks on campus and is supplemented by distance learning. Practical work (which form an integral part of the program) and lectures are offered mostly during school holidays and weekends during the 16 weeks on the Potchefstroom University campus. Teachers make use of cooperative group work, in between contact sessions to work on assignments and other learning tasks.

5.2 Discussion of the electricity syllabus

Electricity constitutes about 35% of the entire HDE physics syllabus. Other topics included in the physics syllabus are mechanics, thermodynamics, waves, gasses, and modern physics. Electricity is treated as a unit course and extends over one semester in the second year of study.

A broad holistic approach is followed in the presentation of the electricity course. Each topic is introduced at grassroots level. Topics drawn from the secondary school syllabus are integrated with other basic concepts to form a unit electricity course from which teachers can benefit directly. Although the present school syllabus for electricity serve as a guide for the content and the arrangement of topics, topics in the SEDIBA course are however not necessarily presented in the same sequence as at secondary schools. The syllabus is handled topic by topic. Topics are not segmented as is the case with some topics in the school syllabus. Several basic concepts in electricity not frequently found in text books also form part of the syllabus. Although the topics covered in the syllabus are presented at the level comparable to that of first year university physics, care is taken to ensure that emphasis is placed on those themes which are relevant for the school syllabus and for the needs of the science teacher. The entire electricity course is non-calculus based and places more emphasis on qualitative explanations of fundamental laws and concepts rather than on mathematical derivations and calculations. As much as possible, an attempt is made to relate electricity to other areas of physics and science in general, and to highlight the relevance of

electricity to real life situations (for example how electricity bills are worked out) and natural phenomenon (for example lightning).

Practical work, which form an integral part of the electricity course, includes all electricity experiments prescribed by the current syllabus from grade 8 to 12, a number of enrichment experiments not included in school syllabi and some experiments drawn from first year university level. Teachers use worksheets, and work through these experiments in small groups. The apparatus used by teachers in experiments are mostly similar to those present at their respective schools. These apparatus are manufactured and supplied by STA (Science Teaching Aids). Some of the apparatus, mostly for those experiments not prescribed in the current syllabus are made of inexpensive and readily available material.

The content of the electricity syllabus is given in *Appendix 2* The study of alternative conceptions in electricity does not form part of the electricity syllabus of the HDE students. This theme is included in the subject didactics syllabus, which is treated during the semester subsequent to that in which electricity is taught.

5.4 Teaching strategy for the SEDIBA electricity syllabus

The teaching strategy used in the presentation of the electricity course is based on results of research conducted at the Potchefstroom University (Smit & Vreken, 1988; Smit & Nel, 1997) and by a number of researchers at various institutions (Stanton, 1989; Van der Linde *et al*, 1994). A practical approach is followed. Care is taken to integrate practical work with theory, so that the two are not viewed as separate from one another. Teachers are allowed to work through experiments in groups of four. Worksheets are used by each teacher to record experimental observations and deductions. Theoretical abstractions are framed on the basis of teachers' observations and deductions. Thus teachers are allowed to be active participants who discover knowledge individually. This approach broadly follows the constructivistic approach to teaching discussed in chapter 4.

The teaching strategies used are directed at assisting teachers to form appropriate conceptual models for concepts in electricity and to solve problems. Problems with models

in electric circuits and with conventional current concepts are addressed. The significance and function of any electric circuit (energy transfer) are addressed. The purpose served by operational definitions of core concepts in electricity (for example emf, potential difference, resistance, current) is also addressed.

The classroom and laboratory activities are further reinforced by computer aided instruction. Teachers are regularly allowed to engage in computer tutorials, which involve the use of software program such as Matphicof, Falcon and GRD. These programs are interactive and include practically orientated exercises.

5.5 Conclusion

The electricity course outlined above was presented to the first group of SEDIBA teachers in the first semester of 1997. The teaching strategy used in presenting the course was also outlined in section 5.4 above. A pre-test was administered prior to instruction, and after instruction a post-test was administered to assess instructional success gain. The empirical study will be discussed in the next chapter.

CHAPTER 6

EMPIRICAL STUDY AND DISCUSSION OF RESULTS

6.1 Introduction

The empirical investigation in this study was done by means of a pre- and a post-test. The pre-test was administered by means of a questionnaire to teachers in the beginning of their second year of study (January 1997) in the SEDIBA Project, prior to any instruction in electricity. The same questionnaire was used in the post-test after completion of the electricity course (six months after the pre-test was administered). Teachers were also interviewed after completing the questionnaire. Observation during lecture periods, practical sessions and analysis of teachers' assignments; tests and examination scripts also formed part of the investigation. A total of 32 teachers registered in the SEDIBA Project, took part in this survey.

The survey was basically aimed at probing teachers' cognitive domains in three areas. Firstly, to investigate their (teachers') knowledge and understanding of core concepts in electricity identified and discussed in section 2.2.1 - 2.4.8. Secondly, to investigate how they apply these concepts, which can be regarded as an extension of the probe into understanding. Lastly to probe into teachers' alternative conceptions to see if they still cling to alternative conceptions commonly held by students. Only concepts (identified in section 2.5.7) regarded as core concepts in the domain of electrodynamics were focused on in the investigation. The questionnaire that was used is given in Appendix 1.

There was no time limit for answering the questionnaire in both the pre- and the post-tests. Teachers were allowed time to write until they have finished. The questionnaire was open-ended and teachers were requested to give their own explanations and motivations to their responses. Teachers were not fore-warned about both the pre- and the post tests. This was done to ensure that teachers do not prepare for these tests through rote learning

and memorization, as the survey was aimed at testing for permanent knowledge and understanding.

The results of the pre- and post-tests are summarized in TABLES 6.1 and 6.2 respectively. The discussion of these results (teachers' responses) will be given in section 6.3 (pre-test) and 6.6 (post-test). The scientifically acceptable responses to the pre- and the post-test are compared and discussed in section 6.7. Changes brought forward by tuition in teachers' conceptualization will also be discussed in this section. Section 6.8 deals with teachers' general problems and misconceptions identified through the study.

6.2 Results of the pre-test

Teachers' responses in the pre-test are summarized in TABLE 6.1.

TABLE 6.1: TEACHERS' RESPONSES IN THE PRE-TEST (N = 32)

ITEMS	RESPONSES	NO.	%
1.1 What is a conductor?	• Substance through which current/charge can flow	17	52
	• Substance through which electricity can flow	7	22
	• Substance that can conduct electricity	4	13
	• Others (partially correct)	4	13
1.2 What is an insulator?	• Substance through which charge/current cannot flow	15	47
	• Substance that cannot conduct electricity	8	25
	• Substance through which electricity cannot flow	1	3
	• Substance that retains both current and heat	2	6
	• Others (partially correct)	4	13
	• Others (incorrect)	2	6
2. What is the prime function of <i>any</i> electric circuit?	• To make the flow of current/charge possible	16	50
	• For use in teaching	7	22
	• For energy conversion (for human use)	6	19
	• Others (unacceptable + no response)	3	9

3.1 Define emf	<ul style="list-style-type: none"> Total energy supplied by the cell Others (correct) Others (incorrect) 	5 2 25	16 6 78
3.2 Define potential difference	<ul style="list-style-type: none"> Energy transferred to a circuit component by one coulomb of charge Energy transferred/consumed by a component in a circuit Others (incorrect) No response 	1 5 23 3	3 16 72 9
3.3 Define resistance	<ul style="list-style-type: none"> The substance's ability to resist the flow of current/charge Disturbance/something/friction experienced by flowing charges Quantitative definition Others (incorrect) No response 	6 13 2 9 2	19 41 6 28 6
3.4 Define electric current	<ul style="list-style-type: none"> Flow of charges Flow of electricity Rate of flow of charge Others (incorrect) No response 	24 3 1 2 2	75 10 3 6 6
4.1 Explain why scientists need to define emf	<ul style="list-style-type: none"> To know the amount of energy the cell can supply To show/explain relations between other electrical quantities Others (incorrect) No response 	5 7 13 7	15 22 41 22
4.2 Explain why scientists need to define potential difference	<ul style="list-style-type: none"> To specify the amount of energy a particular appliance need To describe energy/voltage changes in the circuit To show/explain relation between electrical quantities Others (incorrect) No response 	4 4 3 15 6	13 13 9 47 18
4.3 Explain why scientists need to define resistance	<ul style="list-style-type: none"> To know which resistor (devise) to use and for which specific purpose To know the extend of current reduction/conductivity in the circuit To explain/demonstrate certain electrical phenomena Others (incorrect) No response 	4 16 1 6 5	13 50 3 18 16

5. Describe the difference between emf and potential difference	<ul style="list-style-type: none"> • Incorrect responses • No response 	26 6	81 19
6. Explain whether energy is conserved in an electric circuit or not	<ul style="list-style-type: none"> • Yes (no explanation) • Yes, energy is converted from one form to the other • Yes, energy cannot be created or destroyed • Yes, so that it can be supplied to other components in the circuit • Yes (incorrect explanation) • No, (various reasons) • No response 	4 9 2 2 8 5 2	13 28 6 6 25 16 6
7. The voltage source in figure 1 (Appendix 1) has no internal resistance. Both bulbs M and N are lit. N is removed from its socket. Consequently :	<ul style="list-style-type: none"> • A: current no longer divides hence more energy goes to M • A: resistance is decreased • B: since no current flows • C: potential difference across parallel components stays the same • D: since no current flows and no resistance when N is removed • No response 	15 2 5 6 3 1	47 6 16 19 9 3
8.1 The amount of energy transferred to the bulb by each coulomb of charge is: (Appendix 1, figure 2)	<ul style="list-style-type: none"> • Correct responses • Incorrect responses • No response 	3 14 15	9 44 47
8.2 The amount of charge passing through the bulb in 3 minutes is:	<ul style="list-style-type: none"> • Correct responses • Incorrect responses • No response 	9 16 7	28 50 22
8.3 The amount of energy delivered to the bulb in 3 minutes is:	<ul style="list-style-type: none"> • Correct responses • Incorrect responses • No response 	6 13 13	18 41 41
8.4(i) The power of the bulb is:	<ul style="list-style-type: none"> • Correct responses • Incorrect responses • No responses 	8 11 13	25 34 41
8.4(ii) The amount of energy transferred to the bulb in 1 second is:	<ul style="list-style-type: none"> • Correct responses • Incorrect responses • No response 	7 8 17	22 25 53

9. How much energy is lost inside the battery when 1C of charge passes through it?	<ul style="list-style-type: none"> • Correct response • Incorrect response • No response 	12 5 15	37 16 47
10. Causal relation between voltage and current	<ul style="list-style-type: none"> • Current gives rise to potential difference. • potential difference gives rise to current 	20 12	63 37
11. How do you visualize the electron current in a copper wire forming part of an electric circuit?	<ul style="list-style-type: none"> • Movement of tiny energetic <i>particles</i> through the conductor • Others (acceptable) • Others (incorrect) • No response 	12 6 5 9	37 19 16 28
12(i) How do you visualize the conventional current in a copper wire forming part of an electric circuit?	<ul style="list-style-type: none"> • Flow of charge from positive to negative • Movement of positive charges • Flow of protons through conductors • No real movement of positive charges • Others (incorrect) • No response 	6 5 3 1 6 11	19 16 9 3 19 34
12.(ii) What particle(s) are charge carriers in conventional current?	<ul style="list-style-type: none"> • Positive charges • Electrons • Protons • Others (unacceptable) • No response 	7 7 6 6 6	22 22 19 19 18
13. Current at A will be: (figure 3, Appendix 1)	<ul style="list-style-type: none"> • the same as at B • larger than at B • smaller than at B • No response 	22 6 2 2	69 19 6 6
14. Will the bulb light? (fig. 4, Appendix 1)	<ul style="list-style-type: none"> • No • Yes • No response 	27 4 1	84 13 3
15. Draw the circuit diagram for this torch (fig. 4 Appendix 1)	<ul style="list-style-type: none"> • Correct sketch • Incorrect sketch • No sketch 	24 7 1	75 22 3
16. Draw the circuit diagram for the circuit (fig. 5 Appendix 1)	<ul style="list-style-type: none"> • Correct • Incorrect sketch • No sketch 	5 26 1	16 81 3

17. Fill in the values for I_1 , I_2 and I_3 in the circuit shown in figure 5.6. The bulbs are identical (fig. 6 Appendix 1)	<ul style="list-style-type: none"> • $I_1 = I_2 = I_3 = 0,4 \text{ A}$ • $I_1 = I_2 = I_3 = 1,2 \text{ A}$ • $I_3 = 0,3 \text{ A}; I_2 = 0,3 \text{ A}; I_1 = 0,6 \text{ A}$ • $I_1 = 0,6 \text{ A}; I_2 = 0,3 \text{ A}; I_3 = 0,015 \text{ A}$ • No response 	14 12 3 1 2	44 38 9 3 6
18. What will happen if 1,5 V bulb is connected to a 12 V battery?	<ul style="list-style-type: none"> • (d) • (b) • (a) • (c) • No response 	19 7 4 1 1	59 22 13 3 3
19. What will happen if a 12 V bulb is connected to a 1,5 V torch cell?	<ul style="list-style-type: none"> • (b) • (c) • (a) • No response 	15 13 3 1	47 41 9 3
20. In figure 5.7, a 9V battery with negligible internal resistance is connected to a series circuit of an electric motor; a 1,5 and a 2 V bulb. What must the voltage rating of the motor be for proper functioning?	<ul style="list-style-type: none"> • Correct response (5,5 V) • Incorrect responses • No response 	2 19 11	6 60 34

6.3 Discussion of teachers' responses to the pre-test

ITEM 1.1: *Explain what a conductor is*

This was the best attempted item in this questionnaire. However, a number of conceptual problems with regard to conductors and electrical conduction were brought to surface by the responses to this item. Slightly more than half (52 %) of the teachers responded to this item by saying that a conductor is *a substance through which current/charge can flow*. This is a scientifically accepted description. Thirteen percent of teachers responded by saying that a conductor is *a substance that conducts electricity*. Personal interviews with teachers revealed that most of them used this description without actually understanding what

"conducting electricity" means. Most of the teachers interviewed could not explain which entities are involved in electrical conduction.

A considerable number (22 %) of teachers responded by saying that *a conductor is a substance through which electricity can flow*. A deduction that can be made from this response is that teachers who responded in this manner think of *electricity* as something that flows. Another possibility is that teachers tend to use the term *electricity* as though it is synonymous to *current*. The distinction between the terms *current* and *electricity* is thus not clear to some of the teachers.

Other responses by teachers (13 %) were considered partially correct. This includes responses in which teachers define a conductor in a narrower sense in terms of *electron flow* only, and responses in which metals are regarded as the only conductors. These definitions are under-extended and do not include some non-conductors such as carbon and electrolytes. It is however correct that metals are generally good conductors, but not all conducting substances are metals. None of the responses to this item could be considered totally incorrect. This indicates that most of the teachers in this group have some understanding of the concept "electrical conductor" is generally understood (or only partially understood) by teachers.

ITEM 1.2: Explain what an insulator is

This item, together with item 1.1 above were meant to check as to whether teachers can differentiate between the concepts *conductor* and *insulator*. These concepts are briefly described in section 2.2.2. There is correlation in the manner in which teachers responded to both items 1.1 and 1.2. About half of the teachers (47 %) responded to this item correctly by saying that an insulator is *a substance through which charge/current cannot flow*. Most of the teachers who defined a conductor in terms of current/charge flow in item 1.1 above, also defined an insulator in terms of current/charge flow. There is therefore consistency in the manner in which these teachers conceptualize *electric conduction*. Twenty five

percent of the teachers defined an insulator as a substance that cannot conduct electricity. Similarly, most of the teachers who responded in this manner are the ones who defined a conductor as a substance that conducts electricity in item 1.1 above. Only one teacher defined an insulator as a substance through which electricity cannot flow. Two teachers defined an insulator as a substance that retains both electricity and heat. Thirteen percent of the responses were considered partially correct. As in item 1.1 above, a response is considered to be partially correct if it contains elements of the truth, but does not describe the concept in question completely. Only 6 % of the responses were incorrect.

ITEM 2: *What would you say is the prime function(s) of any electric circuit?*

This item was meant to check as to whether teachers understand the significance of constructing *any* electric circuit. Half (50%) of the teachers responded to this item by saying that electric circuits are constructed to make the flow of charge/current possible. Teachers who responded in this manner understand an important role played by an electric circuit: that is, to provide the path for the flow of electric charge/current. However, providing a path for current/charge to flow is not all what engineers and scientists want to achieve by connecting electric circuits. The interest is in the consequences of charge/current flow and not merely on its flow.

Twenty two percent of the teachers responded to this item by saying that electric circuits are connected so that they can be used in teaching; to demonstrate some electrical phenomena. This response indicates that some teachers perceive electric circuits in a much narrower sense and cannot think of them (electric circuits) beyond the confines of a classroom/laboratory situation. All what electric circuits mean to these teachers is what they usually construct in the classroom using circuits boards and electric connectors. This perception of electric circuits shows no sensitivity to everyday use of electric circuits in electrical devices/appliances such as radios, electric kettles, cars and torches.

Only nineteen percent of the teachers responded to this item by saying that the significance of connecting an electric circuit is to allow energy conversion to take place. Some of the teachers (included in the 19 %) responded by saying the electric circuit makes it possible for energy to be converted into the form that is usable by human beings. Some gave examples of this "usable energy" as light and heat. It is true that an electric circuit makes energy conversion *possible*, but (electrical) energy is actually converted into a more usable form in the electrical appliance (e.g. bulb) and not in the entire circuit. Thus an electric circuit only serve the purpose of conveying energy from the source (e.g. cell) to the electrical appliance (where it is to be converted).

Nine percent of the teachers did not respond to this item or gave incorrect or unclear responses.

ITEM 3.1: *Define emf*

Only two (6 %) of the responses to this item can be considered acceptable from a scientist's point of view. One of these responses was that emf is the potential difference across the cell when the cell is not connected to the circuit, and the other one was that emf is the total potential difference in the circuit. The latter response is considered correct in the sense that according to Kirchhoff's rule: the sum of all the potential drops in the circuit is equal to the emf of the source.

Non of the teachers could define emf as the total energy supplied by the source to each coulomb of charge passing through it, which is how it is defined in most text books currently in use. Sixteen percent of the teachers responded by only saying that emf is the total energy supplied by the cell.

Seventy two percent of the teachers gave scientifically unacceptable definitions. These include responses whereby emf is defined as the force that makes electrons move through the circuit. Two teachers did not even respond to this item.

These results are also indicative of the fact mentioned in section 2.4.8 that emf is one of those concepts which most students and teachers find difficulties on.

ITEM 3.2: *Define potential difference*

The responses to this item indicates little understanding of the concept potential difference. Only one teacher responded to this item by saying that potential difference is the energy transferred to a circuit component by one coulomb of charge passing through the component. Sixteen percent of the teachers defined potential difference only in terms of the amount of energy transferred to (or converted) by the circuit component, neglecting to state that this energy is transferred by a unit charge. Seventy two percent of the teachers gave incorrect responses, and 9 % did not respond to this item.

ITEM 3.3: *Define resistance*

The concept *resistance* was better defined by teachers as compared to emf and potential difference. Nineteen percent of the teachers responded to this item by saying that resistance is the substance' ability to prevent/resist the flow of current/charge. Forty one percent of teachers responded by saying that resistance is the disturbance/something/friction/opposition or difficulties experienced by flowing charges/current. It is striking that only two teachers could give the scientific definition for resistance by stating that it (resistance) is the ratio of potential difference to current. Twenty eight percent of the teachers gave incorrect responses, and 6 % did not respond to this item at all. Included in the incorrect responses are those responses (13 %) whereby teachers define resistance as a substance/object/apparatus that decrease/resists current flow. This indicates that some teachers have a problem in differentiating between the terms *resistance* and *resistor*. This problem may be attributed to the fact that English is not the first language to teachers who took part in this survey.

ITEM 3.4: *Define electric current*

It is astonishing that most of the teachers defined current as merely the flow of charges (75%) or the flow of electricity (9%). Only one teacher (3%) defined

current correctly by saying that it is the rate of flow of charge. Six percent of the teachers gave incorrect responses and the other 6% did not respond.

ITEM 4.1: *Explain why scientists need to define emf*

Items 4.1- 4.3 were meant to check as to whether teachers understand why specific concepts (emf, potential difference and resistance) are defined. The significance of defining these concepts is discussed in sections 2.4.3 and 2.4.6. Fifteen percent of the teachers responded to this item by saying that scientists define *emf* because they need to know the amount of energy the cell can supply. Teachers who responded in this manner are those who have defined emf as the amount of energy supplied to charges in item 3.1. No mention was made by these teachers that, it is the energy supplied by the cell to one coulomb of charge. Twenty two percent of the teachers responded by saying that emf is defined in order to show and explain electrical phenomena and relations between other electrical quantities. Other incorrect responses were given by 41% of the teachers. These included responses whereby teachers say that emf is defined so that the amount of force that pushes electrons can be known. Similarly, most teachers who responded in this manner are those who defined emf as the force that pushes the electrons in item 3.1. The difficulty that teachers have with the understanding of the significance of defining specific concepts was further indicated by the fact that 22% of the teachers did not respond to this item at all.

The difficulty experienced by teachers to respond correctly to this item can be attributed to their inability to define the concept emf as shown in item 3.1.

ITEM 4.2: *Explain why scientists need to define potential difference*

The responses to this item indicated little understanding of the significance of defining specific concepts in science. Thirteen percent of the teachers responded to this item by saying that potential difference is explained by scientists in order for them to specify the amount of energy a particular appliance needs. The other 13% responded by saying that "in order to describe energy/voltage changes in the

circuit". As in item 4.1 above, non of the teachers mentioned that it is actually the energy change (or energy required) per one coulomb of charge across a particular appliance (or circuit component) that scientists are interested in when they define potential difference. Nine percent of the teachers responded by saying that potential difference is defined for the purpose of showing and defining phenomena and relationships between other electrical quantities. A further 58% of the teachers gave a wide variety incorrect responses. Eighteen percent of the teachers did not even respond to this item.

ITEM 4.3: *Explain why scientists need to define resistance.*

In the same way as in items 4.1 and 4.2 above, teachers responded to this item in ways that indicate little understanding of the significance of defining specific concepts in science. Thirteen percent of the teachers responded by saying that resistance is defined for the purpose of knowing which resistor (or devise) to use and for which specific purpose. Half of the teachers (50%) responded by saying that resistance is defined so that the extend of conductivity or current reduction in the circuit can be known. In this case only one teacher responded by saying that resistance is defined for the purpose of explaining and demonstrating certain electrical phenomena. A further 18% of the teachers gave incorrect responses. Sixteen percent of the class did not even respond to this item.

ITEM 5: *Describe the difference between emf and potential difference.*

This item was aimed at checking as to whether teachers can differentiate between potential difference and emf. Responses to this item indicate that teachers have difficulties in the understanding of these two concepts. Failure of teachers to respond correctly to this item can also be attributed to the teachers' inability to define the two concepts in question as reflected in items 3.1 and 3.2. The discussion of the difference between the concepts potential difference and emf was made in section 2.4.6. All the teachers who responded to this item (81%) gave a

wide variety of incorrect responses. The other 19% did not even respond to this item.

ITEM 6: *Explain whether energy is conserved in an electric circuit or not.*

This item was aimed at checking as to whether teachers understand the fundamental law of energy conservation. Thirteen percent of the teachers responded to this item by saying "yes" and gave no explanation, and 28% responded by saying "yes" and substantiated by saying that energy is converted from one form to the other. Two teachers (6%) responded by saying " yes, since energy cannot be created or destroyed". Another 6% of the teachers who responded with a "yes" substantiated by saying that energy is conserved in the circuit so that it can be supplied to all other components in the circuit. This response reflect poor understanding of what is meant by "conservation of energy". Teachers who responded in this manner think of energy conservation in electric circuit as implying that sufficient energy is supplied such that all components get their "share". According to this interpretation of energy conservation, energy will not be conserved in an electric circuit if energy runs out in the circuit and not all the components get supplied with energy. A quarter of the class also responded by saying "yes" but gave incorrect explanations.

A wide variety of explanations were given by 16% of the teachers who responded by saying "no". These explanations include an assertion by some teachers that energy is not conserved in an electric circuit since the cell/battery runs out when connected to the circuit. Six percent of the teachers did not respond to this item.

ITEM 7: *In figure 1 (Appendix 1), the voltage source has no internal resistance. Both bulbs M and N are lit. N is removed from its socket. Consequently:*

This item was aimed at checking as to whether teachers understand how voltage is shared between components in parallel and in series. Forty seven percent of the teachers selected "A" (bulb M will light more strongly) and substantiated by saying that since current is no longer divided, more energy goes to M. The other 6% of

respondents who selected "A" said that resistance was decreased when N was removed. This claim indicates a lack of understanding by teachers of the fact that the effective resistance in the circuit actually decrease when more components/resistors are connected in parallel. Sixteen percent of the teachers selected "B" (the potential difference between D and E will become zero) on the ground that if no current flows, the potential difference becomes zero. This response indicates a misunderstanding by teachers of the causal relationship between current and potential difference. Like many students (as explained in section 3.2.8), these teachers also harbor the misconception that current gives rise to potential difference. Nineteen percent of the teachers selected "C" (the potential difference between D and E will not change) and explained scientifically correctly by saying that the potential difference across parallel components stays the same. The 9% who selected "D" (the potential difference between D and E will increase) claimed that the potential difference between D and E will increase because of the absence of both the resistance due to N and current in branch DEF. Only one teacher did not respond to this item.

ITEM 8.1: *In figure 2 (Appendix 1), the amount of energy transferred to the bulb by each coulomb of charge is:*

This items (8.1) and the next three (8.2- 8.4) were aimed at probing into teachers' ability to apply concepts in solving problems. Only 9% of the teachers responded correctly to this item. Forty four percent gave incorrect answers and 47% did not respond to this item. It was evident from the responses of teachers who gave incorrect answers that they struggled to find the correct equation to be used to solve the problem. In fact some of the teachers requested the test supervisor to supply them with equations as they could not remember them. This reveals a lack of understanding.

ITEM 8.2: *In figure 2 (Appendix 1), the amount of charge passing through the bulb in three minutes is:*

Only 28% of the teachers obtained the correct answer to this item. Half of the teachers (50%) obtained incorrect answers. Most of them encountered difficulties with equations similar to that in item 8.1 above. Thirteen percent of these teachers (included in the 50%) used the relevant equation but substituted time in minutes instead of converting it to seconds. Twenty two percent of the teachers did not respond to this item.

ITEM 8.3: *In figure 2 (Appendix 1), the amount of energy delivered to the bulb in three minutes is:*

Only 18% of the teachers obtained correct answers to this item, 41% obtained incorrect answers, and 41% did not respond.

ITEM 8.4 (i): *In figure 2 (Appendix 1), the power of the bulb is:*

Twenty five percent of the teachers obtained the correct answer. The answer was mostly obtained through straight forward application of the equation ($P = IV$). Thirty four percent of the teachers obtained incorrect answers, and 41% did not respond.

ITEM 8.4 (ii): *In figure 2 (Appendix 1) the amount of energy transferred to the bulb in one second is:*

This item was meant to check as to whether teachers understand the fact that the amount of energy transferred in one second means the same thing as *power*. Only 22% of the teachers could answer this question correctly. Slightly more than half (53%) of the teachers did not respond to this item, and 25% of the responses were incorrect.

ITEM 9: *In figure 2 (Appendix 1), how much energy is lost inside the battery when 1 C of charge passes through it?*

This item was meant to probe into teachers' understanding of the concept of the "lost volts". This concept was discussed in section 2.4.7. Thirty seven percent of the teachers obtained the correct answer and 16% obtained incorrect answers, while 47% did not even respond.

The relative high frequencies of correct responses to items 8.2, 8.3, 8.4 and 9 indicate that the respondees can apply an algorithm.

ITEM 10: *In a discussion about electric current and potential difference Thabo states:*

"A current in a resistor gives rise to a potential difference across the resistor." Thomas says no, it is the other way round. A potential difference across a resistor causes a current in the resistor." With whom do you agree? Motivate your answer.

This item was intended to probe into teachers' understanding of the causal relationship between current and potential difference. The majority of teachers (63%) responded by saying that current gives rise to potential difference. Thirty seven percent gave the scientifically acceptable response: potential difference gives rise to current. This result shows that most of the teachers are "current orientated" in their reasoning about electric circuits. They tend to think of current as the primary concept in electric circuits, while potential difference is thought of as a consequence of current flow. This way of thinking about current and potential difference is in accordance with a common misconception in electric circuits discussed in section 3.2.8. The correct scientific description of the causal relationship between the concepts current and potential difference is made in section 2.3.7 and 2.4.4.

ITEM 11: *How do you visualize electron current in a copper wire forming part of an electric circuit?*

In this item, teachers were requested to explain, with the help of a diagram, how they visualize electron current in a copper wire forming part of an electric circuit. The responses of 37% of the teachers indicate that they visualize electron current as the movement of tiny energetic particles through the conductor. Nineteen percent of the teachers gave a variety of acceptable models of electron current. Sixteen percent of them gave a wide range of models scientists would not agree with. One of the teachers responded by saying that the electron current is a winding movement of electrons through the wire. A sketch of a winding line with an arrow accompanied the explanation. In one of the scientifically unacceptable responses a teacher said that electron current consists of both positive charges and negative charges moving in opposite directions. Some of the teachers only supplied sketches of electric circuits with arrows in the direction negative to positive on the connecting wires and gave no explanation. Twenty eight percent of the teachers did not respond to this item. Some of the teachers who did not respond indicated during interviews that they did not understand what the question was asking for. The fact that only 37% of the respondents gave an acceptable visual picture of the electron current indicates that teachers generally have problems with visualization of entities in science.

ITEM 12 (i): *How do you visualize conventional current in a copper wire forming part of an electric circuit?*

As in item 11 above, in this item teachers were requested to explain by means of a diagram how they visualize conventional current in a copper wire forming part of an electric circuit. Only one teacher out of 32 responded by saying that the conventional current does not involve the actual movement of positive charges. Nineteen percent of teachers explained by saying that conventional current is the flow of charge from positive to negative and 16% said that it is the movement of positive charges. Nine percent of the teachers said that conventional current is the flow of protons. A further 19% of the teachers gave a wide range of incorrect responses and 31% did not respond to this item.

ITEM 13: *In figure 3 (Appendix 1), the current is measured at A and at B*

simultaneously. What would you expect the measurements to be?

The purpose of this item was to test whether teachers held the popular misconception that current is consumed by the bulb in the circuit. Sixty nine percent of the teachers responded correctly to this item by saying that the current at A will be the same as at B. Most of these teachers substantiated their response by saying that current is the same at all points in a series circuit. Nineteen percent of the teachers said that the current at A will be larger than that at B. This a popular misconception (see section 3.2.3). The reason given by most of these teachers is that current gives rise to the light at the bulb. Six percent of the respondees said that the current at A will be smaller than at B. No explanation was given for this response. Only 6% of the class did not respond to this item.

ITEM 14: *Will the bulb in figure 4 (Appendix 1) light?*

The intention of this item was to test whether teachers reason according to the *unipolar model* in electric circuits. This model (unipolar) of reasoning was discussed in section 3.2.1. Eighty four percent of the teachers responded to this item scientifically correct by saying "no". The main reason given by most teachers is that the circuit is not complete. Thirteen percent of the teachers responded by saying "yes", without providing any explanation. Only one teacher did not respond to this item.

ITEM 15: *Draw the circuit diagram for the torch shown in figure 5 (Appendix 1).*

This item and item 16 were meant to probe into teachers' ability to draw circuit diagrams from real circuits. This items are related to the discussion on *misinterpretation of real circuits* made in section 3.2.14. The majority of the respondees (75%) gave correct diagrams. Twenty two percent of them gave incorrect sketches. These include sketches with one or more of the components of the circuit missing, for example the switch, bulb or cell. Only one teacher did not respond to this item. When asked (in an interview) why he could not draw a

circuit, this teacher responded by saying that "I cannot see any electric circuit in the diagram". This response indicates that the teacher in question can only associate electric circuit with connecting wires and circuit boards usually used in a classroom situation.

ITEM 16: *Draw the circuit diagram for the circuit shown in figure 6 (Appendix 1).*

Only 16% of the teachers' responses were scientifically correct. Most of the responses (81%) were unacceptable. The most common of these incorrect responses was whereby the ammeter was connected in series with the bulbs. In other incorrect responses the ammeter was connected in parallel with all the three bulbs. In some cases teachers connected a voltmeter in the place of an ammeter. The conclusion from this results is that the majority of teachers in this group is unable to translate information from a real situation (a picture of an electric circuit) to symbol form (a circuit diagram).

ITEM 17: *In figure 5.6, the bulbs are identical. Fill in the values for I_1 , I_2 and I_3 .*

The purpose of this item was to test whether teachers use the so-called *local reasoning* (discussed in section 3.2.10) when dealing with electric circuit. Forty four percent of the group gave scientifically accepted responses by saying that current in all the three branches will be 0,4 A. Thirty eight percent responded by saying that current will not divide, thus 1,2 A of current flows in all the three branches. Only 9% of the teachers responded by saying that $I_1 = 0,3$ A; $I_2 = 0,3$ A and $I_3 = 0,6$ A. Similar response can be obtained through *sequential reasoning* (discussed in section 3.2.9). One of the teachers responded by saying that $I_1 = 0,6$ A; $I_2 = 0,3$ A and $I_3 = 0.15$ A. According to this response, current is dividing into half at each successive junction. Only 6% of the teachers did not respond to this item.

ITEM 18: *What will happen if a 1,5 V bulb is connected to a 12 V battery? The bulb will:*

This item was included to test teachers' knowledge of energy transfer in electric circuits, and the ability to match appliances with a compatible energy source. A 12 V battery supplies 12 J of energy to every coulomb of charge passing through it. A 1,5 V bulb functions normally if every coulomb of charge passing through it transfers 1,5 J of energy. If connected to a 12 V battery an excess of 10,5 J of energy will be transferred to the bulb, causing it to fuse with a bright flash. Fifty nine percent of the teachers responded by saying that the bulb will only give a bright flash. Twenty two percent said that the bulb will not light at all and 13% indicated that it will light normally. Only one teacher said the bulb will light normally. One teacher did not respond.

ITEM 19: *What will happen if a 12 V bulb is connected to a 1,5 V torch cell?*

The purpose of this item was just the opposite as with the previous one. Forty one percent of the teachers responded correctly by saying that the bulb will glow dim red and 47% said that the bulb will not light at all. Nine percent said that the bulb will light normally and 3% did not respond to this item.

ITEM 20: *In a series circuit (figure 5.6) a 9 V battery with negligible internal resistance is connected to a series circuit of an electric motor; a 1,5 and a 2 V bulb. What must the voltage rating of the motor be for proper functioning?*

This item was intended to probe into teachers' ability to match components in a circuit. Only 6% of the teachers supplied the correct answer (5,5 V). Sixty percent of the answers constituted a wide range of incorrect responses. Thirty four percent of the teachers did not respond to this item.

6.4 General conclusion on responses given in the pre-test

From the results of the pre-test discussed above, it is clear that teachers who participated in this survey had problems with the knowledge and understanding of core concepts in electricity prior to formal instruction in electricity in the SEDIBA Science Teacher Upgrading Project. The average percentage of the scientifically accepted responses was 26%. This results verify the hypothesis which was stated in section 1.2 that teachers at secondary school level experience problems with the understanding of core concepts in electricity. The general problems encountered by teachers in the pre-test are summarized below.

The pre-test results revealed that some of the teachers in this group still harbor misconceptions (discussed in section 3.2) commonly held by students. Thirteen percent of the teachers reason according to the *unipolar model* (discussed in section 3.2.1). Nine percent of them used the *local or the sequential* model of reasoning. The consumer's model was used by 19% and 63% of them regard potential difference as the consequence of current flow and not as its cause.

Most of the teachers could explain the concepts *conductor* and *insulator*. Potential difference and emf (discussed in section 2.3.7, 2.4.6 and 2.4.8) however showed to be more difficult concepts as only a few of the teachers could explain and apply them in a scientifically acceptable manner. The reason for this may be that the concepts *conductor* and *insulator* are more related to real life than the concepts emf and potential difference. The relatively high frequencies of correct responses to items 8.2, 8.3, 8.4 and 9 indicates that the respondees could apply algorithms. Items 11 and 12 which involve visualization were poorly attempted, indicating that teachers in this group generally have problems with the formation of mental images of concepts in electricity. One difficulty experienced by teachers in the pre-test was with regard to the matching of components in an electric circuit as indicated by low frequency of correct responses to item 20. This is a consequence of the lack of understanding of the core concepts emf and potential difference.

From the above discussion, a conclusion can be drawn that the teachers who took part in this survey were not sufficiently prepared for their task. Although one must bear in mind that these teachers were not fore-warned about the pre-test (for reasons mentioned in section 6.1), the average performance of 26% is far too low, considering the fact that these teachers teach physical science in senior classes (up to grade 12).

6.5 Results of the post-test

Teachers' responses in the post-test are summarized in TABLE 6.2 below. A discussion of the results is given in section 6.6.

TABLE 6.2: TEACHERS' RESPONSES IN THE POST-TEST (N = 32)

ITEMS	RESPONSES	NO.	%
1.1 What is a conductor?	• Substance through which current/charge can flow	16	50
	• Substance through which electricity can flow	8	25
	• Substance that can conduct electricity	4	13
	• A substance through which energy can flow	2	6
	• Others (partially correct)	2	6
1.2 What is an insulator?	• A substance through which current/charge/heat cannot flow	16	50
	• A substance through which electricity cannot flow	6	19
	• A substance that cannot conduct electricity	4	13
	• Others (partially correct)	3	9
	• Substance through which energy cannot flow	2	6
	• Substance used to cover conductors	1	3
2.1 What is the prime function of <i>any</i> electric circuit	• To make the flow of current/ charge/ electricity possible	11	34
	• To transfer electric energy from the source	13	41
	• To make energy conversion possible (for human use)	4	13
	• To illustrate electrical phenomena	1	3
	• To create energy	2	6
	• No response	1	3

3.1 Define emf	<ul style="list-style-type: none"> • Total energy supplied by/ contained in a cell • Total energy acquired by 1C of charge when passing through a cell • Total potential difference in a circuit • Potential difference of a cell when not connected to the circuit • Energy transferred to a circuit component by 1C of charge • Energy lost in a circuit • Force needed to push charges through conductors 	<p>13</p> <p>12</p> <p>2</p> <p>2</p> <p>1</p> <p>1</p> <p>1</p>	<p>41</p> <p>38</p> <p>6</p> <p>6</p> <p>3</p> <p>3</p> <p>3</p>
3.2 Define potential difference	<ul style="list-style-type: none"> • Energy transferred by 1C of charge between two points in a circuit • Energy delivered by charges per second • Voltage transferred by 1C between two points in a circuit • Total energy of the circuit/cell • Energy transferred between two points in a circuit • Amount of charge through a point in a circuit • Flow of current • Energy supplied to 1C of charge • Product of R and I • No response 	<p>16</p> <p>4</p> <p>1</p> <p>2</p> <p>4</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>50</p> <p>13</p> <p>3</p> <p>6</p> <p>13</p> <p>3</p> <p>3</p> <p>3</p> <p>3</p> <p>3</p>
3.3 Define resistance	<ul style="list-style-type: none"> • Substance's ability to prevent/ disturb/ decrease current/ charge /electrical flow • The substance that resists current flow • Potential difference per unit current • Force that makes the flow of charge difficult • No response 	<p>22</p> <p>3</p> <p>5</p> <p>1</p> <p>1</p>	<p>69</p> <p>9</p> <p>16</p> <p>3</p> <p>3</p>
3.4 Define electric current	<ul style="list-style-type: none"> • Flow of charges (both positive & -negative) • Amount of charge passing a given point/time • Flow of charge from positive to -negative • The flow of 1C of charge (per second) • Energy to move charges • The ratio V/R • The flow of 1C of charge when 1V is maintained across 1 ohm resistor • No response 	<p>18</p> <p>3</p> <p>3</p> <p>4</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>57</p> <p>9</p> <p>9</p> <p>13</p> <p>3</p> <p>3</p> <p>3</p> <p>3</p>

4.1 Explain why scientists need to define emf	<ul style="list-style-type: none"> To know the amount of energy the cell can supply (per coulomb) To explain other electrical phenomena To know the amount of force between the terminals of the cell Others (incorrect) No response 	11 12 2 6 1	34 38 6 19 3
4.2 Explain why scientists need to define potential difference	<ul style="list-style-type: none"> Need to determine the amount of energy a specific component needs To explain/show other electrical phenomena Others (incorrect) No response 	9 7 15 1	28 22 47 3
4.3 Explain why scientists need to define resistance	<ul style="list-style-type: none"> To know the extend of resistance to current To show explain other electrical phenomena To determine whether the appliance is good to serve a specific purpose Others (incorrect) No response 	10 9 4 8 1	31 28 13 25 3
5. Describe the difference between emf and potential difference	<ul style="list-style-type: none"> Energy transferred to a charge Energy lost by a charge (between two points) Others (incorrect) No response 	16 14 2	50 44 6
6. Explain whether energy is conserved in an electric circuit or not	<ul style="list-style-type: none"> Yes: correct explanation Yes: incorrect (or no explanation) No: Cell runs out/ consumed/ not regained No response 	14 11 6 1	44 34 19 3
7. The voltage source in figure 5.1 has no internal resistance. Both bulbs M and N are lit.. N is removed. Consequently: (fig. 1 Appendix 1)	<ul style="list-style-type: none"> b: circuit is broken c: potential difference stays the same a: more current hence more energy to M d: less resistance when bulb is removed No response 	12 10 6 3 1	38 31 19 9 3
8.1 The amount of energy transferred to the bulb by each coulomb of charge is: (fig. 2 Appendix 1)	<ul style="list-style-type: none"> 6J 30J 5J Others (incorrect) No response 	18 4 3 3 4	56 13 9 9 13
8.2 The amount of charge passing through the bulb in 3 minutes is:	<ul style="list-style-type: none"> 900 C 15 C Others (incorrect) No response 	18 4 5 5	55 13 16 16

8.3 The amount of energy delivered to the bulb in 3 minutes is:	<ul style="list-style-type: none"> • 5400 J • 90 J • Others (incorrect) • No responses 	11 3 13 5	34 9 41 16
8.4 (i) The power of the bulb is:	<ul style="list-style-type: none"> • 30 W • Others (incorrect) • No response 	23 6 3	72 19 9
8.4 (ii) The amount of energy transferred to the bulb in 1 second is:	<ul style="list-style-type: none"> • 30 J • Others (incorrect) • No response 	13 10 9	41 31 28
9. How much energy is lost inside the battery when 1 coulomb of charge passes through it?	<ul style="list-style-type: none"> • 0,5 J • Others (incorrect) • No response 	17 7 8	53 22 25
10. Causal relationship between voltage and current	<ul style="list-style-type: none"> • Thomas: pd. gives rise to current • Thabo: current gives rise to pd. • Thomas: no explanation • Thabo: no explanation • Both are correct/ wrong 	9 9 5 6 3	28 28 16 19 9
11. How do you visualize the electron current In a copper wire forming part of an electric circuit?	<ul style="list-style-type: none"> • Movement of charge from -negative to positive • Electrons moving from positive to negative • Series of electrons moving within a wire • Others (acceptable) • Others (unacceptable) • No response 	13 4 3 4 4 4	39 13 9 13 13 13
12. (i) How do you visualize the conventional current in copper wire forming part of an electric circuit?	<ul style="list-style-type: none"> • Circuit diagrams with arrows pointing away from positive terminal of cell • Positive charges moving from positive to -negative terminal of cell • Electrons moving from positive to -negative terminal of cell • The movement of protons • Not actual movement of positive charge • Others (unacceptable) • No response 	8 8 5 2 1 5 3	25 25 16 6 3 16 9
12. (ii) What particle(s) are charge carries in conventional current?	<ul style="list-style-type: none"> • Positive charges • Electrons • Protons • Others (incorrect) 	10 9 7 6	31 28 22 19

13. In the circuit sketched (fig. 3 Appendix 1), the current at A will be:	<ul style="list-style-type: none"> • b: current is conserved • a: current is consumed • c: 	28 2 2	88 6 6
14. A bulb is connected to a torch cell (fig. 4 Appendix 1). Will the bulb light?	<ul style="list-style-type: none"> • No • Yes 	30 2	94 6
15. Draw the circuit diagram for this torch (fig. 5 Appendix 1)	<ul style="list-style-type: none"> • Correct diagram • Switch missing • Resistor included • Resistor and rheostat included 	25 5 1 1	78 16 3 3
16. Draw the circuit diagram for the circuit sketched in fig. 6 (Appendix 1)	<ul style="list-style-type: none"> • Correct sketch • Ammeter in series with bulbs • Ammeter/ switch omitted • Others (incorrect) 	9 9 4 10	28 28 13 31
17. Fill in the values for I_1 , I_2 and I_3 in the circuit shown in figure 7 (Appendix 1). The bulbs are identical.	<ul style="list-style-type: none"> • 0,4 all • $I_1 = 0,6 \text{ A}; I_2 = 0,3 \text{ A}; I_3 = 0,3 \text{ A}$ • 1,2 A all • $I_1 = 0,6 \text{ A}; I_2 = 0,6 \text{ A}; I_3 = 1,2 \text{ A}$ • No response 	21 8 1 1 1	66 25 3 3 3
18. What will happen if 1,5 V bulb is connected to a 12 V battery?	<ul style="list-style-type: none"> • d • a • b 	24 5 3	75 16 9
19. What will happen if a 12 V bulb is connected to a 1,5 V torch cell?	<ul style="list-style-type: none"> • d • c 	20 12	63 37
20. In fig. 8 Appendix 1) a 9 V battery with negligible internal resistance is connected to a series circuit of an electric motor; a 1,5 and a 2 V bulb. What must the voltage rating of the motor be for proper functioning?	<ul style="list-style-type: none"> • Correct response (5,5 V) • Others (incorrect) • No response 	9 17 6	28 53 19

6.6 Discussion of teachers' responses to the post-test

This section constitutes a discussion of the responses to the post-test and a comparison of the responses to the pre- and the post-tests. A discussion of the changes and improvement brought forward through intervention by instruction will be made in section 6.7.

ITEM 1.1: *Explain what a conductor is*

Half of the teachers responded to this item by saying that a conductor is a substance through which current/charge can flow. Twenty five percent responded by saying that a conductor is a substance through which electricity can flow. This response indicates that the perception of electricity as being synonymous to current was still maintained by teachers even after instruction. Thirteen percent of teachers responded by saying that a conductor is a substance that can conduct electricity. Six percent of the teachers said a conductor is a substance through which energy can flow. This responses were made without any mention of entities that "carry" energy in the process of electrical conduction. Teachers who responded in this manner harbor the perception of energy as something that can flow on its own through conductors. The other 6% of the responses were partially correct. None of the responses could be considered to be completely incorrect.

ITEM 1.2: *What is an insulator?*

Half of the teachers responded to this item by saying that an insulator is a substance through which current/charge cannot flow. Some of these teachers included the fact that heat cannot flow through insulators in their responses. Nineteen percent of the teachers described an insulator as a substance through which electricity cannot flow. Thirteen percent responded by saying that an insulator is a substance that cannot conduct electricity. Six percent responded by saying that an insulator is a substance through which energy cannot flow. These responses were made by the same teachers who defined a conductor as a substance through which energy can flow in item 1.1 above. Nine of the responses were

partially correct. One teacher said an insulator is a substance used to cover conductors.

ITEM 2.1: *What is the prime function of any electric circuit?*

Forty one percent of the teachers responded to this item by saying that the prime function of any electric circuit is to make the transfer of electrical energy from the source possible. Thirty four percent of the teachers responded by saying that any electric circuit's prime purpose is to make the flow of charge/current/electricity possible. Thirteen percent of the teachers said electric circuits make the conversion of energy (for human use) possible and 6% said that electric circuits are connected so as to create energy. One teacher said that electric circuits are connected to illustrate electrical phenomenon (in teaching), and one did not respond to this item.

ITEM 3.1: *Define emf*

Forty one percent of the teachers responded to this by saying that emf is the total energy contained or supplied by the cell. Only 38% of the teachers responded correctly by defining emf as the energy acquired by 1 C of charge when passing through a cell. Six percent of the teachers defined emf as the total potential difference in a circuit. This definition is correct since according to Kirchhoff's rule, the total emf in the circuit is equal to the total sum of the individual potential differences. The other 6% of the teachers defined emf as the potential difference across a cell when the cell is not connected to the circuit. This definition is also acceptable. One teacher defined emf as though it meant the same thing as potential difference by saying that it (emf) is the energy transferred to a circuit component by 1 C of charge, and the other one defined it (emf) by saying that it is the energy lost in a circuit. Only one teacher defined emf as a force needed to push charges through conductors.

ITEM 3.2: *Define potential difference*

Half of the teachers defined potential difference correctly as the energy transferred by 1 C of charge between two points in a circuit. Thirteen percent of the teachers defined potential difference by saying it is the energy transferred between two points in a circuit. One teacher responded by saying that potential difference is the product of resistance and current. Only one did not respond to this item. The other 31% of teachers gave a wide range of incorrect responses.

ITEM 3.3: *Define resistance*

Sixty nine percent of the respondents defined resistance as the substance's ability to resist/prevent/disturb/decrease the flow of charge/current/electricity. Only 16% of them defined resistance in a scientifically accepted manner by saying it is the ratio of potential difference and current. Nine percent of the teachers defined resistance as the substance that resists current flow. This response indicates that these teachers cannot differentiate between the terms "*resistance*" and "*resistor*". One teacher defined resistance as the force that makes the flow of charge difficult and one did not respond to this item.

ITEM 3.4: *Define electric current*

Slightly more than half of the teachers (57%) defined electric current as the flow of charges. Only 9% of them responded in a scientifically accepted manner by saying that electric current is the amount of charge passing a give point per unit time. One teacher defined electric current as the ratio of potential difference and resistance. Thirty seven percent of the teachers gave a wide range of incorrect responses. Only one teacher did not respond to this item.

ITEM 4.1: *Explain why scientists need to define emf*

Thirty four percent of the teachers responded to this item by saying that emf is defined in order to know the amount of energy the cell can supply per coulomb of charge. Thirty percent of them said that emf is defined in order to explain other

electrical phenomena. Only 6% of the teachers said that emf is defined in order to know the amount of force between the terminals of the battery. One teacher did not respond to this item and 22% of them gave a wide range of incorrect responses. The reason why scientists define the concept emf was stated in section 2.4.7 as being to enable a qualitative description of energy transfer in a circuit.

ITEM 4.2: *Explain why scientists need to define potential difference*

The reason why scientist define the concept potential difference is the same as that for defining emf given in item 4.1 above. Only 28% of the teachers responded to this item by saying that scientists need to define potential difference in order to determine the amount of energy a specific circuit component needs. Twenty two percent of the teachers responded by saying that potential difference is defined in order to explain /illustrate other electrical phenomena. Only one teacher did not respond to this item and 47% gave a wide range of incorrect responses.

ITEM 4.3: *Explain why scientists need to define resistance*

Thirty one percent of the teachers responded by saying that resistance is defined in order to know the extend of resistance/disturbance/obstruction to current and 28% responded by stating that resistance is defined in order to explain and illustrate other electrical phenomena. Thirteen percent said resistance is defined to determine whether a specific appliance is suitable to serve a specific purpose or not. Twenty five percent of them gave other incorrect responses. Only one teacher did not respond to this item.

ITEM 5: *Describe the difference between emf and potential difference.*

Half of the teachers responded to this item in a scientifically acceptable way by saying that emf is the energy transferred to a charge by the cell while potential difference is the energy lost by a charge between two points in the circuit. Forty four percent gave a wide range of incorrect responses and two teachers did not respond to this item.

ITEM 6: *Explain whether energy is conserved in an electric circuit or not*

Forty four percent of teachers responded by saying "yes" and gave a wide range of scientifically correct explanations. The other 34% of teachers who responded "yes" gave scientifically incorrect or no explanations. Nineteen percent of the teachers responded by saying "no". The reason given for this response was that the energy is not conserved since the cell runs out, and the energy consumed is not regained. Only one teacher did not respond to this item.

ITEM 7: *The voltage source in figure 5.1 has no internal resistance. Both bulbs M and N are lit. N is removed. Consequently:*

Thirty eight percent of the teachers responded by selecting "b" (the potential difference between D and E will become zero). An explanation given for this choice was that when the circuit is broken, no potential difference exists between points D and E (figure 1, Appendix 1). Thirty one percent of the teachers selected "c" (the potential difference between D and E will not change) and explained their choice by saying that the potential difference is not affected by the removal of N. Nineteen percent of them selected "a" (the bulb M will light more strongly) and reasoned that more energy will go to M since more current flows through M. "d" (the potential difference between D and E will increase) was selected by 9% of the teachers with the explanation that the resistance will decrease when N is removed. Only one teacher did not respond to this item.

ITEM 8.1: *The amount of energy transferred to the bulb by each coulomb of charge is:*

(figure 2, Appendix 1)

More than half of the teachers (56%) gave a correct response (6 J). Thirty one percent of the responses were incorrect. The most common of these incorrect responses were 30 J and 5 J. Thirteen percent of the teachers did not respond to this item.

ITEM 8.2: *The amount of charge passing through the bulb in three minutes is:*

(figure 2, Appendix 1)

More than half of the teachers (56%) obtained the correct answer (900 J) to this item. Twenty eight percent of the responses were incorrect. The most common of these incorrect responses was 15 C. Sixteen percent of the teachers did not respond to this item.

ITEM 8.3: *The amount of energy delivered to the bulb in 3 minutes is: (figure 2,*

Appendix 1)

Only 34% of the teachers obtained the correct answer (5400 J). Half of the group obtained incorrect answers. The most common of these answers was 90 J. Sixteen percent of the teachers did not respond.

ITEM 8.4 (i): *The power of the bulb is: (figure 2, Appendix 1)*

Most of the teachers (72%) obtained the correct answer (30 W) and 19% obtained a range of incorrect answers. Nine percent did not respond to this item.

ITEM 8.4 (ii): *The amount of energy transferred to the bulb in 1 second is: (figure 2,*

Appendix 1)

Only 41% of the teachers obtained the correct answer (30 J). Thirty one percent of the teachers obtained a wide range of incorrect answers and 28% of them did not respond.

ITEM 9: *How much energy is lost inside the battery when 1 coulomb of charge passes*

through it? (figure 2, Appendix 1)

Slightly more than half of the teachers (53 %) obtained the correct answer (0,5 J) and 22 % obtained a range of incorrect answers. Twenty five percent of the teachers did not respond.

ITEM 10: *In a discussion about electric current and potential difference Thabo states:*

"A current in a resistor gives rise to a potential difference across the resistor." Thabo says no, it is the other way round. "A potential difference across a resistor causes a current in the resistor." With whom do you agree?

Motivate your answer:

Only 44 % of the teachers responded to this item by saying that potential difference gives rise to current and the other 47 % said that current gives rise to potential difference. It is interesting to note that 9 % of the teachers either agreed with both Thomas and Thabo or disagreed with both.

ITEM 11: *How do you visualize the conventional current in a copper wire forming part of an electric circuit?*

Forty one percent of the teachers responded to this item by saying that the electron current constitutes the movement of charge from the negative to the positive terminal of the cell and 13 % of them explained more specifically by saying that it is the movement of the electrons from the positive to the negative terminal. Nine percent of them described their view as that of a series of electrons moving within the wire without specifying the direction of movement. Thirteen percent of them gave responses which have some elements of truth but do not contain all aspects of scientifically acceptable models. Another 13 % of the responses were from a scientist's point of view incorrect. Thirteen percent of the teachers did not respond to this item.

ITEM 12 (i): *How do you visualize the conventional current in a copper wire forming part of an electric circuit?*

Twenty five percent of the teachers responded to this item by making circuit diagrams with arrows pointing away from the positive terminal of the cell. The other 25% of the teachers explained their view of conventional current as movement of positive charges from the positive to the negative terminal of the cell and 16% of them said that it is the movement of electrons from the positive to

negative terminal of the cell. Six percent of the teachers said that conventional current is the movement of protons, and only one teacher mentioned that conventional current does not involve the actual movement of positive charges. Sixteen percent of the responses were scientifically incorrect and 9 % of the teachers did not even respond to this item.

ITEM 12(ii): *What particles are charge carriers in conventional current?*

Thirty one percent of the teachers responded by saying that charge carriers in conventional current are the positive charges. Twenty eight percent of them said that it is the electrons. Twenty two percent of the teachers said that it is the protons that carry charge in conventional current. Nineteen percent of the teachers gave a range of incorrect responses.

ITEM 13: *The current at A will be: (figure 3, Appendix 1)*

Most of the teachers (88 %) responded by choosing "b" (current at A and at B are the same) and reasoned that current is conserved in an electrical circuit. Only 6 % of the teachers chose "a" (current at A is larger than at B) and mentioned that current is consumed by the bulb. The other 6 % chose "c" (current at A is smaller than at B) and gave no explanation for their choice.

ITEM 14: *A bulb is connected to a torch cell (figure 4, Appendix 1). Will the bulb light?*

Most of the teachers (94 %) responded to this item by saying "no", and only 6 % responded by saying "yes".

ITEM 15: *Draw the circuit diagram for this torch (figure 4, Appendix 1)*

Most of the diagrams (78 %) were scientifically correct and 22 % were not.

ITEM 16: *Draw the circuit diagram sketched in figure 6, Appendix 1*

Only 28 % of the teachers' responses were scientifically correct and 72 % of them were incorrect. Most of the incorrect diagrams had ammeters connected in series with the bulbs, or either the switch or the ammeter was omitted in the sketch.

ITEM 17: *Fill in the values for I_1 , I_2 and I_3 in the circuit shown in figure 7, Appendix 1. The bulbs are identical.*

Most of the teachers (66 %) responded by saying that the current in all the three branches will be 0,4 A. Twenty five percent of them responded by saying that current will divide such that $I_1 = 0,6$ A, $I_2 = 0,3$ A and $I_3 = 0,3$ A. One teacher said that current will be 1,2 A in all the three branches and only one did not respond.

ITEM 18: *What will happen if a 1,5 V bulb is connected to a 12 V battery? (figure 8, Appendix 1)*

Most of the teachers (75 %) responded in a scientifically correct manner by saying that the bulb will only give a bright flash, and 16 % said it will light normally. Nine percent of the teachers said that the bulb will not light at all.

ITEM 19: *What will happen if a 12 V bulb is connected to a 1,5 V torch cell? (figure 8, Appendix 1)*

Most of the teachers (63 %) responded by saying that the bulb will only give a bright flash, and only 38 % responded in a scientifically correct manner by saying that the bulb will glow dim red.

ITEM 20: *In the sketch (figure 8, Appendix 1) a 9 V bulb with negligible internal resistance is connected to a series circuit of an electric motor, a 1,5 and a 2 V bulb. What must the voltage rating of the motor be for proper functioning?*

Only 28 % of the teachers obtained the correct answer and 53 % obtained incorrect answers. A whole 19 % did not respond to this item.

The next section deals with the comparison of scientifically correct responses to the pre- and the post-test and improvement in teachers' responses as a result of intervention by instruction.

6.7 Comparison of scientifically correct responses to the pre- and post-test.

Table 6.3 gives the data on which a comparison of scientifically correct responses in the pre- and post-test is based. The changes in teachers' responses brought forth as a result of intervention by instruction are also discussed.

TABLE 6.3: COMPARISON OF SCIENTIFICALLY ACCEPTABLE (CORRECT) RESPONSES TO THE PRE- AND POST-TEST (N = 32)

ITEMS	CORRECT RESPONSES (%)		IMPROVEMENT (%)
	PRE-TEST	POST-TEST	
1.1 What is a conductor?	65	63	-2
1.2 What is an insulator?	72	63	-9
2.1 What is the prime function of any electric circuit?	19	54	35
3.1 Define emf	6	50	32
3.2 Define potential difference	3	50	47
3.3 Define resistance	6	16	10
3.4 Define electric current	3	12	9
4.1 Explain why scientists need to define emf.	0	34	34
4.2 Explain why scientists need to define potential difference.	0	28	28
4.3 Explain why scientists need to define resistance.	13	44	31

5. Describe the difference between emf and potential difference	0	50	50
6. Explain whether energy is conserved in an electric circuit or not.	34	44	10
7. The voltage source in figure 5.1 has no internal resistance. Both bulbs M and N are lit. N is removed. Consequently: (fig. 1 Appendix 1)	19	41	22
8.1 The amount of energy transferred to the bulb by each coulomb of charge is: (fig. 2 Appendix 1)	9	56	47
8.2 The amount of charge passing through the bulb in 3 minutes is:	28	55	27
8.3 The amount of energy delivered to the bulb in 3 minutes is:	18	34	16
8.4 (i) The power of the bulb is:	25	72	47
8.4 (ii) The amount of energy transferred to the bulb in 1 second is:	22	41	19
9. How much energy is lost inside the battery when 1 coulomb of charge passes through it?	37	53	16
10. Causal relationship between voltage and current	37	44	7
11. How do you visualize the electron current in a copper wire forming part of an electric circuit?	19	52	33
12. (i) How do you visualize the conventional current in the copper wire forming part of an electric circuit?	3	3	0

12. (ii) What particle(s) are charge carries in conventional current?	0	0	0
13. In the circuit sketched (fig. 3 Appendix 1), the current at A will be:	69	88	19
14. A bulb is connected to a torch cell (fig. 4 Appendix 1). Will the bulb light?	84	94	10
15. Draw the circuit diagram for this torch (fig. 5 Appendix 1)	75	78	3
16. Draw the circuit diagram for the circuit sketched in fig. 6 (Appendix 1)	16	28	12
17. Fill in the values for I_1 , I_2 and I_3 in the circuit shown in figure 7 (Appendix 1). The bulbs are identical.	44	66	22
18. What will happen if a 1,5 V bulb is connected to a 12 V battery?	59	75	16
19. What will happen if a 12 V bulb is connected to a 1,5 V torch cell?	41	37	- 4
20. In fig. 8 (Appendix 1) a 9 V battery with negligible internal resistance is connected to a series circuit of an electric motor; a 1,5 and a 2 V bulb. What must the voltage rating of the motor be for proper functioning?	6	28	22

The results of the pre-test indicate that teachers who took part in this survey generally had problems with the understanding of core concepts in electricity prior to instruction in electricity. The post-test results show that there was some improvement in their understanding of electricity concepts after instruction in general, but however no improvement was shown in the understanding of concepts such as *conductor* and *an*

insulator by teachers after instruction. In fact the average performance on these two concepts dropped slightly in the post-test. On the contrary, marked improvement was shown (by the post-test results) in the understanding of more difficult concepts such as emf and potential difference. These findings suggest that teachers tended to focus more on the understanding of what was not familiar to them prior to instruction and retained that which was familiar to them. The drop in performance on the concepts conductor and insulator in the post-test, can be accounted for by the fact that some of the teachers might have explained these concepts scientifically correctly without understanding them. As a result of intervention by instruction, notions which were just taken for a fact and not understood were dropped. It is also possible that some of the teachers supplied scientifically correct answers based on wrong reasons. Such answers are likely not to be repeated by teachers in the light of new scientifically correct information. It must also be mentioned that despite a drop in the number of scientifically correct responses in the post-test, the overall quality of responses to items dealing with these two concepts was much better in the post-test than in the pre-test. Thus a drop in performance does not necessarily imply that intervention by instruction had a negative impact on the teachers' understanding of concepts.

Both the results of the pre- and the post-test show that teachers have problems with the usage of the terms "electricity" and "electric current". These terms are used interchangeably as though they are synonymous. The reason why teachers have problems with the usage of the term *electricity* may be that *electricity* is not a defined term. It is a broad concept which involves a number of other concepts. It was discovered through interviews that some teachers regard the statement "to conduct electricity" to mean the same thing as "to conduct current". This gives rise to the perception that to "conduct electricity" implies that electricity flows. It was evident that teachers tend to be consistent in the manner in which they define the concepts conductor and insulator, by defining both of them either in terms of "current flow" or "charge flow".

The question on what the prime function of the electric current is, is very basic to electric current. This question is however not addressed in secondary school text-books currently in use. As a result this question was poorly attempted by teachers in both the pre- and the post-tests. A common response (to explain and illustrate electrical phenomena/ for use in teaching) given by teachers, to items 2; 4.1; 4.2; and 4.3 indicates that teachers' understanding of electricity is limited to what they experience and do in the classroom, and has very little or no relevance to everyday application of electricity phenomena.

The results of this survey verifies the findings by a number of researchers (Smit & Vreken, 1988:796 and Cohen *at al.*, 1983:407) that the concepts emf and potential difference are difficult to understand. Even after instruction, some of the teachers could still not give correct definitions for these concepts and were unable to describe the difference between them. The question on differentiating between emf and potential difference was also included in the final examination which was written by the teachers who participated in this survey two weeks before the post-test was administered. It is interesting to note that 66% of the teachers responded correctly to this item in the examination. In the post-test, the percentage of correct responses dropped to 50%. This leads to the conclusion that teachers learned the concepts for the purpose of the examination without understanding them. By the time the post-test was administered, it was forgotten.

Teachers' responses to item 6 in both the pre- and the post-test indicate that some teachers do not understand what "*conservation of energy*" means, and responses to item 3.3 indicate that some of the teachers cannot differentiate between the terms *resistance* and *resistor*. Failure by teachers to understand what these terms imply, basically arises from their failure to understand their grammatical meaning, since almost all the teachers who participated in this survey do not have English as their first language.

It is interesting to note that the fact that the cell runs out when connected to a bulb is according to some of the teachers explanatory to their assertion that energy is not conserved in electric circuit.

Despite a slight improvement in the post-test, questions involving visualization of both electron and conventional current were poorly attempted by teachers. Some of the teachers indicated during the post-test session that they could not understand what the question wanted. Some mentioned that they do not know how to represent conventional current by means of a diagram. In studies conducted by Smit and Nel (1997:202), amongst 142 secondary school science teachers, 56% of them indicated that they are confused by the use of conventional and electron current. Some of the teachers indicated during interviews that they are not used to forming mental pictures. In another study by Smit and Nel (1996) amongst 308 science teachers, teachers rated the significance of forming mental images of electricity concepts high. More than half of these teachers indicated that they never form mental images. Without proper visual images, problems associated with concepts such as "conventional current" will be difficult to address. Teachers who do not form mental images usually resort to rote learning.

Questions involving calculations were relatively better attempted in both the pre- and the post-test. The fact that some teachers could not solve numerical problems stated in ways not used in text books indicates a lack of conceptual understanding of electricity concepts rather than lack of numerical skills. In interviews, one of the teachers asked: "how can we do calculations if equations are not given to us?". The other one said: "I know how to solve the problems, but I cannot remember the relevant equations". It was found in teachers' solutions to assignments that they tend to focus on mathematical manipulation to solve for the required quantity and ignore the physical interpretation of the problems. To them an equation is the "*key*" to the right answer.

The results of this empirical survey also reveal that teachers have difficulties in using voltage ratings of electrical components or appliances to match them to appropriate voltage sources. This difficulty emanates from teachers' failure to understand the meaning of the concept voltage and emf.

The average performance obtained in the pre-test was 26%, which is far too low. In the post-test, the averaged performance increased to 45%, which is still far from perfect. The average improvement in performance attained through intervention by instruction was thus 19%. It is interesting that the average performance of this group of teachers in the final examination of the electricity course which was written two weeks before the post-test was administered was 61 %. The disparity between the average performances in the examination and in the post-test, despite the fact that both (the examination and the post-test) were based on the same content and written only two weeks apart is indicative of two things. Firstly, that examinations are limited as a means of assessing learning gains, particularly understanding. Secondly, that teachers in this group primarily rely on memorization and rote learning as a means of studying and preparing for examinations. The latter is indicated by a drop of 16 % in performance in the post-test for which they (teachers) were not warned.

6.8 Misconceptions and general problems of teachers identified through the study.

In general, teachers who participated in this survey were mostly found to harbor alternative conceptions in electricity similar to those harbored by students. Both the qualitative and quantitative investigations in this study revealed that in addition to these alternative conceptions, teachers also harbor misconceptions and encounter general problems discussed below. These misconceptions were gleaned from the pre- and post-test, assignments, class tests, examination and from personal interviews, classroom discussions, and discussions during laboratory sessions with the teachers.

6.8.1 Misinterpretation of strings and Ohm's law

It was discovered during class discussions that teachers tend to think that when the voltage across the ends of a conductor is increased, the resistance of the conductor decreases. The decrease in the resistance is attributed to the fact that according to Ohm's

law, the current increases when the potential difference is increased. Teachers reason that an increase in current in the conductor must result in a decrease in the resistance of the conductor. This misconception emanates from firstly, the use of strings: *"the more the resistance the less the current and the less the current the more the resistance"*. Teachers interpret this commonly used string as implying that since a decrease in resistance causes an increase in the current, an increase in current causes a drop in the resistance of the conductor. This misconception is also a result of failure by teachers to apply Ohm's law correctly. They fail to recognize that in case of ohmic conductors, resistance is a property of the conductor and is independent of both the current passing through it and the potential difference across its ends.

6.8.2 "More resistors in parallel more resistance"

One concept which was found to be unacceptable (at first look) to teachers is that connecting more resistors in parallel reduces the effective resistance in the circuit. Teachers naively argue that since more resistors are connected, less current should flow. This misconception could be easily addressed by an experimental demonstration which involved increasing the number of bulbs (resistors) in parallel and noting the reading on the ammeter connected to the main circuit as the number of parallel branches is increased.

6.8.3 "Bulbs give the same brightness regardless of how they are connected"

It was found that teachers think that two identical light bulbs connected in series to a cell give the same brightness when connected in parallel to the same cell, since the same strength cell is used. The same reasoning was applied to bulbs connected first in series and then in parallel to the same cell.

6.8.4 The geometrical interpretation of the term "parallel"

When working with diagrams similar to the one in figure 6.1 below, many teachers think that l_1 is parallel to l_2 .

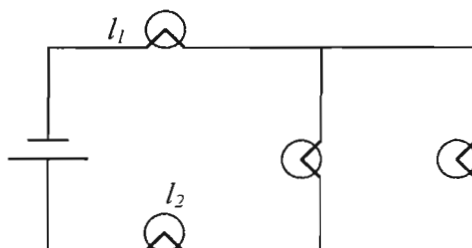


figure 6.1

The term "parallel" retains a geometrical interpretation rather than electrical interpretation.

6.8.5 Current cannot flow in the "reverse" direction through the cells

In the figure 6.2 below, the three cells have the same emf. Teachers think that current cannot flow in the circuit and the bulb cannot glow since the cells are not connected "correctly"

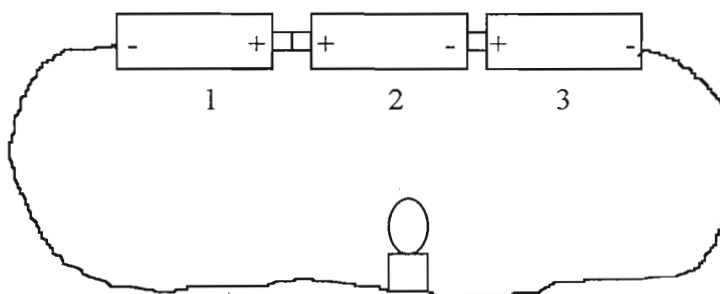


figure 6.2

This conception held by teachers is based on the assumption that current cannot flow in the reverse direction through the cell marked 1 in figure 6.2. Teachers fail to realize that the cell marked 1 will consume energy in the circuit and thus lead to potential drop

equivalent to voltage supplied by each of cell 2 or cell 3. There will therefore be a net voltage supply equal to that of cell 2 or cell 3. The three cells will thus give rise to the net voltage equal to that of a single cell. If this voltage is comparable to that required to light the bulb, the bulb will glow.

6.8.6 Failure to distinguish between "cause" and "effect"

The responses of the majority of teachers reveal another flaw in their thinking. That is, to inter-change cause and effect in causal relationships of quantities or not to distinguish between them. This fact was made evident by teachers' responses to item 10 dealing with the causal relationship between current and potential difference in both the pre- and the post-tests. The cause and effect relationships is a very important and fundamental issue in scientific reasoning and need further investigation. Investigation into this aspect can be extended to other sections of physics, for example the force and acceleration relationships.

6.8.7 Inability to translate information from a real situation to symbol form.

It was discovered from teachers' responses and throughout the electricity course that teachers have difficulties in translating information from a real situation to symbol form. Teachers with this difficulties can also be expected to fail to attach reality to information represented in symbol form.

6.9 Conclusion

From the discussion of the empirical survey, it is clear that the teachers who participated in this study, were not prepared for their task prior to instruction. This verifies the hypothesis that was stated in section 1.2 that physical science teachers generally experience problems with the understanding of core concepts in electricity. An improvement of 19% in performance that was attained through intervention is still not enough. A lot of work can still be done to improve on it. It was clear that teachers still

harboured alternative conceptions even after formal instruction of electricity. This fact is indicative of the difficulty involved in dealing with problems associated with alternative conceptions in electricity. The next chapter gives the summary of this study and the recommendations on how to deal with problems associated with the understanding of core concepts in electricity.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

7.1 Introduction

This chapter constitutes a summary of the study and recommendations. The recommendations given in section 7.3.1 - 7.3.7 are based on recent research done locally and abroad in the teaching of electricity and physics in general. It is envisaged that when applied appropriately, these recommendations will be helpful in alleviating problems associated with the understanding and conceptualization of core concepts in electricity and in physics at large.

7.2 Summary

This study was aimed at investigating the conceptualization of core concepts in electricity by physical science teachers. The study was motivated by the fact that according to a number of recent research results, not only students, but teachers as well encounter problems with the understanding of concepts in electricity. Core concepts in electricity were regarded to be those concepts which are specific to the domains of electricity and can be defined operationally. Included in this study is a brief discussion of each of these concepts. Core concepts which were discussed are *charge, electric field, electrostatic potential, electric current, conductors and insulators, resistance, emf, potential difference, and electromagnetic induction*. The discussion which broadly followed the epistemological development of the concepts was done at the level comparable to that of the secondary school syllabus.

Since this study is concerned with teachers' understanding of concepts in electricity, alternative conceptions commonly held by students in electricity were discussed, to form the basis for investigation of teachers' conceptualization. The origin and the nature of alternative conceptions were also discussed. A chapter was devoted to the discussion of

constructivism, the traditional teaching model, and the heuristic teaching approach. This was followed by the discussion of the teaching strategies and syllabus used in the electricity course of the Sediba Project.

Although this study was concerned with teachers' conceptualization of core concepts in electricity, the empirical survey was however restricted to macroscopic concepts related to electrodynamics. Concepts related to electrostatics and electromagnetism were not subjected to investigation as the inclusion thereof would have made the scope of the study too wide. Concepts subjected to investigation in this survey were *electric current, resistance, emf, potential difference, energy conservation in an electric circuit and conventional current*. The concepts *a conductor* and an *insulator* were also subjected to investigation. These concepts are not regarded as core concepts in electricity but were however subjected to investigation by virtue of their relation to resistance and significance to the understanding of phenomena related to electric circuit.

The empirical survey was done by means of a pre- and a post-test. Teachers' written and oral responses to assignments, tests and examination were also noted. The results of the pretest reveal that teachers had inadequate understanding of concepts in electricity. Teachers showed lack of understanding of concepts such as emf, potential difference, and resistance. The results also showed that teachers harbor most of the alternative conceptions harbored by students. Other aspects such as the significance of connecting electric circuits and the reasons why scientists define concepts such as resistance, emf and potential difference were generally misunderstood. The results largely showed teachers' inability to solve problems. This inability does not necessarily imply lack of problem solving skills, but the lack of conceptual understanding. The post-test results showed an improvement in teachers' understanding of these concepts. Both the pre- and the post-test revealed that teachers generally have problems with qualitative understanding and visualization of concepts in electricity.

7.3 Recommendations

7.3.1 *The epistemological approach to the teaching of electricity*

The study of electricity dates back to the time of Thales of Miletus in 600 BC. It is one of the sections of physics which has undergone a series of developments throughout history. The immense influence of the technological developments, following the scientific developments on the human race cannot be under-estimated. In order to understand the impact of major scientific developments on society, it is necessary to understand the major trends in their development. We thus need the type of science teaching that will take into account the wider context of the whole social system. It is thus necessary not only to teach electricity content but also to teach about the historical development of electricity to enable students to see this specialized knowledge into its proper perspective (Jung, 1994:115).

The epistemological developments of the subject can be utilized in a number of ways in teaching. Firstly, it can be used as an organizing principle of the curriculum by delineating the historical development of today's knowledge from its beginning, or by going back to the origins, beginning with the recent knowledge. Secondly, it can be used to enrich students with the knowledge of the emergence of important conceptual schemes, ideas, experiments, major arguments and historical circumstances. Thirdly, it can be used as an anecdotal enrichment, in order to relax students from strains of working with "*raw physics*" and for motivational reasons. Fourthly, one may use the history of the subject in order to introduce the philosophical element into physics teaching and to familiarize students with the scientific thinking patterns and the manner in which scientific knowledge is constructed (Jung, 1994:117).

It must be mentioned, regrettably that the historical development of electricity and physics in general, is a subject that has been grossly ignored in current secondary school syllabi and university physics text-books. This tendency deprive students the opportunity to lay a

solid foundation for the learning of the subject content, and to appreciate the brilliance that characterizes physics. A closer look at history may help students to see the physics of today as a continuation and to understand the factual knowledge from which developments start and which sets limits to it. In the process, students learn from the point of view of research how the existing scientific knowledge is applied in resolving controversy and the basis on which new knowledge arises and old knowledge dissolves. Teachers should not fail to acquaint students with the fact that even highly accomplished physicists blundered in the course of development. This will encourage students to build the appropriate attitudes towards the subject, not to have exaggerated confidence in authority but to think for themselves (Jung, 1994:124).

7.3.2 Using multiple representations

The presentation of physics is often done in algorithmic and procedural manner in which students are assigned problems which they solve by mimicking the way similar problems are solved by the teacher and the text books. This type of presentation emphasizes quantitative problem solving which involves selecting and manipulating one or two appropriate equations to obtain the solution. Unfortunately, this type of problem-solving does not result in deep understanding of concepts nor in robust problem solving skills. The reasons for this are that students usually select and apply the equation without checking its appropriateness nor to seek to understand its content. As a result students emerge from electricity classes with a shallow understanding of concepts and with a narrow set of problem-solving skills. Dufresne *et al.* (1997:270) have developed an approach to problem solving in secondary school and college physics courses that puts greater emphasis on concepts and qualitative reasoning and encourage students to be more flexible in how they approach problems. This approach involves the use of multiple representations to analyze and solve problems.

When confronted with a problem, the formation of a problem representation occurs naturally as the person attempts to analyze the problem. However, the ways to represent

and solve the problem does not come naturally or easily for many students. They need proper instruction and support in order to be able to try out different representations when working on problems. Students must be provided with a rich set of examples of different ways to represent problem situations, and then encouraged to use these representations to solve problems. A variety of representations that can be used include *strobe diagrams*, *field-line diagrams*, *free-body diagrams*, *graphs*, *equations*, *etc.* These representations can be used in a large variety of problem situations to enhance both the teaching and the learning of electricity. Strobe diagrams and free-body diagrams can be used effectively to sketch the physical situation to elucidate a problem and summarize the given information. This support the student's efforts to solve the problem and to structure the way the problem can be approached (Dufresne *et al.*, 1997:272).

Strobe diagrams and free body diagrams can be used effectively in electrostatics to solve problems involving interactions between stationary charges. Sketches showing relative positions and distances between interacting charges help to elucidate the problem. The use of a *linear model for the teaching of the concepts emf and potential difference* discussed in section 2.4.8 is an example of how graphical representations can be used to analyze energy changes taking place in electric circuits. This analysis of energy changes in an electric circuit is usually done by calculations involving the use of a number of equations. Teachers and students routinely carry out these calculations without proper visualization and understanding of the physical set-up (Dufresne *et al.*, 1997:272).

When assisting students to learn to use multiple representations in problem solving, it may be necessary to engage them in an activity involving description of a problem using at least three different representations for example, diagrams, equations and graphs. After working with all three representations, students may be led to compare the three representations. Questions such as, "Which is the easiest to use?" and "Which contains the most information?" can be discussed. Such similar discussions will lead students to realize that the algebraic representation is not always the most useful one (Dufresne *et al.*, 1997:270).

7.3.3 *The qualitative problem-solving approach*

There are two primary goals for the teaching of introductory physics at secondary schools and colleges: to help students learn major concepts and principles, and to help students learn how to use them to solve problems. The perception that teaching students how to solve problems will help develop in students the understanding of concepts and principles has been proved wrong by research (Leonard *et al.*, 1996:1495). Problem solving does not develop a deep understanding of concepts and principles, even amongst students who become proficient problem solvers. Although emerging instructional approaches emphasizes more on conceptual development, the problem of adhering to traditional teaching approaches still exists, despite the desire to change. A lot of effort is required to turn the situation around, and improve instruction. At the center of the approach to improve the situation, lies the qualitative strategies to approach physics problems.

The difference between the qualitative and quantitative description of physical phenomena can be explained as follows:

Physicists use mathematical expressions to describe/ formulate the laws of nature, which convey not only qualitative but also quantitative information related to the nature and amount of the participating quantities. For example, Ohm's law gives the qualitative relationship between three electrical quantities: current, resistance and potential difference. This description only explains the nature of the relationship between the quantities but does not tell anything about the extend to which these quantities influence one another. If the actual amounts of these quantities are used to describe the set-up, then the description becomes quantitative. The quantitative description therefore determines the extend to which the participating quantities influence the set-up.

When confronted with a problem, students usually resort to manipulating equations in an attempt to isolate the desired "unknown" and seldom consider the conceptual knowledge that underpins the mathematical solution. Such students perceive problem-solving in physics as an exercise involving memorizing, recalling, and manipulating equations to get

answers. In contrast, experienced problem solvers with strong conceptual understanding, solve problems by first considering the principles and concepts that might be applied, and how these principles can be implemented mathematically. In its true perspective problem-solving in physics involves applying a small number of central ideas across a wide range of problem-solving context. Although the mathematical procedures are useful in solving physics problems, they fall short of the inherent description which leads towards understanding of major concepts and principles (Leonard *et al.*, 1996:1495).

According to Leonard *at al* (1996:1496), the qualitative problem-solving strategy involves three elements. Firstly, the identification of the major physics principles and concepts that are useful in solving the problem, secondly, the articulation of the rationale for using a particular principle or concept and lastly, the application of these concepts to solve the problem at hand. Unfortunately the order of the application of these elements is usually reversed. This tendency results in a variety of problems associated with conceptual understanding and deny the students the appreciation of the brilliance and beauty that are characteristic of physics.

7.3.4 The use of concept maps in the teaching of electricity

Concept maps are representations of meaningful relationships between concepts in the form of propositions. The technique for constructing concept maps involves identifying all the concepts under the topic and arranging them such that those that are related are closer together. Concepts that are related are then joined by lines drawn between them. On each line the nature of the relation between the concepts is written. The result is a map of interwoven linkages and explanation of relations between concepts.

An example of a concept map of electricity is shown in figure 7.1 below.

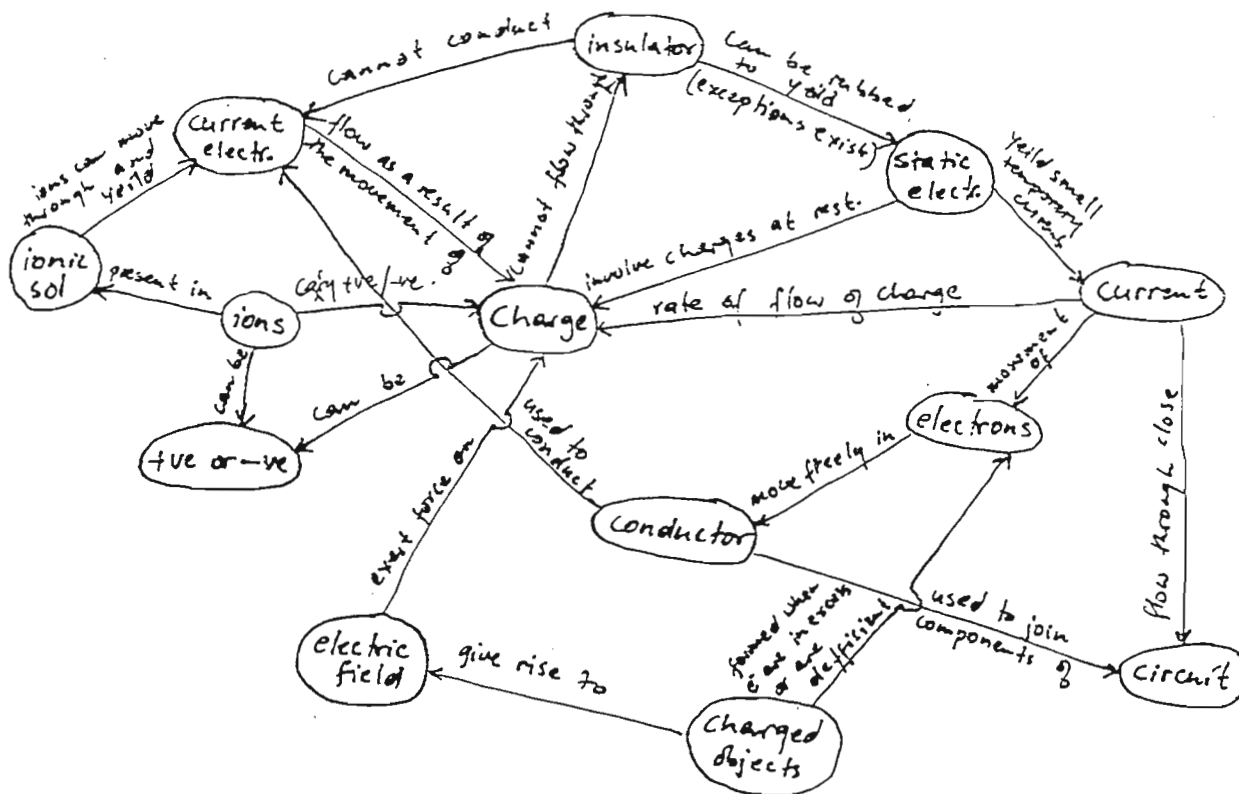


figure 7.1

The use of concept maps result in a number of instructional gains. Firstly, they reinforce understanding of knowledge acquired through other instructional strategies and encourage higher order thinking. Secondly, they help students to structure and organize their understanding. Thirdly, concept maps are valuable evaluation tools since they can provide good information about how students think and link ideas - the information that cannot be provided by traditional assessment strategies. Through the use of concept maps, teachers can probe into students' alternative conceptions and on how they visualize the structure of a large topic (Novak *et al.*, 1983:626).

It must be noted that the introduction of the use of concept maps requires effort. Students need to be familiarized with the technique for constructing concept maps before they can use the technique effectively. A student who can construct a good coherent concept map with many concepts and linkages has a good understanding of the subject content (Gunstone & White, 1992). On the other hand, the student whose concept map is skeletal and sketchy usually lack understanding of the subject content. It is in this sense that concept maps are useful assessment tools. In addition, upon drawing links and explaining relations between concepts, the learner is engaged in an important learning process which involve the construction of a set of knowledge (Novak *et al.*, 1983:631). Although the use of concept maps have not yet featured in current curricula, the effectiveness thereof in any teaching and learning situation cannot be under-estimated.

7.3.5 The modeling approach to the teaching of electricity

A number of research projects have been carried out both locally and abroad on the modeling approach and the use of models in the teaching of electricity and physics in general. A study by Smit and Nel (1997:202) amongst South African teachers indicates that teachers generally have problems with the use of scientific models and with models of electric current in particular. These results are not surprising since in neither physical science syllabi nor physical science text-books currently in use is the role and the significance of models in physics addressed.

A lot has been said about secondary school and college students who pass tests and examinations with very little comprehension on what they have been doing. Research results show persistent deficiencies after instruction, in both the structure of students' knowledge of physics and in their problem-solving skills. Halloun (1996:1019) proposed a schematic modeling approach which can be used to help students learn physics in a meaningful way and resolve learning deficiencies. In his proposal, Halloun (1996:1020) argues that modeling is a major process for constructing and employing the core content of scientific knowledge. According to McDermott (1991:304), the scientific realism can

take place at any level only when the structure of physics theory and physicists' mental processes are presented explicitly. This may best be realized in model based instruction (Halloun, 1996:1020). The study of physics thus involves the process of building up models of how the physical world operates. These models may be conceptual (mathematical) or physical (material artifact). Halloun's schematic modeling approach involves five steps, that is *selection, construction, validation, analysis* and *deployment*. The first step involves the use of familiar models to select an appropriate model to map out the specific physical situation. The second step involves the construction of the selected model. The construction may be mathematical or descriptive. The third step, validation, involves assessment and evaluation of the model. The fourth step, analysis, proceeds once the model has been validated and involve application of the model to fulfill the purpose for which it was constructed. This may involve solving problems, getting answers to questions and interpreting and justifying the answers. The final step of model deployment involves making inferences and extrapolating the current model to build new ones (Halloun, 1996:1022).

All the above steps must be executed with the original purpose of constructing the model in mind. It is important to note that models are not real entities but are just representations of reality. Hence models are intended to illustrate, explain and predict certain properties of its prototypes, and may not be necessarily applicable to other situations. The limitations of models in this regard must be taken into consideration (Hesse, 1966).

According to McDermott (1991:308), students fail to make correct qualitative predictions about the behavior of electric circuits because of a lack of a conceptual model for electric circuits. An example of a how models can be used to explain phenomena related to electric circuits is illustrated below. In this case a conveyor belt is used as an analogue model for a DC circuit.

Conveyor belt

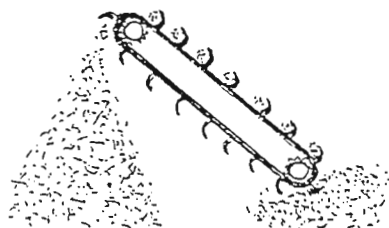


figure 7.2

- The belt is loaded with rock at lower end
- The belt goes up loaded with rock
- The belt delivers rock to the top of the dump
- The belt returns empty to the lower end

Electric circuit

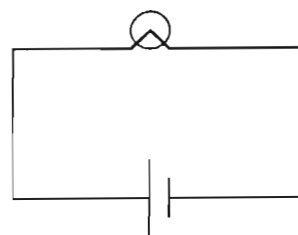


figure 7.3

- Current is "loaded" with energy in the cell
- Current carries energy to the bulb
- Current delivers energy to the bulb
- Current returns unaltered to the cell

When used correctly, this model can be very effective in dealing with alternative conceptions associated with electric current, especially the consumer's model of reasoning about electric current (discussed in section 3.2.3) (Black & Solomon, 1987:250). It is important to note that this model is only useful when dealing with energy transfer in an electric circuit, but may not be useful in explaining phenomena associated with other concepts such as potential difference, emf and resistance. To explain phenomena associated with these concepts, other models are necessary. *The linear model for teaching the concepts emf and potential difference* discussed in section 2.4.8 is an example of such models. It is important to note that analogue models have a positive and a negative part. The positive analogue corresponds and the negative analogue differs from the real situation that is modelled (Hesse, 1966).

7.3.6 A more practical approach in the teaching of electricity

It is a well known fact that effective teaching of physical science and electricity in particular is not possible without exposure to practical work. Studies by Van der Linde *et al.*, (1994:49) in South African schools indicate that very little effort is being made to

introduce a more practical approach in the teaching of science. There are basically three major constraints which hamper the introduction of the more practical approach in science teaching. Firstly, teachers still cling to lecturing as the major teaching method. Secondly, there is a shortage of well trained science teachers who are motivated and confident to carry out practical work. Thirdly, many schools are still without well equipped laboratories (Van der Linde *et al.*, 1994:51). There is no doubt that this state of affairs adds to the extremely low pass rates and growing unpopularity of the subject.

The use of the practical approach in science teaching has been justified by many researchers (Van der Linde *et al.*, 1994:50). Woolnough and Allsop (1985:41) claim that practical work in the classroom is significant in the sense that it:

- develops the practical skills and techniques;
- encourage the development of the scientific attitudes and creativity
- enable students to get the "feel for phenomena"

The latter relates to getting acquainted with the physical world the child lives in as well as making sense of it. The spirit of inquiry and the manipulative skills can only develop through hands-on experience. In addition, practical work makes the learning experience enjoyable for the children by stimulating their interest and mental skills (Van der Linde *et al.*, 1994:50).

It is unfortunate that in instances where practical work is done, most of the teachers do not follow correct experimental procedures. For instance, teachers have the tendency of teaching theory first and only conduct experimental work afterwards to "verify" and support theoretical assertions. This tendency relegates the status of practical work to a means of "*checking*" and proving the correctness of theory while in actual fact, practical work forms the basis on which theory is formulated. The correct procedure is to place students in the situation of the original discoverer and guide them to make observations on the basis of which conclusions are made. For instance, when teaching Ohm's law, it is

necessary that students be allowed to carry out the experiment, record the observations, make generalizations and draw conclusions before the statement of the law is brought to their attention. In this manner, students shall have constructed their own knowledge. This act is very essential for effective learning.

Gunstone and White (1992) proposed that there are three essential steps in practical work, that is, *predict, observe and explain* (the so-called POE method). These steps involve making predictions of the outcome of the experiment or demonstration, before actually performing it; making observations and recording the measurements and lastly explaining and making conclusions based on recorded data and the observations made. These three steps are essential in the sense that they enable the learner to extract all useful information from the experiment. If correctly followed, the POE method can be a very useful tool towards effective and rewarding practical work.

7.3.7 Other recommended teaching strategies

It was not possible to include in this chapter all effective teaching strategies that can be recommended for the teaching of electricity. Teaching strategies which can also be used in the teaching of electricity and are not discussed in this chapter include group work and cooperative learning. Research has shown that these two teaching strategies can be used effectively in the teaching of electricity, especially when working with DC circuits. Recent research strongly recommends the use of the constructivistic approach in dealing with problems associated with alternative conceptions. This approach was discussed in details in chapter 4.

7.3.8 Recommendations for further study

It was mentioned in section 6.8.6 that teachers have a problem of interchanging "cause" and "effect" in a causal relationship and in distinguishing between them. It is recommended that this aspect be investigated further since it is a very important and fundamental in

scientific reasoning. Investigation into this aspect can also be extended to other sections of physics for example force and acceleration relationship.

Also recommended for further investigation is the extend to which teachers who emerge from teacher upgrading projects such as SEDIBA, apply the teaching strategies and skills imparted to them in their day-to-day teaching activities.

7.4 Conclusion

As was already mentioned above, it was impossible to include all recommended strategies for teaching electricity. Only those recommendations which are considered to be more important and are relevant to the situation have been discussed. However, these recommendations do not offer final solutions nor do they constitute a perfect recipe for successful teaching. The situation in which one finds him/herself, determines which strategies will be suitable. Efforts have to be made to find the approaches which are compatible with the situation at hand. Due to time constrains and syllabus limitations it may not be possible to apply some of the recommendations at secondary school level. Most of the recommendations made are suitable for teacher training programs. These recommendations were made specifically for the teaching of electricity. Most of them apply equally well in the teaching of other sections of physics.

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APPENDIX 1 : RESEARCH QUESTIONNAIRE

ELECTRICITY QUESTIONNAIRE

INSTRUCTIONS: Answer the following questions by filling in the space provided.
Multiple choice questions must be answered by making a cross on the appropriate number.
Diagrams can be drawn in boxed spaces provided.

1. Explain what

- 1.1 a conductor of electricity is
-
- 1.2 an insulator is.....
-

2. What would you say is the prime function(s) of *any* electric circuit? (In other words: what is the significance of constructing an electric circuit?)

.....

3. Define

- 3.1 emf
-
- 3.2 potential difference
-
- 3.3 resistance
-
- 3.4 electric current
-

4. With reference to electric circuits explain *why* scientists need to define the following concepts:

- 4.1 emf
-
- 4.2 potential difference
-

4.3 resistance

.....

5. Describe in your own words the difference between emf and potential difference

.....

.....

6. Is energy conserved in an electric circuit or not? Explain:

.....

.....

7. The voltage source ϵ in the figure has no internal resistance. Both bulbs M and N are lit. N is removed from its socket. Consequently:

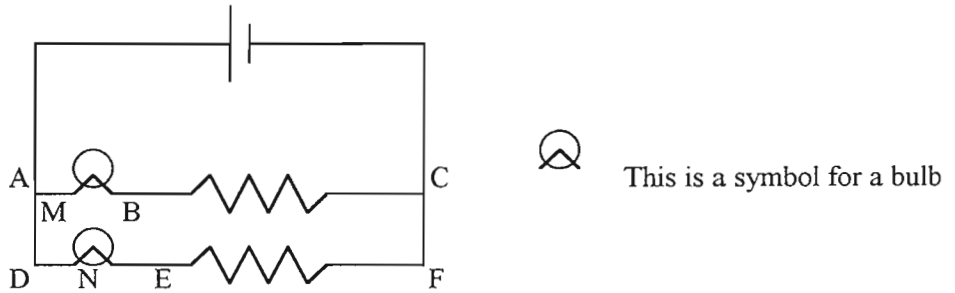


figure 1

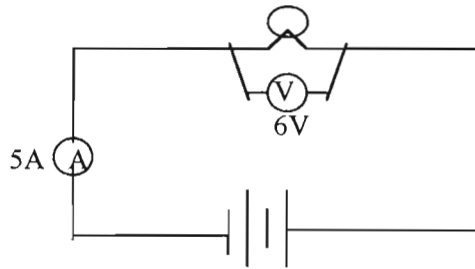
- (a) the bulb M will light more strongly
- (b) the potential difference between D and E will become zero
- (c) the potential difference between D and E will not change
- (d) the potential difference between D and E will increase.

Explanation:

.....

.....

8. Refer to the circuit diagram below. The current in the circuit is 5A and the voltmeter connected to it reads 6V.



$\epsilon = 6,5 \text{ V}$
figure 2

- 8.1 The amount of energy transferred to the bulb by one coulomb of charge passing through it is
- 8.2 The amount of charge passing through the bulb in 3 minutes is
- 8.3 The energy delivered to the bulb in 3 minutes is
- 8.4 (i) The power of the bulb is
- (ii) The amount of energy transferred to the bulb in one second is
-

9. Refer to the circuit sketched in item 5 above.

If the emf of the battery is 6,5V and the voltage across the terminals drops to 6V when the bulb is switched on. How much energy is "lost" inside the battery when 1C of charge passes through it?.....

.....

.....

10. In a discussion about electric current and potential difference Thabo states: "A current in a resistor gives rise to a potential difference across the resistor."
Thomas says no, it is the other way round: "A potential difference across a resistor causes a current in the resistor."

With whom do you agree? Thabo or Thomas? Motivate your answer:

.....

.....

11. How do you visualize the electron current in a copper wire forming part of an electric circuit? (Diagrams may be helpful)

.....

.....

.....

.....

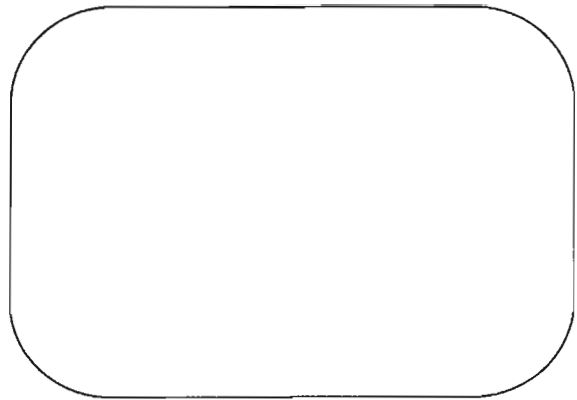
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.....

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.....



12. (i) How do you visualize the conventional current in a copper wire forming part of an electric circuit? (Diagrams may be helpful)

.....

.....

.....

.....

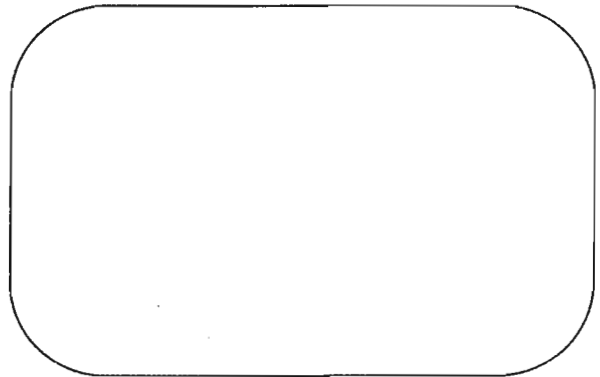
.....

.....

.....

.....

.....



(ii) What particle(s) are charge carriers in conventional current?

Explanation:

.....

.....

13. In the circuit sketched, the current is measured at A and at B simultaneously.

What would you expect the measurements to be?

The current at A will be:

- (a) larger than at B
- (b) the same as at B
- (c) smaller than at B

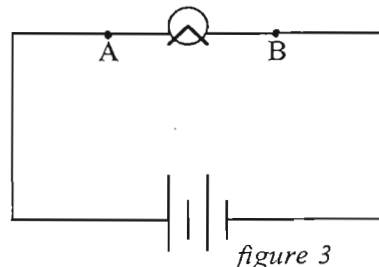


figure 3

Explain your answer:

.....

.....

14. A bulb is connected to a torch cell as sketched. Will the bulb light?

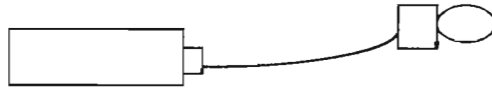


figure 4

Explain your answer:

.....

15. Draw the circuit diagram for this torch.

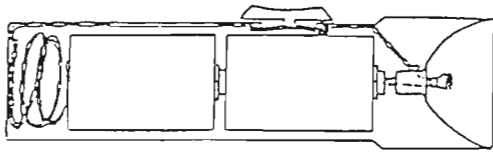
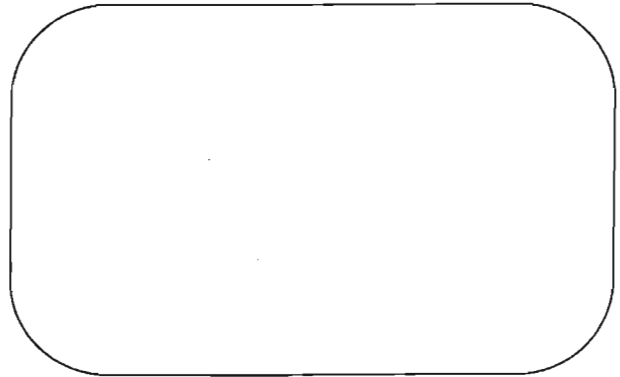


figure 5



16. Draw the circuit diagram for the electric circuit below.

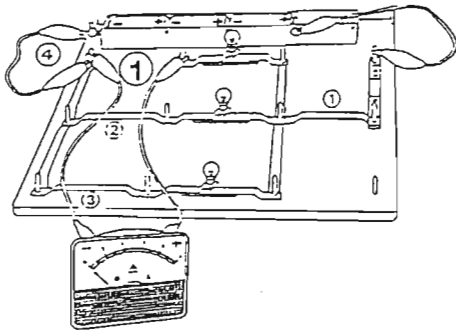
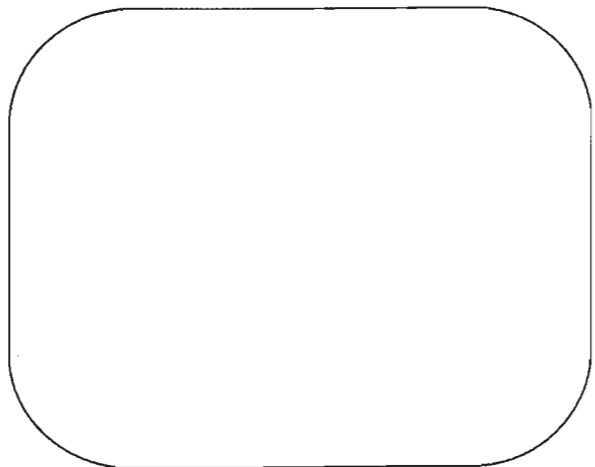


figure 6



17. In the circuit below, the bulbs are identical

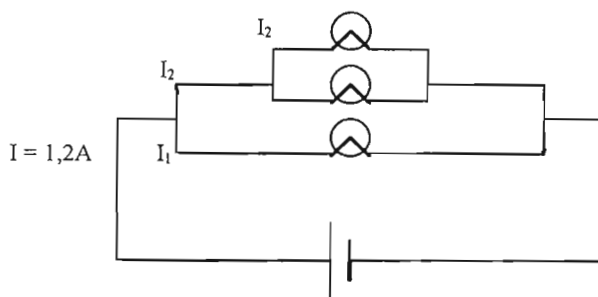


figure 7

Fill in the values for I_1 , I_2 and I_3 in the circuit diagram.

Explain your answer.

18. What will happen if a 1,5 V bulb is connected to a 12 V battery?

The bulb will

- (a) light normally
- (b) not light at all
- (c) glow dim red
- (d) only give a bright flash

Explain your answer

19. What will happen if a 12 V bulb is connected to a 1,5 V torch cell?

The bulb will

- (a) light normally
- (b) not light at all
- (c) glow dim red
- (d) only give a bright flash

Explain your answer:

20. In the series circuit sketched in figure 8, a 9 V battery with negligible internal resistance is connected to a series circuit of an electric motor; a 1,5 and a 2 V bulb.

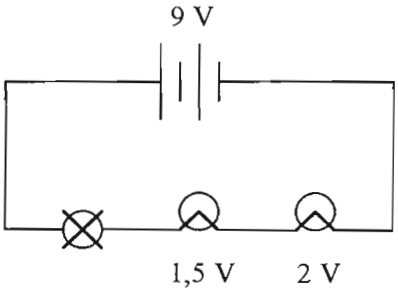


figure 8

What must the voltage rating of the motor be for proper functioning?

Explain your answer:

.....

APPENDIX 2: ELECTRICITY SYLLABUS OFFERED IN THE SEDIBA PROJECT

1. Electric circuits - I

- 1.1 What is an electric circuit?
- 1.2 Conductors and insulators
- 1.3 The use of a voltmeter
- 1.4 The use of a an ammeter
- 1.5 Current strength in an electric circuit
- 1.6 Cells in series
- 1.7 Light bulbs in series
- 1.8 Light bulbs in parallel

2. Current and resistance

- 2.1 Current electricity
- 2.2 Series and parallel connections of cells
- 2.3 Resistance
- 2.4 Resistance of metallic conductors
- 2.5 Measurement of resistance and Ohm law
- 2.6 Resistors
- 2.7 Resistors in series and in parallel

3. Electrostatics - I (Qualitative treatment)

- 3.1 Composition and nature of atoms
- 3.2 Charging by friction
- 3.3 The use of the Van de Graaff generator
- 3.4 Gold leaf electroscope

4. Electrostatics - II (Quantitative treatment)

- 4.1 Coulomb's law
- 4.2 Electric field
- 4.3 Electric field strength and Coulomb's law
- 4.4 Electrostatic potential and energy in an electric circuit
- 4.5 Work on charges in electric fields

4.6 Electric potential difference

4.7 Millikan's demonstration

5. Energy in an electric circuit

5.1 What makes charge flow?

5.2 Electric current

5.3 What makes a lamp to glow?

5.4 Conventional current and the direction of the electric current

5.5 Cells and batteries as sources of electrical energy

5.6 Chemical cells and batteries

5.7 Potential difference and emf

5.8 Internal resistance

5.9 Heating effect of electric current

5.10 Joule's demonstration

5.11 Electrical power

5.12 Buying electricity

6. Electric circuits - II

6.1 Combination of series and parallel connection of resistors

6.2 Qualitative analysis of complicated circuits

6.3 Kirchhoff's rules

7. Electromagnetism

7.1 Ferromagnetism and the domain theory

7.2 The magnetic field

7.3 Magnetic effect of the electric current

7.4 The motor effect

7.5 Electromagnetic induction

7.6 The transformer

7.7 Alternating current